USING RECLAIMED WATER FOR GOLF COURSE IRRIGATION TO IMPROVE WATER RESOURCE MANAGEMENT IN THE LOWER ARKANSAS RIVER BASIN

by

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Abstract

With an increasing population, municipalities in the United States are struggling to secure safe, reliable water sources for future water demands. Alternative water sources are being considered to improve the overall water management picture. Wastewater reuse, reusing wastewater effluent for beneficial purposes, is an alternative water source that is gaining popularity in the United States.

In this study a theoretical framework was developed to enable a region to quickly assess the feasibility of reusing wastewater for irrigation needs. Three criteria were established for the framework; they are, regulations and guidelines for reuse, adequate flow ratio, and cost benefit analysis. As a region moves through the framework and criteria a list of feasible wastewater facilities and end users are established. A model was developed for the cost benefit analysis based on regional input. As regulatory frameworks and economic factors evolve over time the model can be updated to assess how these changes will affect water reuse in a region. The model will provide a useful tool for a region to integrate wastewater reuse into the water resource management process.

The Lower Arkansas River Basin (LARK) was highlighted by the Kansas Water Office as a region that should investigate the role of reuse in water conservation. Results from this report indicate 963 million gallons per year (MG/yr) of wastewater effluent could feasibly be used to irrigate 9 hole and 18 hole golf courses in the region. The results determined that any 18 hole golf course within a 15.9 mile radius of a wastewater treatment facility in the LARK could payback the capital costs for wastewater reuse within 10 years. This information is a useful tool for the region to start the discussion for implementing wastewater reuse in the region.

The results from this report indicate wastewater reuse for golf course irrigation is economically feasible in the LARK. Establishing a safe reliable water source for the future is paramount to the future of Kansas. Future research is needed to determine how the wastewater diversion affects the environmental balance of the permitted discharge location.

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Acknowledgements

There are many people who made this thesis possible for me. First, I would like to thank my advisor, Dr. David Steward, for encouraging my interest in the water conservation field and providing me an opportunity to research it further. Second, I would like to thank my husband Paul and my children Connor, Madelyn and Gavin for making the sacrifices that were needed for me to complete my graduate degree and thesis. Third, I would like to thank Dr. Stephen Welch and Dr. Robert Stokes for taking time to serve on my committee and review my research thesis.

Dedication

This thesis is dedicated to my husband Paul who supported me in so many ways throughout my journey in pursuing my graduate degree and writing this thesis.

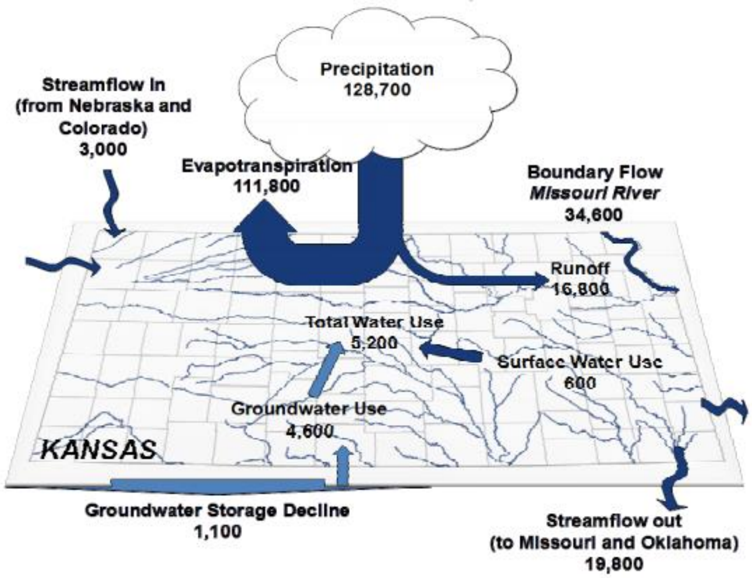
Chapter 1 - Introduction

1.1 Overview

With an increasing population, a lack of sufficient fresh water sources is a problem facing many parts of the world today. The United States Geological Survey (USGS) estimated the 2010 water use was 355 billion gallons per day (Bgal/d).[13] Water resources are being depleted and municipalities are faced with the difficult task of securing a reliable source for potable water. Water conservation trends have reduced the amount of water used per capita, however alternative water sources need to be evaluated for potential use, especially in water-stressed regions. One such alternative source is wastewater reuse. Wastewater reuse involves diverting wastewater effluent that has been fully treated in the wastewater treatment facility from its discharge location to a customer who will use it for beneficial purposes. California, Florida, Texas and Arizona are already employing wastewater reuse and can serve as valuable models for other regions of the country. Of the 355 Bgal/d the USGS reported thermoelectric power and irrigation were the two largest uses of water reported in 2010 with 161 Bgal/d and 115 Bgal/day respectively. [13] Many parts of the country are pursuing wastewater reuse for these categories, however much more work needs to be done. There are no national standards for water reuse projects; each state has their own regulations. Many states have vague or no formal standards, resulting in a difficult decision making process for evaluating the benefit of employing wastewater reuse in a region.[23]

Like many other parts of the country, Kansas is facing a water supply shortage in the future if additional water sources are not secured. Kansas population has increased steadily from 2.5 million people in 1990 to 2.9 million in 2012. [12] Summers in Kansas are typically hot and dry; record droughts have been recorded over the last decade. The water supply shortage becomes magnified during periods of low precipitation as more water is being used for irrigation purposes to compensate for the low rainfall. The Kansas Water Office established a water budget for Kansas to get an overall view of the hydrological process in Kansas.[9] Figure 1.1 illustrates the water budget and clearly shows a decline in groundwater storage due to less water coming into the budget than leaving. According to the 2014 Kansas Water Plan, irrigation is the dominant use of water with an average of 85% of the water used from 1990 to 2011. [10] Water use fluctuates with precipitation patterns; Kansas typically receives 16 to 22 inches of rain each year. A potential exists in Kansas to alleviate some of the water stressed regions by developing a plan to utilize more wastewater for irrigation. As we move into a future where water shortages are going to become more prevalent wastewater should not be considered a waste product anymore.

Figure 1.1: Kansas Water Budget (Source: Kansas Water Office, 2014)



Kansas Water Budget (thousands of acre feet) (adapted from Sophocleous 1998)

This thesis is separated into five chapters, with the appendices and references at the end. Chapter 2 provides information on the current state of wastewater reuse and previous research completed on this topic. Chapter 3 outlines the methodology used to develop a model that can be used to determine the feasibility of wastewater reuse for irrigation purposes in a region. In Chapter 4 the model developed in Chapter 3 is used to determine the feasibility of wastewater reuse for golf course irrigation in the Lower Arkansas River Basin (LARK). Chapter 5 discusses the conclusions of the study and how they relate to wastewater reuse issues in the United States.

Chapter 2 - Literature Review

2.1 Current Status of Wastewater Reuse in the United States

By 2050 it is estimated that the world population will reach 9.5 billion, if not managed properly the world will have a shortage in fresh water supply. A potential exists to increase total water resources by reusing municipal wastewater for beneficial purposes. According to the National Research Council approximately 32 billion gallons per day of wastewater is discharged.[15] Reusing even a portion of this discharged wastewater for beneficial purposes could make a large impact in the total water shortages that are facing many municipalities. Water reuse is gaining popularity in the United States especially in the coastal regions facing serious water shortages. Table 2.1 outlines the reuse flow per capita from the nine states that reported having reuse in 2006 as reported by the Florida Department of Environmental Protection (DEP). [3]

Table 2.1: Reuse Flow Per Capita for the Nine States That Reported Having Reuse in 2006 (Source: Florida DEP)

State	Population (2006 est)	Reported Reuse[1] (MGD)	Reuse per Capita gpd/person	Rank
Florida	18,019,093	663.0	36.79	1
California	36,121,296	580.0[2]	16.06	2
Virginia	7,628,347	11.2	1.46	3
Texas	23,367,534	31.4	1.34	4
Arizona	6,178,251	8.2	1.33	5
Colorado	4,751,474	5.2	1.09	6
Nevada	2,484,196	2.6	1.03	7
Idaho	1,461,183	0.7	0.50	8
Washington[3]	6,360,529	0	0	9

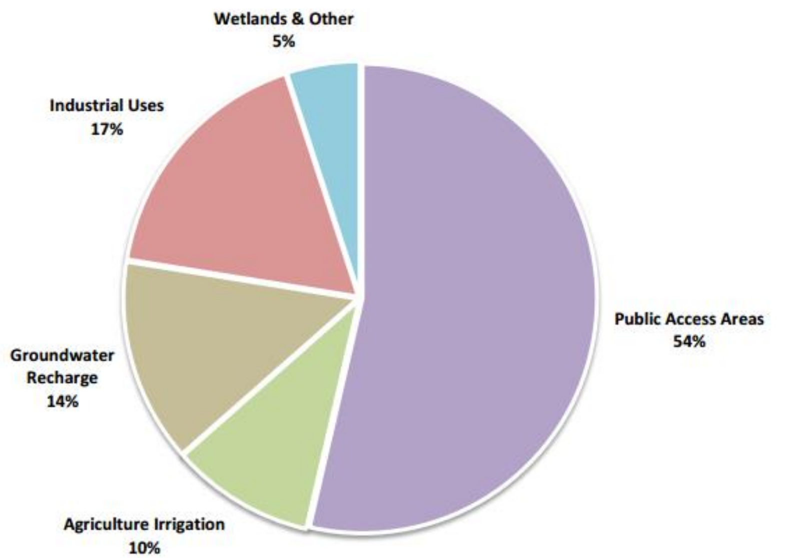
[1] From the Water Reuse Foundation National Database of Water Reuse Facilities Summary Report, 2006.

[2] The reuse data for California was updated in the National Database using data from California's 2002 reuse survey, which was previously missing. So while the 2006 Summary Report reported 87 MGD of reuse for California, the actual reuse flow was more like 580 MGD.

[3] The state of Washington reported reuse systems and reuse pipe, but no reuse flow as of 2006.

Florida is leading the way in wastewater reuse followed by California. Florida's reclaimed water use was reported as 719 MGD in 2013 which accounts for 45% of the total municipal wastewater flow for the state.[3] The largest reuse category is Public Access Areas representing 54% of the reuse.[3] Figure 2.1 illustrates where the reclaimed water is applied in Florida.

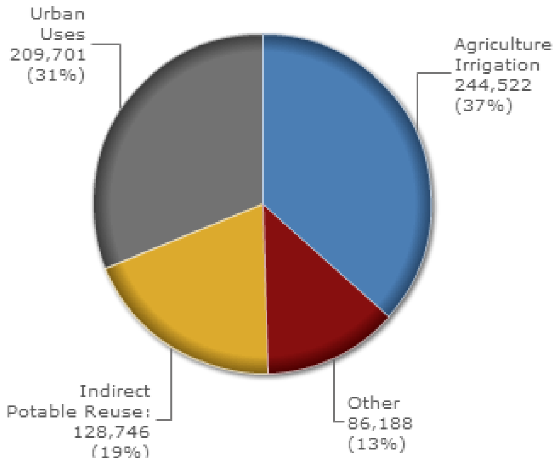
Figure 2.1: Reclaimed Water Utilization by Flow in Florida (Source: Florida DEP)



Note: (1) Agriculture irrigation includes edible crops (e.g., citrus) as well as feed and fodder crops (e.g., sprayfields).

According to the California Water Boards' Annual Performance Report, California's highest category of reuse was agricultural irrigation.[19] Figure 2.2 from the State Water Resources Control Board (SWRCB) in California illustrates the distribution of California's wastewater reuse. Florida and California are leading the way in wastewater reuse and can provide an excellent model for projects in other parts of the country. Reuse is an integral part of the water management plan in Florida and California. The California Water Board included a priority to "increase sustainable local water supplies available for meeting existing and future beneficial uses by 1,725,000 acre-feet per year, in excess of 2002 levels, by 2015, and unsure adequate water flows for fish and wildlife habitat.[19] Integrating wastewater reuse into the state's water resource management plan is a key to successful reuse.

Figure 2.2: Reclaimed Water Utilization by Flow in California (Source: SWRCB)



2.2 Future Water Needs for Kansas

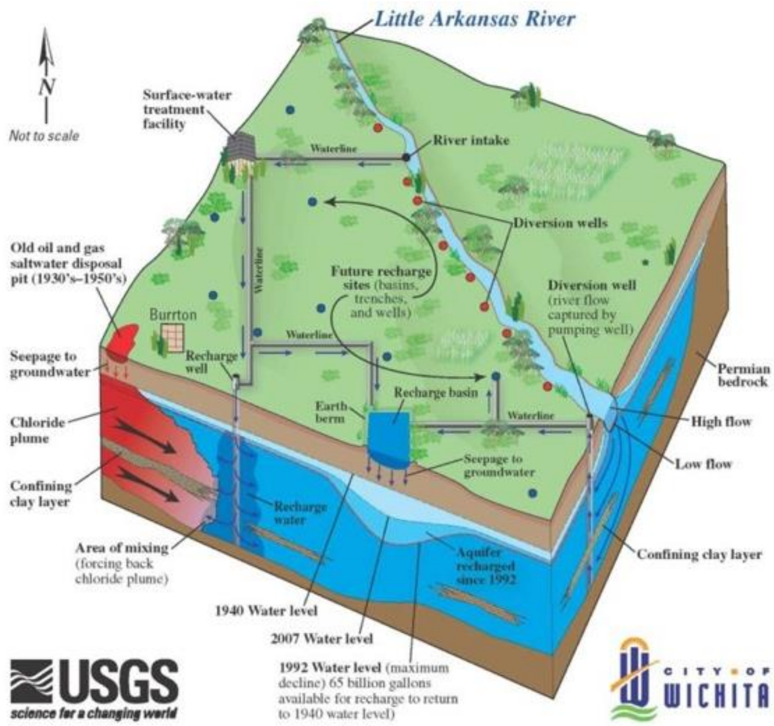
According to the USGS, The High Plains aquifer encompasses 175,000 square miles and eight states – Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The USGS published a report on the water-level and storage changes in the High Plains Aquifer. The USGS report had the following findings:

- Water-level changes from predevelopment to 2013, by well, ranged from a rise of 85 feet to a decline of 256 feet;
- Area-weighted, average water-level changes in the aquifer was a decline of 15.4 feet from predevelopment to 2013;
- Area-weighted, average water-level changes in the aquifer was a decline of 2.1 foot from 2011-2013;
- Total water storage in the aquifer in 2013 was about 2.92 billion acre-feet;

- Change in water storage, predevelopment to 2013, was a decline of 266.7 million acre-feet; and
- Change in water storage, 2011-13, was a decline of 36.0 million acre-feet.[14]

The High Plains aquifer is an extremely valuable resource for the state of Kansas. The Kansas Water Office has made it a state goal is to conserve and extend the High Plans aquifer. Wichita, the largest city in the LARK, projects their current water resources will not meet projected city water needs into the 21st century. They have embarked on an Artificial Recharge Process to increase the water levels in the Equus Beds Aquifer, a main water source for the municipality.[28] A chloride plume exists southwest of the region that will move closer to the city's water source as the aquifer levels decline. Figure 2.3 illustrates an overview of the Equus Beds Aquifer region.[27] The Kansas Water Office has made it a high priority issue to investigate how to better utilize reclaimed water as a valuable water resource in the LARK.[28]

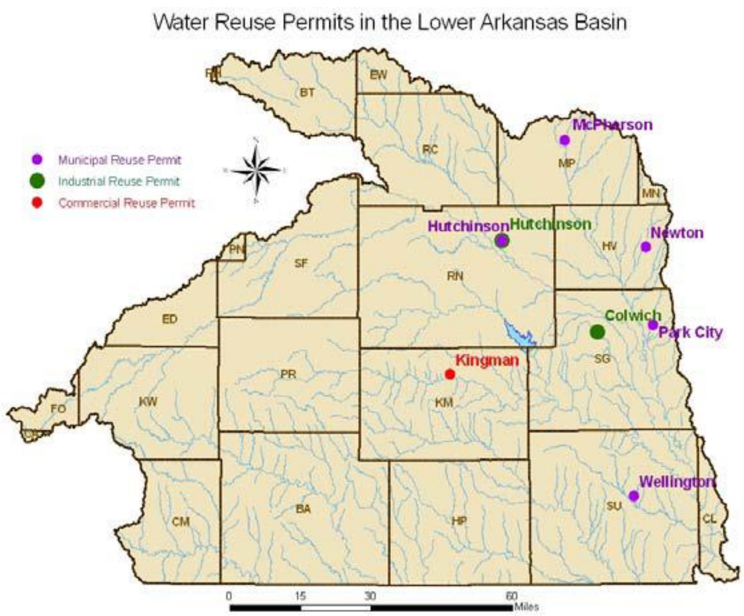
Figure 2.3: Equus Beds Aquifer Region (Source: USGS, Equus Beds Groundwater Recharge Project)



2.3 Status of Wastewater Reuse in Kansas and the LARK

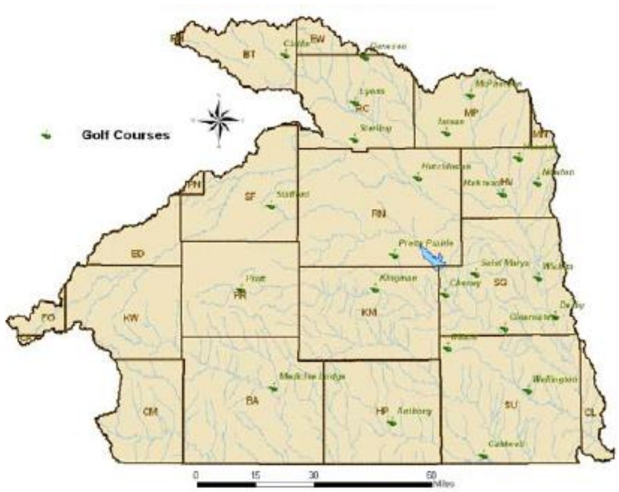
The current status of wastewater reuse in Kansas and the LARK can be used as a baseline for the region and provide guidance for future planning. As Kansas looks to the future and anticipates growth, wastewater reuse must be considered as an alternative water source. Currently, there are more than 140 communities and facilities authorized to reuse wastewater for beneficial purposes.[11] These beneficial purposes include irrigating turf on golf courses and parks. The LARK has a total of 11 communities and commercial facilities that are currently authorized to reuse wastewater.[11] These communities are illustrated in Figure 2.4. Eight municipalities in the LARK are currently authorized to use wastewater effluent for irrigation of golf courses and other public areas.[10]

Figure 2.4: Water Reuse Permits in the LARK (Source: KWO, 2009)



According to the 2009 Kansas Water Plan, more than 24 communities in the LARK have at least one golf course.[11] There lies a potential beneficial end user for wastewater reuse, each of these communities will be included in the results section of this report to determine how much wastewater in the LARK can feasibly be reused for golf course irrigation. Figure 2.5 shows the locations of the municipalities with golf courses.

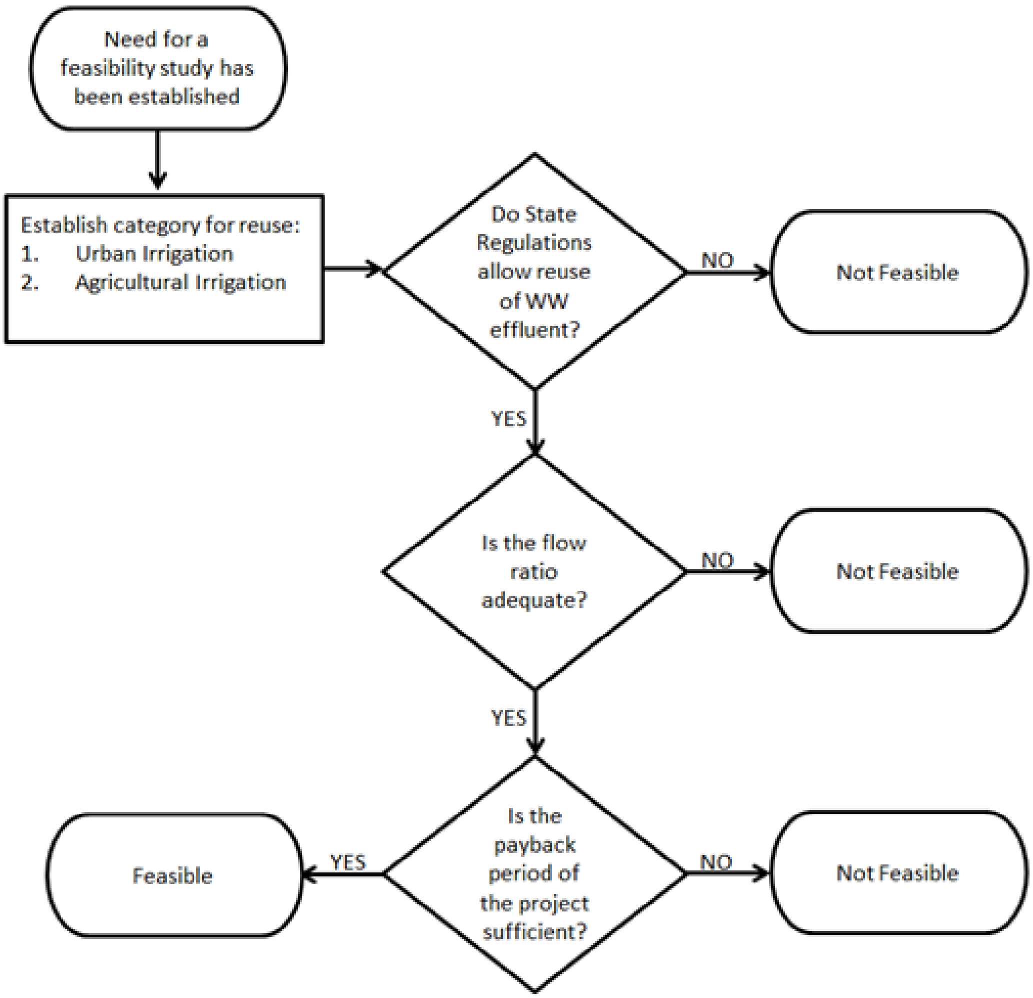
Figure 2.5: Golf Courses in the LARK (Source: KWO, 2009)



Chapter 3 - Methodology

The key to successful implementation of wastewater reuse in a region is integrating it into the water resource management planning. A straightforward method that regions could use to determine the potential of wastewater reuse in a region would provide a useful tool to promote integration. In this chapter, the methodology of developing a criteria based model to use for evaluating wastewater reuse potential is discussed. The focus of this research project is on reusing wastewater effluent for urban irrigation and agricultural irrigation in a region. This methodology is applied in Chapter 4 to determine if wastewater reuse for golf course irrigation is feasible in the LARK. Three distinct criteria make up the model; they are developed and discussed in this chapter. In the first section criteria 1, regulations and guidelines for reuse is developed. National regulations do not exist for wastewater reuse, each state has unique regulations and requirements. In this section, the resources are gathered and referenced to establish this first criterion. In the absence of regulations there are guidelines that have been established and adopted for use; these are also discussed in this section. In the second section, a process for calculating an adequate flow ratio is developed. Guidelines are established in this section for gathering wastewater design capacity. In addition, a procedure for estimating water use for irrigation is established. An equation is developed that determines if the wastewater treatment facility has an adequate flow ratio for the irrigation demands. In the third section methods for developing a cost benefit analysis are developed. The process of creating a payback period to analyze the feasibility of wastewater reuse in a region is developed and discussed. Figure 3.1 illustrates a flow diagram for the entire process. At the end of the model the result will be a list of facilities that are determined to be feasible for using wastewater effluent for their irrigation needs. This method is intended as a preliminary look at a region to determine if wastewater reuse for irrigation would help the water management profile and how much it could potentially help.

Figure 3.1: Flow Diagram of Wastewater Effluent Reuse Feasibility Process



3.1 Regulations and Guidelines (Criteria 1)

Regulations and guidelines dictate whether or not wastewater reuse is feasible in a region. There are no national regulations regarding reuse, each state has its own unique factors that govern when wastewater effluent reuse can be used. This highly impacts wastewater reuse project feasibility, for example reuse in Kansas for human consumption crops is prohibited. Regulations are set forth by each state's governing agency and can be accessed through the department of health and environment or equivalent state agency. The Environmental Protection Agency (EPA) conducted a survey for their 2012 Guidelines for Water Reuse report to inventory regulations and guidelines in the U.S. states, tribal communities, and territories. These regulations are compiled and available at the following link <https://www.watereuse.org/government-affairs/usepa-guidelines>. [23] Each state has a link that will access any regulations available. Some states have well developed regulatory statutes, however many states do not have specific regulations in place. In the absence of well-defined regulations in the area of study, there are guidelines for wastewater reuse.

Guidelines have been published for the United States and the World to help navigate through the factors that need to be considered and evaluated before wastewater effluent is reused. The EPA published updated Guidelines for Water Reuse in 2012 that outlines recommended practices in the United States.[23] In 2006, the World Health Organization (WHO) published the WHO Guidelines for the safe use of wastewater, excreta and greywater which outlines policy and regulatory aspects for the world.[27] These two documents make up the recommendations, or guidelines to be used when there are no clear regulations in place. The national guidelines are discussed in the next sections.

3.1.1 Guidelines for Urban Irrigation

Urban irrigation includes using wastewater effluent to irrigate recreational fields, golf courses, landscaping, etc. Public access is a critical piece of the regulatory requirements. Regulations differentiate between urban irrigation where public access is restricted or controlled and urban irrigation where public access is not controlled. Wastewater used for urban irrigation must be treated and therefore does not pose a direct health threat. Guidelines exist in most states that determine the level of treatment required and when the irrigation system can be running. In Kansas, for example irrigation is not allowed during hours when the public is allowed in the vicinity.

Although not regulated, a concern for urban irrigation is how the treated wastewater will affect the crop, in this case grass and turf. Wastewater effluent quality is dependent on the treatment process, the infiltration rate and storage. Each project must be evaluated on a case by case basis to determine how the water quality will affect the crop. Table 3.1 outlines the EPA guidelines for interpretation of water quality for irrigation as found in the 2012 Guidelines for water reuse document.[23] These guidelines are designed to help irrigation facilities know when to restrict using wastewater based on the water quality.

Table 3.1: Guidelines for interpretation of water quality for irrigation[1] (Source: USEPA, 2012)

Potential Irrigation Problem		Units	Degree of Restriction on Irrigation		
			None	Slight to Moderate	Severe
Salinity (affects crop water availability)[2]					
	EC_w	dS/m	<0.7	0.7-3.0	>3.0
	TDS	mg/L	<450	450-2000	>2000
Infiltration (affects infiltration rate of water into the soil: evaluate using EC_w and SAR together)[3]					
SAR	0-3	And EC_w =	>0.7	0.7-0.2	<0.2
	3-6		>1.2	1.2-0.3	<0.3
	6-12		>1.9	1.9-0.5	<0.5
	12-20		>2.9	2.9-1.3	<1.3
	20-40		>5.0	5.0-2.9	<2.9
Specific Ion Toxicity (affects sensitive crops)					
	Sodium (Na)[4]				
	Surface irrigation	SAR	<3	3-9	>9
	Sprinkler irrigation	meq/L	<3	>3	
	Chloride (Cl)[4]				
	Surface irrigation	meq/L	<4	4-10	>10
	Sprinkler irrigation	meq/L	<3	>3	
	Boron (B)	mg/L	<0.7	0.7-3.0	>3.0
Miscellaneous Effects (affects susceptible crops)					
	Nitrate (NO_3-N)	mg/L	<5	5-30	>30
	Bicarbonate (HCO_3)	meq/L	<1.5	1.5-8.5	>8.5
	pH		**Normal Range 6.5-8.4**		

[1] Adapted from FAO (1985)

[2] EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25° C (dS/m) or in millimhos per centimeter (mmho/cm); both are equivalent

[3] SAR is the sodium adsorption ratio: at a given SAR, infiltration rate increases as water salinity increases.

[4] for surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride: most annual crops are not sensitive. With overhead sprinkler irrigation and low humidity (<30 percent), sodium and chloride may be adsorbed through the leaves of sensitive crops.

The three categories of restriction in Table 3.1 are somewhat arbitrary and open for interpretation. End users will need to evaluate conditions of the crop being irrigated and the wastewater effluent water quality to determine how restricted the irrigation will be. Values in the table are based on normal field conditions in most arid and semi-arid parts of the world. Table 3.2 outlines the recommended water quality criteria for irrigation as developed in the 2012 Guidelines for Water Reuse document.[23] These are recommended values, the remarks section provides useful information for the end user to determine if the water quality is high enough.

Table 3.2: Recommended Water Quality Criteria for Irrigation (Source: USEPA, 2012)

Constituent	Maximum Concentrations for Irrigation (mg/L)	Remarks
Aluminum	5.0	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans
Boron	0.75	Essential to plant growth; sufficient quantities in reclaimed water to correct soil deficiencies. Optimum yields obtained at few-tenths mg/L; toxic to sensitive plants (e.g., citrus) at 1 mg/L. Most grasses are tolerant at 2.0 – 10 mg/L
Cadmium	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L; conservative limits are recommended
Chromium	0.1	Not generally recognized as an essential element; due to lack of toxicity data, conservative limits are recommended
Cobalt	0.05	Toxic to tomatoes at 0.1 mg/L; tends to be inactivated by neutral and alkaline soils
Copper	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/L
Fluoride	1.0	Inactivated by neutral and alkaline soils
Iron	5.0	Not toxic in aerated soils, but can contribute to soil acidification and loss of phosphorus and molybdenum
Lead	5.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	Tolerated by most crops up to 5 mg/L; mobile in soil. Toxic to citrus at low doses – recommended limit is 0.075 mg/L
Manganese	0.2	Toxic to a number of crops at few-tenths to few mg/L in acidic soils
Molybdenum	0.01	Nontoxic to plants; can be toxic to livestock if forage is grown in soils with high molybdenum
Nickel	0.2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH
Selenium	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium
Tin, Tungsten, and Titanium	--	Excluded by plants; specific tolerance levels unknown
Vanadium	0.1	Toxic to many plants at relatively low concentrations
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils

3.1.2 Guidelines for Agricultural Irrigation

Guidelines for Agricultural irrigation are typically more stringent because it directly impacts public safety. Agricultural reuse is divided into two distinct categories based on what is being irrigated:

1. Food crops
2. Processed food crops and non-food crops

The first category includes any crop that is intended for human consumption while the second category includes crops that are either processed before human consumption or not intended for human consumption.[23] Clearly guidelines will be more stringent for food crops because they are being used for human consumption. Many states, including Kansas do not allow wastewater effluent for agricultural irrigation. Table 3.3 outlines the suggested guidelines for water reuse from the 2012 Guidelines for water reuse report.

Table 3.3: Suggested Guidelines for Water Reuse (Source: USEPA, 2012)

Reuse Category and Description	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]
Urban Reuse				
Unrestricted The use of reclaimed water in municipal settings where public access is not restricted.	Secondary[4] Filtration[5] Disinfection[6]	- pH = 6.0-9.0 - ≤ 10 mg/L BOD[7] - ≤ 2 NTU[8] - No detectable fecal coliform/100ml [9,10] - 1 mg/l Cl_2 residual (min.) [11]	pH – weekly BOD – weekly Turbidity – continuous Fecal coliform – daily Cl_2 residual - continuous	50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media[18]
Restricted The use of reclaimed water in nonpotable applications in municipal settings where public access is controlled or restricted	Secondary[4] Disinfection[6]	- pH = 6.0-9.0 - ≤ 30 mg/L BOD[7] - ≤ 30 mg/L TSS - ≤ 200 fecal coliform/100ml [9,13,14] - 1 mg/l Cl_2 residual (min.)[11]	pH – weekly BOD – weekly TSS – daily Fecal coliform – daily Cl_2 residual - continuous	- 300 ft (90 m) to potable water supply wells - 100 ft (30 m) to areas accessible to the public (if spray irrigation)

by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction				
Agricultural Reuse				
<u>Food Crops</u>[15] The use of reclaimed water for surface or spray irrigation of food crops which are intended for human consumption, consumed raw.	Secondary[4] Filtration[5] Disinfection[6]	- pH = 6.0-9.0 - ≤ 10 mg/L BOD[7] - ≤ 2 NTU[8] - No detectable fecal coliform/100ml [9,10] - 1 mg/l Cl_2 residual (min.) [11]	pH – weekly BOD – weekly Turbidity – continuous Fecal coliform – daily Cl_2 residual - continuous	50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media[18]
<u>Processes Food Crops</u>[15] The use of reclaimed water for surface irrigation of food crops which are intended for human consumption, commercially processed. **<u>Non-Food Crops</u>** The use of reclaimed water for irrigation of crops which are not consumed by humans, including fodder, fiber, and seed crops, or to irrigate pasture land, commercial nurseries, and sod farms	Secondary[4] Disinfection[6]	- pH = 6.0-9.0 - ≤ 30 mg/L BOD[7] - ≤ 30 mg/L TSS - ≤ 200 fecal coliform/100ml [9,13,14] - 1 mg/l Cl_2 residual (min.) [11]	pH – weekly BOD – weekly Turbidity – daily Fecal coliform – daily Cl_2 residual - continuous	- 300 ft (90 m) to potable water supply wells - 100 ft (30 m) to areas accessible to the public (if spray irrigation)

Footnotes

[1] These guidelines are based on water reclamation and reuse practices in the U.S. and are specifically directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in many areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries. It is explicitly stated that the direct application of these suggested guidelines will not be used by USAID as strict criteria for funding.

[2] Unless otherwise notes, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

[3] Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.

[4] Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contactors, and may stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and SS do not exceed 30 mg/L

[5] Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite; or the passing of wastewater through microfilters or other membrane processes.

[6] Disinfection mean the destruction, inactivation or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, ozonation, other disinfectants, UV, membrane processes, or other processes.

[7] As determined from the 5-day BOD test

[8] The recommended turbidity should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If SS is used in lieu of turbidity, the average SS should not exceed 5 mg/L. If membranes are used as the filtration process, the turbidity should not exceed 0.2 NTU and the average SS should not exceed 0.5 mg/L.

[9] Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation tube technique may be used.

[10] The number of total or fecal coliform organisms (whichever one is recommended for monitoring in the table) should not exceed 14/100 ml in any sample.

[11] This recommendation applies only when chlorine is used as the primary disinfectant. The total chlorine residual should be met after a minimum actual modal contact time of at least 90 minutes unless a lesser contact time has been demonstrated to provide indicator organism and pathogen reduction equivalent to those suggested in these guidelines. In no case should the actual contact time be less than 30 minutes.

[12] It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementation of a reuse program.

[13] The number of fecal coliform organisms should not exceed 800/100 ml in any sample.

[14] Some stabilization pond systems may be able to meet this coliform limit without disinfection

[15] Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.

[16] Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, advanced oxidation, air stripping, ultrafiltration, and ion exchange.

[17] Monitoring should include inorganic and organic compounds, or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

Wastewater treatment level is often directly listed in the regulations and guidelines for wastewater reuse. For both urban and agricultural reuse the level of wastewater treatment is a significant piece of the regulatory puzzle and need to be fully understood in this section of the methodology. Primary, secondary and advanced treatments are defined below:

- “Primary – Removal of a portion of the suspended solids and organic matter from the wastewater.
- Secondary – Biological treatment to remove biodegradable organic matter and suspended solids. Disinfection is typically, but not universally, included in secondary treatment.

- Advanced treatment – Nutrient removal, filtration, disinfection, further removal of biodegradable organics and suspended solids, removal of dissolved solids and/or trace constituents as required for specific water reuse applications." (National Research Council, pg.24).[15]

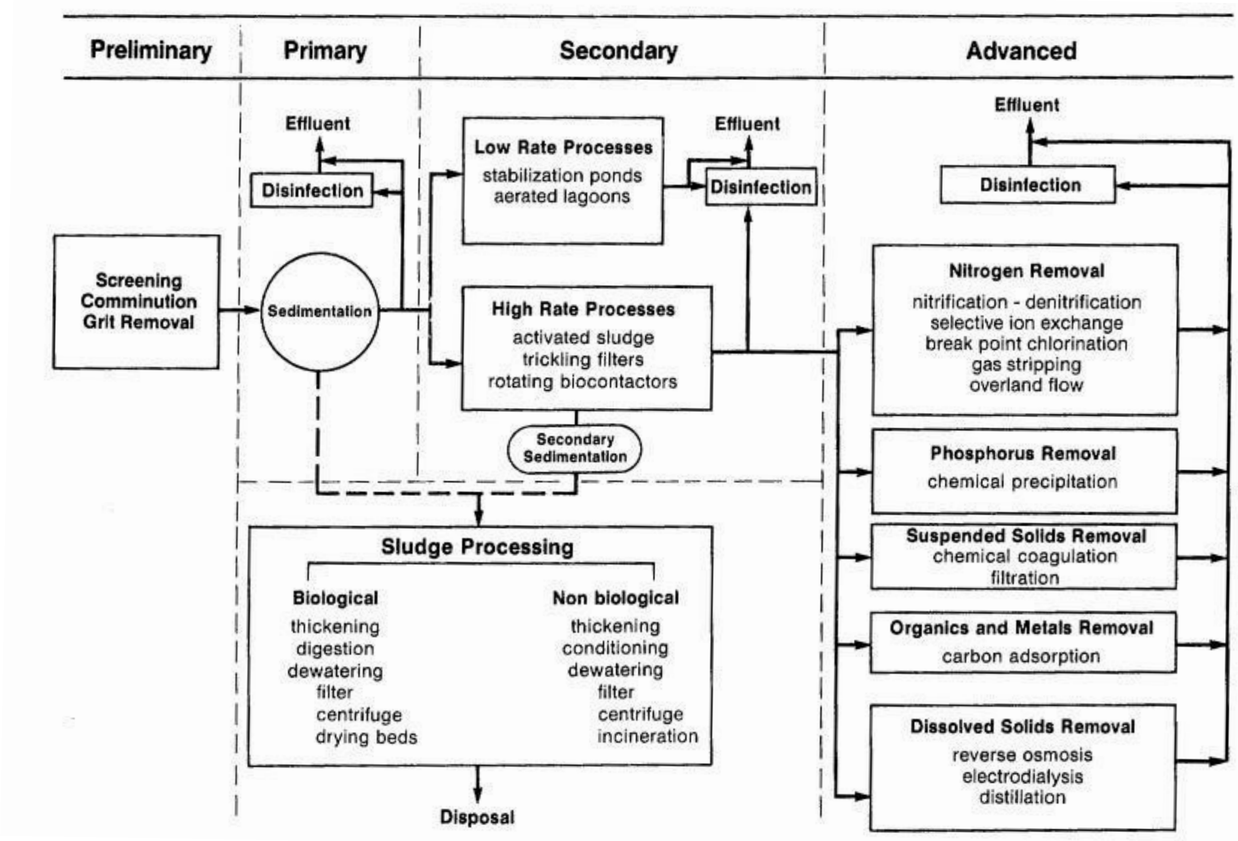
Table 3.4 illustrates the types of reuse appropriate for increasing levels of wastewater treatment as determined by the 2012 Guidelines for Water Reuse.[23] It is noted that the cost of treating wastewater increases with the level of treatment, however the acceptable levels of risk of human exposure increase. This table is useful because wastewater reuse projects will incur higher costs if the wastewater treatment plant needs to be upgraded to a higher level of treatment.

Table 3.4: Types of Reuse Appropriate for Increasing Levels of Treatment (Source: USEPA, 2012)

Treatment Level	Increasing Levels of Treatment →			
	Primary	Secondary	Filtration and Disinfection	Advanced
Processes	Sedimentation	Biological oxidation and disinfection	Chemical coagulation, biological or chemical nutrient removal, filtration, and disinfection	Activated carbon, reverse osmosis, advanced oxidation processes, soil aquifer treatment, etc.
End Use	No Uses Recommended	Surface irrigation of orchards and vineyards	Landscape and golf course irrigation	Indirect potable reuse including groundwater recharge of potable aquifer and surface water reservoir augmentation and potable reuse
		Non-food crop irrigation	Toilet flushing	
		Restricted landscape impoundments	Vehicle washing	
		Groundwater recharge of nonpotable aquifer	Food crop irrigation	
		Wetlands, wildlife habitat, stream augmentation	Unrestricted recreational impoundment	
		Industrial cooling processes	Industrial systems	
Human Exposure	Increasing Acceptable Levels of Human Exposure →			
Cost	Increasing Levels of Cost →			

Figure 3.2 gives a more detailed description of the processes involved in each stage of the wastewater treatment process. [16] This diagram is useful in determining the level of treatment a wastewater facility is achieving.

Figure 3.2: Generalized Flow Sheet for Wastewater Treatment (Source: Pettygrove, 1985)



Maintaining public safety is the highest priority in any wastewater reuse project however, there are characteristics of wastewater that provide benefits to urban and agricultural crops. Nitrogen, phosphorus, and potassium all have the possibility of providing valuable nutrients to the crops. Many farmers and golf course owners apply fertilizer to their crop or grass to promote growth and health. In many cases the end user can reduce the amount of fertilizer used on the crops because the nutrients are already available in the water.

Local regulations in conjunction with national guidelines need to be evaluated to determine if wastewater effluent reuse is feasible in the region of interest. If the regulations do not allow the specific reuse application, or the wastewater treatment facility does not treat the water to a high enough level, then the project is clearly not feasible. Regulations and guidelines need to be carefully evaluated to determine how much manpower will be needed for any sampling, or paperwork that needs to be completed. In some cases the regulatory requirements are not feasible with the available resources. If regulations and guidelines do allow or recommend the use of wastewater effluent for the application the project is moved to the next phase of evaluation for feasibility.

3.2 Adequate Flow Ratio (Criteria 2)

Adequate flow ratio is extremely important in determining the feasibility of wastewater reuse projects because it evaluates whether or not the wastewater facility has enough discharge for the reuse application. Calculating a Flow Ratio involves several steps as follows:

1. Compile all wastewater treatment facility design capacity information for the region.
2. Estimate water usage numbers for the category of reuse chosen in the region.
3. Determine a distance that will be used to match wastewater treatment facilities with end users.
4. Calculate flow ratio for all end users within the specified distance of the wastewater treatment facility.
5. Move the group of wastewater treatment facilities and end users to the next criteria if they have an adequate flow ratio.

Adequate flow ratio is a comparison of the quantity of wastewater effluent available and the calculated quantity of water needed for irrigation. A project will not be feasible unless the wastewater treatment facility has sufficient effluent to adequately fulfill the needs of the end user. Section 3.2.1 will discuss the definitions and sources for wastewater treatment facility design capacity and Section 3.2.2 will discuss the resources and equations needed to estimate the urban and agricultural water use demands.

3.2.1 Wastewater Treatment Facility Design Capacity

Each state has a regulatory agency that governs all National Pollutant Discharge Elimination System (NPDES) permits for wastewater treatment facilities. In Kansas the agency is the Kansas Department of Health and Environment (KDHE). Design capacity, in addition to any data on the permit, for each permitted wastewater treatment facility is available through the KDHE office. Data for all wastewater treatment facilities in the region of study should be gathered in this step of the model. If the wastewater treatment facility does not meet the regulatory requirements from section 3.1, the wastewater treatment facility should be removed from the list of potential candidates for reuse. Permits should be reviewed to determine if there are any wastewater treatment facilities that are currently permitted for reuse projects. The amount of water permitted for reuse should be subtracted from the design capacity of the facility because that effluent is not available for future projects. The list of wastewater treatment facilities that are left should be compiled to be evaluated for adequate flow ratio.

It is important to understand the meaning of wastewater treatment plant design capacity in order to accurately estimate the quantity of effluent available. As set forth by the 10 State Standards[5] the following are definitions of hydraulic capacity:

a. Design Average Flow
The design average flow is the average of the daily volumes to be received for a continuous 12 month period expressed as a volume per unit time. However, the design average flow for facilities having critical high hydraulic loading periods (e.g., recreational areas, campuses, industrial facilities) shall be based on the average of the daily volumes to be received during the seasonal period.

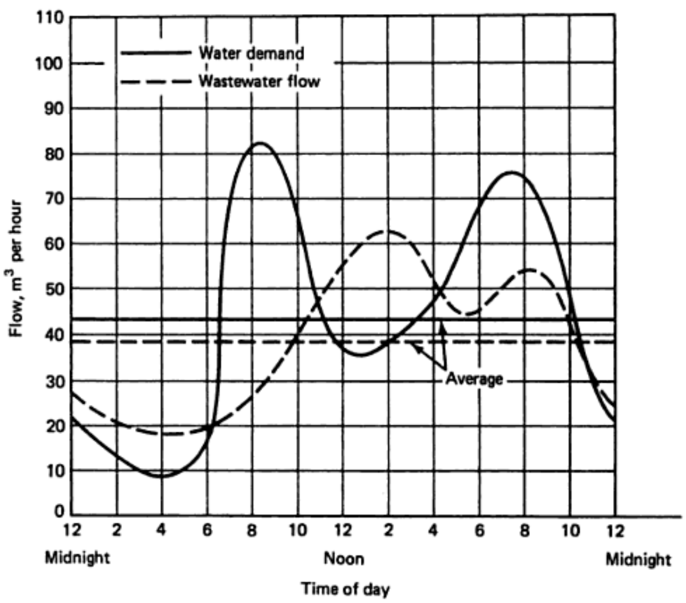
b. Design Maximum Day Flow
The design maximum day flow is the largest volume of flow to be received during a continuous 24 hour period expressed as a volume per unit time.

c. Design Peak Hourly Flow
The design peak hourly flow is the largest volume of flow to be received during a one hour period expressed as a volume per unit time.

d. Design Peak Instantaneous Flow
The design peak instantaneous flow is the instantaneous maximum flow rate to be received.[5]

The Recommended Standards for Wastewater Facilities defines wastewater treatment facility design capacity as the design average flow at the design average BOD_5.[5] Urban and agricultural irrigation can have significant seasonal variations depending on the region. The seasonal variations of the end user and the flow variations of the wastewater treatment facility should be analyzed to determine if storage will be needed to overcome offset peaks. Figure 3.3 illustrates typical variation in municipal water demand and wastewater flow (Qasim, 1985).[17] As illustrated, there is a time offset between the wastewater flow peaks and the water demand peaks. This information will be used in the cost benefit analysis described later in this report because it brings storage into the equation.

Figure 3.3: Typical Variations in Municipal Water Demand and Wastewater Flow (Source: Qasim, 1985)



Section 3.2.2 Urban and Agricultural Irrigation Demands

Estimations for urban and agricultural irrigation water use demands include many project specific factors including type of crop, weather conditions, rainfall, soil type, etc. Seasonal irrigation demands depend on an evapotranspiration rate for the crop, a determination of the period of plant growth, annual precipitation data, and soil permeability and water holding capacity. The U.S. Department of Agriculture's National Engineering Handbook provides methods for calculating irrigation requirements (USDA).[21] If available, historical data can be another method that can be used to determine the approximate irrigation requirements in a region. An example of one such resource is the Kansas Irrigation Water Use report published each year. These reports are readily available on the Kansas Department of Agriculture website.

Every state should have similar reports available on their department of agriculture website. In the reports, water use, acres irrigated, and average application rate by crop and region1al location are reported.[8] Table 3.5, 3.6 and 3.7 show the results for 2012, 2011 and 2010 respectively.

Table 3.5: Water Use, Acres Irrigated, and Average Application Rate By Crop and Regional Location (Source: Kansas Department of Agriculture, 2014)

	Alfalfa			Corn			Grain Sorghum			Soybeans			Wheat			Other or Multiple Crops [a/]		
Regional Location	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A
Western Kansas																		
GMD No. 1	1,719	924	1.86	68,108	48,221	1.41	1,291	1,382	0.93	381	253	1.51	3,084	4,567	0.68	152,785	142,485	1.07
GMD No. 3	172,395	91,563	1.88	669,031	386,876	1.73	16,481	16,215	1.02	33,882	21,092	1.61	52,644	52,546	1.00	1,132,677	853,729	1.33
GMD No. 4	6,461	4,564	1.42	331,383	217,764	1.52	1,711	2,021	0.85	23,344	16,157	1.44	3,443	4,522	0.76	172,586	141,315	1.22
Remainder	14,211	10,008	1.42	43,745	33,205	1.32	2,358	2,295	1.03	5,062	4,134	1.22	3,513	4,483	0.78	62,243	54,115	1.15
Central Kansas																		
GMD No. 2	1,384	1,274	1.09	58,339	47,482	1.23	2,704	2,976	0.91	35,683	31,892	1.12	1,256	1,658	0.76	55,633	50,825	1.09
GMD No. 5	26,111	18,972	1.38	267,231	195,434	1.37	12,181	11,247	1.08	100,325	74,685	1.34	14,529	20,333	0.71	159,992	134,401	1.19
Remainder	5,666	5,390	1.05	85,909	84,963	1.01	5,601	5,989	0.94	41,992	45,048	0.93	1,679	2,680	0.63	101,364	103,696	0.98
Eastern Kansas																		
All Eastern KS	201	369	0.54	22,318	31,497	0.71	23	30	0.77	11,688	18,511	0.63	0	0	0	21,261	29,743	0.71
State Total	228,148	133,064	1.71	1,546,064	1,045,442	1.48	42,350	42,155	1.00	252,357	211,772	1.19	80,148	90,789	0.88	1,858,541	1,510,309	1.23

[a/] Other includes irrigated oats, barley, rye, dry beans, sunflowers, pasture, turf grass, cotton, grapes, other unspecified crops, golf courses, truck farms, orchards, and nurseries. Multiple crops are reported combinations of irrigated alfalfa, corn, grain sorghum, soybeans, and other crops.

Table 3.6: Water Use, Acres Irrigated, and Average Application Rate by Crop and Regional Location (Source: Kansas Department of Agriculture, 2014).

	Alfalfa			Corn			Grain Sorghum			Soybeans			Wheat			Other or Multiple Crops [a/]		
Regional Location	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A
Western Kansas																		
GMD No. 1	1,476	1,106	1.33	68,596	52,618	1.30	1,966	1,548	1.27	503	425	1.18	3,134	4,850	0.65	132,619	140,064	0.95
GMD No. 3	171,472	94,822	1.81	795,855	433,260	1.84	9,118	7,487	1.22	40,489	22,759	1.78	57,161	49,462	1.16	1,222,135	843,083	1.45
GMD No. 4	4,486	3,673	1.22	265,643	212,926	1.25	518	1,156	0.45	17,770	15,984	1.11	4,093	7,955	0.51	136,142	140,160	0.97
Remainder	12,508	9,243	1.35	41,020	33,975	1.21	2,090	1,914	1.09	4,228	4,912	0.86	4,044	5,270	0.77	58,827	53,750	1.09
Central Kansas																		
GMD No. 2	1,872	1,477	1.27	59,933	46,089	1.30	1,662	1,726	0.96	43,399	33,888	1.28	530	597	0.89	67,331	50,456	1.33
GMD No. 5	24,659	16,741	1.47	318,257	215,399	1.48	5,935	4,825	1.23	132,614	86,393	1.54	6,900	8,414	0.82	180,268	128,865	1.40
Remainder	5,101	5,764	0.89	70,453	85,383	0.83	5,060	4,623	1.09	35,394	45,468	0.78	1,344	2,680	0.50	79,456	98,115	0.81
Eastern Kansas																		
All Eastern KS	27	66	0.40	17,208	29,121	0.59	0	0	0.00	9,576	19,270	0.50	13	70	0.18	16,929	27,264	0.62
State Total	221,602	132,892	1.67	1,636,965	1,108,771	1.48	26,350	23,279	1.13	283,972	229,099	1.24	77,220	79,298	0.97	1,893,707	1,481,757	1.28

[a/] Other includes irrigated oats, barley, rye, dry beans, sunflowers, pasture, turf grass, cotton, grapes, other unspecified crops, golf courses, truck farms, orchards, and nurseries. Multiple crops are reported combinations of irrigated alfalfa, corn, grain sorghum, soybeans, and other crops.

Table 3.7: Water Use, Acres Irrigated, and Average Application Rate by Crop and Regional Location (Source: Kansas Department of Agriculture, 2014).

Regional Location	Alfalfa			Corn			Grain Sorghum			Soybeans			Wheat			Other or Multiple Crops		
	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A	Water Use (AF)	Acres Irrig.	AF/A
Western Kansas																		
GMD No. 1	1,960	1,727	1.14	55,393	51,111	1.08	637	1,483	0.43	774	831	0.93	2,901	6,566	0.44	116,414	139,307	0.84
GMD No. 3	169,819	101,818	1.67	680,099	453,110	1.50	7,605	8,700	0.87	34,111	25,297	1.35	38,520	49,166	0.78	897,918	811,109	1.11
GMD No. 4	5,137	5,468	0.94	215,266	199,993	1.08	1,467	1,812	0.81	21,833	21,760	1.00	2,391	7,035	0.34	115,208	142,049	0.81
Remainder	11,530	9,585	1.20	36,372	35,190	1.03	1,522	1,620	0.94	5,573	5,587	1.00	2,181	3,540	0.62	42,996	48,048	0.89
Central Kansas																		
GMD No. 2	968	1,358	0.71	40,238	44,009	0.91	409	757	0.54	33,502	37,272	0.90	445	986	0.45	39,706	45,106	0.88
GMD No. 5	19,918	19,560	1.02	253,010	218,025	1.16	2,561	2,829	0.91	109,207	96,281	1.13	5,351	8,518	0.63	113,768	110,604	1.03
Remainder	3,599	6,085	0.59	51,418	75,827	0.68	2,173	3,263	0.67	32,977	54,796	0.60	628	1,642	0.38	56,977	91,054	0.63
Eastern Kansas																		
All Eastern KS	42	101	0.42	7,523	26,706	0.28	0	0	0.00	6,054	18,709	0.32	0	0	0.00	10,114	24,313	0.42
State Total	212,973	145,702	1.46	1,339,319	1,103,971	1.21	16,374	20,464	0.80	244,031	260,533	0.94	52,417	77,453	0.68	1,393,101	1,411,590	0.99

Local resources should be compared with rainfall data to determine if the water usage is an outlier due to extreme precipitation conditions. Averaging several years' worth of water usage data will give a ballpark estimate that can be used in the region to determine an estimated water demand. Each state and region will have historical agricultural water use data available. Urban irrigation uses exactly the same method with grass and or turf substituted for crop.

When the wastewater treatment facility effluent and end user water use demands are estimated the facilities need to be evaluated to determine if an adequate flow ratio is available. The wastewater treatment facilities and end users in a region can be mapped with a variety of tools like Google Maps and ArcGIS. Once the facilities are located, an acceptable distance between facility and end user needs to be established to create a list of facilities to be analyzed. The distance between facilities is determined on a region by region basis and depends on how populated the region is and the general size of the facilities. This number can be revisited after the cost benefit analysis if it is determined the radius should be larger or smaller for the region of study. When a list of end users and wastewater treatment facilities has been matched within a specified radius, the flow ratio can be calculated using the following equation:

$$\text{Flow Ratio} = Q_{ww} / Q_i$$

Where Q_{ww} is the design capacity of the wastewater treatment facility in MGD and Q_i is the irrigation water demand in MGD. A wastewater treatment facility must have a flow ratio greater than one to be considered feasible or adequate. In certain cases if the flow ratio is below

1 the project could still be considered feasible but the end user will have to use supplemental water sources or reduce the amount of irrigation. Using storage in the reuse project could increase the amount of effluent available from the wastewater treatment facility. Flow variation should be carefully evaluated on a case by case basis for both the wastewater treatment facility and the end user. For each matching facility the maps created will be used to estimate distance between the wastewater treatment facility and end user in miles. For the remainder of this report this value will be referred to as distance.

3.3 Cost Benefit Analysis (Criteria 3)

The final step in the model is to develop a cost benefit analysis to determine if the project is feasible. There are many different approaches that can be used for this criterion. The main focus of the cost benefit analysis is the financial bottom line. The financial bottom line is broken down into capital costs of the project, O&M costs and difference in cost of water. For irrigation applications the capital costs are low when compared to other wastewater reuse categories. Figure 3.4, from An Economic Framework for Evaluating the Benefits and Costs of Water Reuse, depicts the financial analysis.[18] It can be derived from this table that the reuse water sales have a large impact on the feasibility of wastewater reuse projects. Table 3.8 outlines the common costs associated wastewater reuse projects. Estimates will be completed for each of the categories based on the regional study parameters. When completing a financial analysis for a region some generalizations can be made as specific information may not be known. It is advantageous to interview end users in the region of study who are currently using wastewater effluent for irrigation to gain additional information.

Figure 3.4: Financial Analysis (Source: Raucher, 2006)

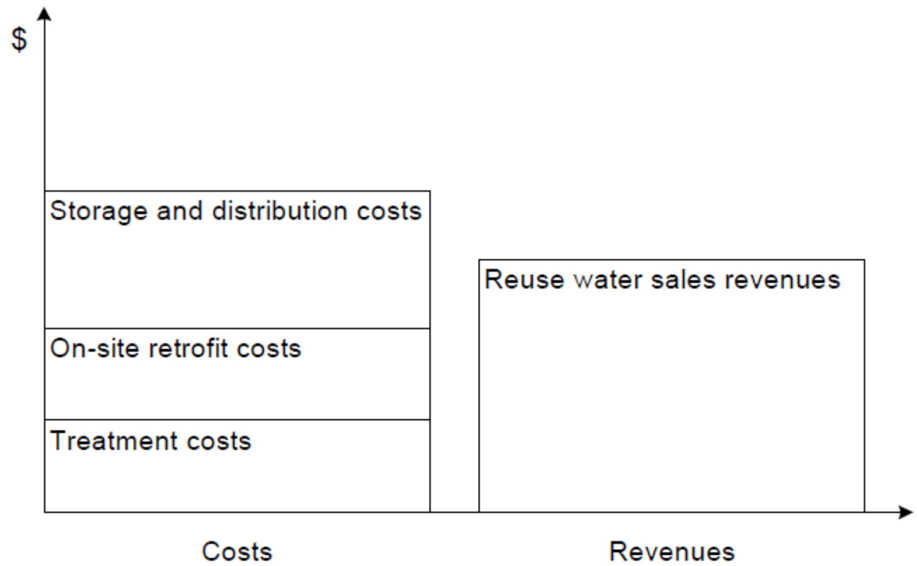


Table 3.8: Financial Analysis Costs

Category	**Description**
Capital Costs	
Distribution	Construction cost of distribution mains, valves
Storage	Construction cost of storage either at WWTF or end user
On-Site Retrofit	Cost of modifications to existing system (backflow preventers, required signage, modifications to irrigation system, etc.)
Treatment	Cost of additional treatment either at the WWTF or end user
Operation and Maintenance Costs (O&M)	
Storage O&M	Labor costs associated with operating the storage unit / annual maintenance costs to keep storage unit operational
Treatment O&M	Labor costs associated with operating the treatment equipment / chemicals required for operating the treatment equipment / annual maintenance costs to keep treatment equipment operational
On-Site Retrofit O&M	Labor costs associated with upkeep of modifications made / annual maintenance costs to keep modifications operational
Annual Savings / Expenditures	
Difference in Cost of Water	Cost difference between the existing water source and reuse water

Capital costs for wastewater reuse projects include distribution, storage, on-site retrofit, and treatment costs. Distribution costs are based on the size of pipe needed and the construction cost associated with laying the distribution main from the wastewater treatment facility to the end user. Distribution main diameters are modeled using the Hazen Williams equation:

$$v = k\,C\,R^{0.63}\,S^{0.54}$$

Where v velocity in ft/s, k is a conversion factor (k=1.318 for US customary units), C is a roughness coefficient, R is the hydraulic radius (in ft), and S is the slope (ft/ft). Multiplying both sides by area allows the equation to introduce flowrate. Assuming the pipe is flowing half full the equation can be modified further.

$$Q = k\,CR^{0.63}\,S^{0.54}A \qquad Q = (k/\pi)C(d/2)^{2.63}A^{0.54}$$

The website engineeringtoolbox.com has a convenient table for determining the carrying capacity of sewer pipe for different slopes.[1] Table 3.9 illustrates this table.

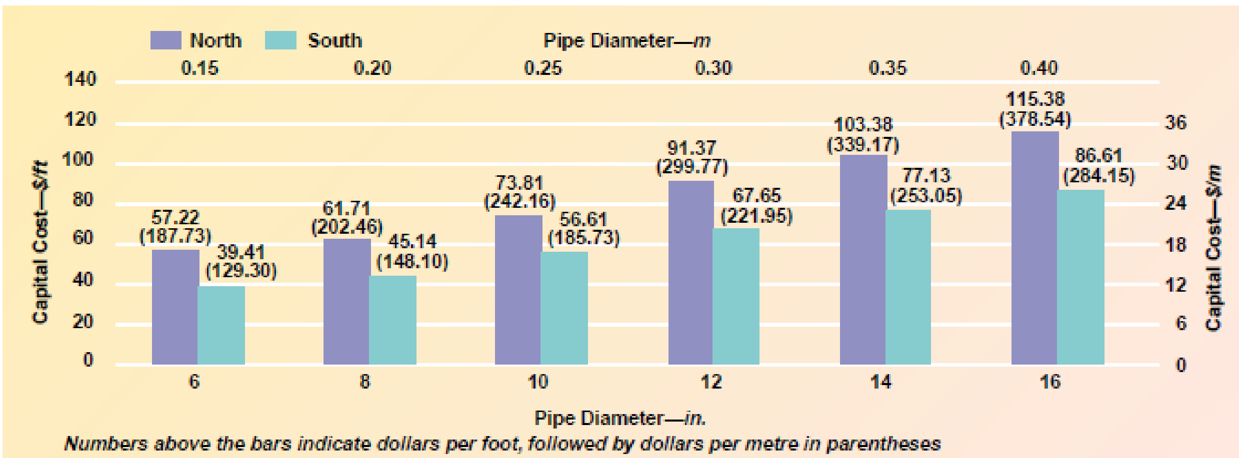
Table 3.9: Carrying Capacity of Sewer Pipe

Carrying Capacity of Sewer Pipe (gallons per minute)[1]								
Size of pipe (inches)	Decline per 100 ft of pipe (ft)							
	1	2	3	6	9	12	24	36
3	13	19	23	32	40	46	64	79
4	27	38	47	66	81	93	131	163
6	75	105	129	183	224	258	364	450
8	153	211	265	375	460	527	750	923
9	205	290	355	503	617	712	1006	1240
10	267	378	463	655	803	926	1310	1613
12	422	596	730	1033	1273	1468	2076	2554
15	740	1021	1282	1818	2224	2464	3617	4467
18	1168	1651	2022	2860	3508	4045	5704	7047
24	2396	3387	4155	5874	7202	8303	11744	14466
27	4407	6211	7674	10883	13257	15344	21770	26622
30	5906	8352	10233	14298	17717	20204	28129	35513
36	9700	13769	16816	23760	29284	33722	47523	58406

[1] The discharge rate is based on clean water and half-filled pipes.

Construction costs for distribution system mains depend on many site and project specific variables. For the purposes of a general regional study local construction data can be used. The USEPA completed a nationwide survey to document the cost of infrastructure needs. Table 3.10 is a compilation of the data received from this study on the capital cost of common size distribution mains as a function of diameter and geographic region. Capital cost numbers from this resource can be used, but should be verified with some local data to validate the accuracy.

Table 3.10: Estimated Capital Cost of Distribution Mains as a Function of Diameter and Geographic Region (Source: Hertzler, 1997)



The estimated capital cost of distribution becomes:

$C_d = C_p * \text{distance} * 5280$

Where C_p is the pipeline cost as a function of diameter ($/ft), distance is the distance between wastewater treatment facility and end user in miles (as estimated in Section 3.2.2), and 5280 is a unit conversion factor.

Storage requirements for wastewater reuse projects are highly variable and depend on the category of reuse. Irrigation has extremely high seasonal demands in semi-arid communities so storage should be considered. Due to the diurnal curves of the wastewater treatment facility, it is typically not practical to reuse wastewater directly from the plant for irrigation purposes. Some form of storage or flow equalization is usually required to make the availability of irrigation water practical. According to the IRRIGATION WITH RECLAIMED MUNICIPAL WASTEWATER, A Guidance Manual, the reasons to include storage in a wastewater reuse project are as follows:

1. "To equalize daily variations in flow from the treatment plant and to store excess when average wastewater flow exceeds irrigation demands; includes winter storage.
2. To meet peak irrigation demands in excess of the average wastewater flow.
3. To minimize disruptions in the operations of the treatment plant and irrigation system. Storage is used to provide insurance against the possibility of unsuitable reclaimed wastewater entering the irrigation system and to provide additional time to resolve temporary water-quality problems.
4. To provide additional treatment. Oxygen demands, suspended solids, nitrogen, and microorganisms are reduced during storage." (Pettygrove, pg. 2-23)[16]

Wet ponds are a means for constructing storage for wastewater reuse in irrigation applications. The pond should be sized to meet peak irrigation demands above the average wastewater flowrate. Table 3.11, from the Stormwater Manager's Resource Center (SMRC), outlines typical maintenance activities that could potentially be needed for a wet pond.[20] It is estimated by the SMRC that O&M costs are typically around 3 to 5% of the construction cost.

Table 3.11: Typical Maintenance Activities for Wet Ponds (Source: WMI, 1997)

Activity	Schedule
• Inspect for damage. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual Inspection
• Repair undercut or eroded areas.	As Needed for Maintenance
• Clean and remove debris from inlet and outlet structures. • Move side slopes.	Monthly Maintenance
• Removal of sediment from the forebay.	5 to 7 year Maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, or the pond becomes eutrophic.	20 to 50 year Maintenance

Costs for wet ponds or retention basins were evaluated by the EPA Preliminary Data Summary of Urban Storm Water Best Management Practices. Construction and design is very similar for wastewater effluent reuse retention basins.[24] Table 3.12 illustrates the base capital costs for detention basins and wetlands by source. This data can be used as a direct input for the storage capital cost in the cost benefit analysis.

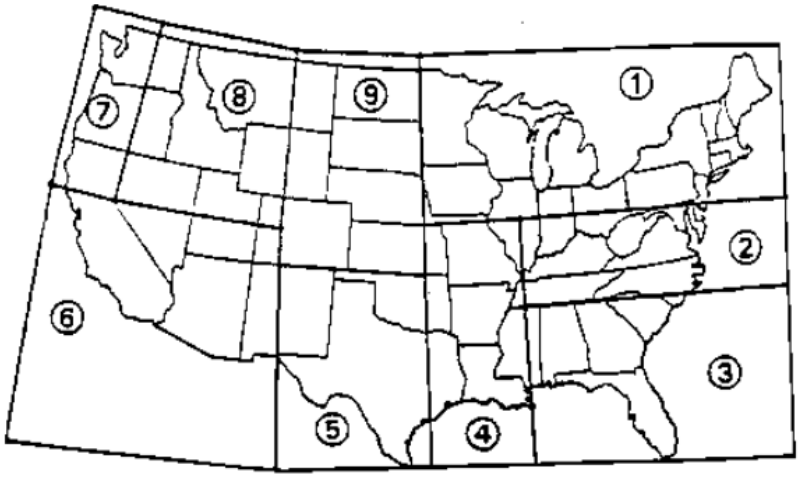
Table 3.12: Base Capital Costs for Storm Water Ponds and Wetlands (Source: USEPA, 1999)

BMP Type	Cost Equation or Estimate	Costs Included		Source
		Construction	E&S Control	
Retention Basins and Wetlands	$7.75V^{0.75}$	✔	✔	Wiegand et al, 1986
	$18.5V^{0.70}$	✔		Brown and Schueler, 1997b
Detention Basins	$7.47V^{0.78}$	✔	✔	Brown and Schueler, 1997b
Retention Basins	1.06V: 0.25 acre retention basin (23,300 cubic feet)	✔		SWRPC, 1991
	0.43V: 1.0 acre retention basin (148,000 cubic feet)			
	0.33V: 3.0 acre retention basin (547,000 cubic feet)			
	0.31V: 5.0 acre retention basin (952,000 cubic feet)			

Notes
V refers to the total basin volume in cubic feet
Costs presented from SWRPC (1991) are "moderate" costs reported in that study.

Storage costs derived from Table 3.12 will need to be adjusted for inflation and regional differences. Based on the EPA's rainfall zones illustrated in Figure 3.5 a regional cost adjustment factor was calculated based on a methodology followed by the American Public Works Association, these adjustments are summarized in Table 3.13 [24]

Figure 3.5: Rainfall Zones of the United States (Source: USEPA, 1999)[22]



Not shown: Alaska (Zone 7); Hawaii (Zone 7); Northern Mariana Islands (Zone 7); Guam (Zone 7); American Samoa (Zone 7); Trust Territory of the Pacific Islands (Zone 7); Puerto Rico (Zone 3) Virgin Islands (Zone 3).
Source: NPDES Phase I regulations, 40 CFR Part 122, Appendix E (US EPA, 1990)

Table 3.13: Regional Cost Adjustment Factors (Source: USEPA, 1999)

Rainfall Zone	1	2	3	4	5	6	7	8	9
Adjustment Factor	1.12	0.90	0.67	0.92	0.67	1.24	1.04	1.04	0.76

Source: Modified from APWA, 1992

On site retrofit costs refer to any changes that need to be made to the existing irrigation system to accommodate wastewater reuse. Typically for irrigation users the onsite retrofit costs are relatively minimal. The American Water Works Association (AWWA) put together recommendations for piping systems in their Guidelines for Distribution of Nonpotable Water document, they are as follows:

1. “Nonpotable pipe should be buried at least 1 foot deeper than the potable water supply.
2. All buried off-site piping in the nonpotable water system, including service lines, should have embossed lettering, integrally stamped/marked, or be installed with warning tape (purple is preferred) should be consistent throughout the service area.
3. Hose bibs discharging reclaimed wastewater should be secured to prevent any use by the public.

4. Hose bibs discharging reclaimed wastewater should be posted with signs reading "Reclaimed Water, Do Not Drink", or similar warnings, or be secured to prevent access by the public.
5. Quick coupler fittings should be such that interconnection cannot be made between the potable and nonpotable system." (USGA, pg. 139).[22]

These recommendations can be used to estimate what needs to be done for retrofitting an installation. In addition to the AWWA recommendations, water fountains must be protected for irrigation spray and backflow preventers must be installed. The United States Golf Association estimated the facility front end cost to retrofit an existing facility is a minimum of $20,000 if facility labor is used. If regulations require an existing lake be lined, these costs are estimated to exceed $45,000 per surface area acre depending on the size and shape and depth of the lake (USGA, pg. 261).[22]

Additional treatment of wastewater effluent for irrigation is typically minimal if the effluent meets regulatory requirements or national guidelines. Based on interviews with facilities in Kansas who are currently reusing wastewater effluent for urban irrigation, the highest concern is salt buildup. In most cases, the facility purchased and uses a sulfur burner to treat the wastewater effluent prior to irrigation. These systems can cost $15,000 - $30,000 depending on accessories required for the installation. O&M costs are mostly associated with the cost of sulfur. Sulfur typically costs around $350 - $400 / ton. There are minimal additional costs associated with the power needed to run these systems.

3.3.1 Financial Analysis Formulas and Data

The financial analysis in this model assumes the end user will pay for all capital costs and O&M costs associated with the project. It is further assumed the end user will benefit from the annual difference in cost of water. In the case of urban reuse it is not uncommon to find an end user owned by the municipality. In some of these cases the municipality assumes the capital costs and O&M costs for the project because the two entities come out of the same budget. It benefits the municipality because they typically are not charging the city owned user to begin with. Additionally, the municipality can sell the potable water to a paying customer so they are still benefitting. The financial analysis can be completed to answer any unknown quantities. For example, an end user may want to know how much money they will gain over a 20 year period if they change from potable water to wastewater reuse. When completing the study on an entire region the cost of wastewater reuse water may not be known so it is useful to evaluate what the cost differential between the current cost of water and future cost of water will need to be for a 5, 10, 15 and 20 year payback period. This information will be useful in determining what the cost savings will need to be in order for the project to be valuable. It is reasonable to assume the life of the equipment will outlast the longest payback period of 20 years. The interest rate should be chosen based on the local economy at the time of the project. Table 3.14 summarizes the costs of a retrofit project with descriptions, financial analysis formulas and variables. At this point in the model the assumed radius between wastewater treatment facility and end user, as discussed in section 3.2.2, can be adjusted if additional information is needed for the study.

Table 3.14: Financial Analysis Data

Category	Description	Formula[1]	Comments
Capital Costs			
Distribution	Construction cost of distribution mains, valves	(F/P,i,n)	C_d
Storage	Construction cost of storage either at WWTF or end user	(F/P,i,n)	C_s
On-Site Retrofit	Cost of modifications to existing system (backflow preventers, required signage, modifications to irrigation system, etc.)	(F/P,i,n)	C_r
Treatment	Cost of additional treatment either at the WWTF or end user	(F/P,i,n)	C_t
Operation and Maintenance Costs (O&M)			
Storage O&M	Labor costs associated with operating the storage unit / annual maintenance costs to keep storage unit operational	(F/A,i,n)	OM_s
Treatment O&M	Labor costs associated with operating the treatment equipment / chemicals required for operating the treatment equipment / annual maintenance costs to keep treatment equipment operational	(F/A,i,n)	OM_t
On-Site Retrofit O&M	Labor costs associated with upkeep of modifications made / annual maintenance costs to keep modifications operational	(F/A,i,n)	OM_r
Annual Savings / Expenditures			
Difference in Cost of Water	Cost difference between the existing water source and reuse water	(F/A,i,n)	A_w

[1] F/P= Future Worth given Present Worth; F/A = Future Worth given Annual Worth; i = interest rate; n = life of project or payback period

3.3.2 Additional Benefits and Costs for Wastewater Reuse Projects

The WateReuse Foundation developed a guide to evaluating additional benefits and costs for wastewater reuse projects, Table 3.15 is a modified version of the one found in An Economic Framework for Evaluating the Benefits and Costs of Water Reuse.[18] This resource is intended to be used when evaluating the benefits of the project that are not directly included in the financial assessment. Many times projects are not financially feasible but are done anyway because the other benefits, like those listed in the table, outweigh the costs for the project. Each project impact is linked to potential benefit and the likely beneficiary.

Table 3.15: Guide for linking types of potential benefits to impacts that may be generated by reuse projects (Source: Raucher, 2006)

Water reuse project impact	Types of benefits potentially generated	Likely beneficiaries
Improve or preserve surface water flows and/or quality (e.g., by reducing surface water extractions, and/or by improving quality of discharged effluent)	+ Recreational benefits to downstream users of instream and near-stream services (e.g., anglers, boaters, hikers, and wildlife viewers), plus related organizations (e.g. Trout Unlimited). + Environmental benefits via improved downstream flows and aquatic and riparian habitat (e.g., protect or enhance populations of fish and wildlife, some of which may be special status species such as endangered salmon). + Financial and other benefits downstream extractive users (e.g., enabling greater surface water extractions by community systems).	All downstream recreational users, including many people from outside the utility service area/customer base. All people with nonuse (passive use) motives (e.g., stewardship, existence, and bequest values) for preserving ecosystems. Includes mostly people and organizations from outside the service area (e.g., Sierra Club and Audubon Society). Customers and owners of downstream water agencies and/or agricultural or other extractive users (as applicable).
Create or enhance recreational facilities, including sports fields, urban parks or greenbelts, or golf courses	+ Recreational benefits to ballplayers, golfers, walkers,	Many users likely to be from the local utility customer base, but

	picnickers, or anyone else who uses reuse-irrigated facilities + Aesthetic, cultural/spiritual, and property value benefits to residents of neighborhoods that are enhanced by parks and other green space. + Environmental benefits, to the extent that reuse-irrigated green spaces provide habitat shading, carbon sequestration, etc.	others from beyond the service area may visit and benefit as well. Utility customers and others who reside in or near the reuse service area. People from a wide area who value ecosystem preservation and enhancement.
Improve groundwater resource quality and/or quantity (e.g., by reducing pumping demands and/or by providing recharge)	+ Increase water supply reliability (e.g., drought protection) through conjunctive use and storage capacity of local aquifer systems. + Decrease subsidence and avoid related elevated pumping costs, potential damages to infrastructure, and risks to public safety. + Manage salt water intrusion and preserve water quality. + Enhance water quality by using aquifer to provide more in situ treatment and uniformity.	All of these potential benefits typically will accrue predominantly to the water supply agency and its customers. These benefits also may extend considerably beyond the service area boundaries, depending on the size and users of the impacted aquifer system (e.g., where the groundwater system is used or underlies other communities, they also are likely to realize benefits).
Increase reliability and diversity of community water supply portfolio	+ Reduce likelihood of water shortages and use restrictions. + Reduce impacts of growth management and maintaining the economic vitality of the community. + Reduce the variability and uncertainty about the volume (and	Customers of the water supply agency, and the utility itself, will be the primary beneficiaries. Empirical estimates suggest residential and business customers place considerable value on steps that will reduce the probability of future water use restrictions.

	cost) of water available to the community in the event of droughts or other source water-impacting events.	There are possible spillover benefits to neighboring communities if reuse in town X enables more raw water availability for town Y.
Provide a “local” water source (i.e., using local resource, under local control in lieu of waters imported from other areas and/or agencies)	+ Enhance local autonomy and local control (where reuse is used in lieu of imported waters). + Reduce energy consumption and air pollution where imported waters would be the alternative to reuse by reducing the need for pumping large volumes of source water across distances and gradients.	Members of the local community (a potentially very important benefit but one that may need to be addressed only qualitatively). Benefits accrue over a large area (e.g., region- or statewide) and potentially globally.
Promote or sustain desired levels of community growth and economic development	+ Provide basis to sustain or support growth in local economic activity (e.g., jobs, incomes, and tax revenues). + Provide a mechanism that the community can use to help manage growth in manner consistent with community goals.	Primary beneficiaries will be the community as a whole, including local government, the water agency, businesses, and general public. Debates over what types and level of growth can be contentious: what some consider beneficial, others may consider to be a cost.
Avoid or postpone investments for expanding water supply and/or wastewater capacity	+ Decrease capital outlays for treatment plant upgrades or expansions and/or buries infrastructure. + Postpone or avoid one-time initial expenses for any required acquisitions of additional water rights, land, etc. +Decrease ongoing O&M.	Beneficiaries are the water supply and/or wastewater agencies and their customers for all these benefits.
Promote sustainability and “doing the right thing” by recycling and	+ Largely covered by other items in this table.	May be very important benefit to members of the local community,

protecting water resources	+ Generate general "feel good" value for "doing the right thing" from a natural resource/environmental perspective.	some public officials, and some stakeholder organizations. May need to limit analysis to a qualitative discussion (hard to measure empirically).

There are many potential costs outside of the financial analysis that should be considered when considering a wastewater reuse project. The potential negative public perception, especially in urban irrigation, could cause delays and financial losses. This can usually be managed with public education but it should be considered. In addition, consideration must be given to what affect the project will have on the existing discharge location. If water is suddenly diverted will it hurt the natural habitat that exists? Will a diversion affect the downstream user if the stream is a raw water source? These could all potentially cause negative impact from the project.

Once the cost analysis is completed a list of feasible wastewater treatment facilities and irrigation facilities will remain based on a predetermined payback period. The benefits of wastewater reuse not associated with cost should also be considered in the process to derive a final list of feasible facilities. The quantity of water that could potentially be used for wastewater reuse is easily calculated by adding the quantity of water that can be delivered to the end user.

Chapter 4 - Results

Utilizing the methodology from Chapter 3 results in tool that highly useful in both wastewater management and water resource management for a region. In this chapter, the methodology is applied to determine the quantity of wastewater effluent in the LARK that can be beneficially used for golf course irrigation and the feasibility based on payback period. Golf course irrigation falls under the urban irrigation category; only 9 and 18 hole golf courses were considered for the study. While agricultural irrigation represents a much larger percentage of water used in the LARK, KDHE does not permit wastewater reuse for crops produced for human consumption. The KWO estimates there are more than 24 communities in the LARK with at least one golf course.[11]

The first section in this chapter addresses the need for wastewater reuse in the LARK. Regulations and guidelines for reuse are compiled in section 2 (criteria 1). In the third section the adequate flow ratio equation is applied to all wastewater treatment plants within a 5 mile radius of a golf course (Criteria 2) to determine which wastewater treatment facilities have an adequate effluent quantity. The fourth section outlines the results from a cost benefit analysis of the feasible golf courses (Criteria 3) and the last section provides a discussion of the results.

4.1 Wastewater Reuse in the LARK

The LARK is situated in the south central region in Kansas and has the second largest population in the state.[11] The Kansas Water Plan outlined 5 high priority issues in the region, one of which is a recommendation to “identify opportunities to better utilize reclaimed water as a valuable water resource”.[11] Figure 4.1 illustrates the boundaries for the twelve regions in Kansas; figure 4.2 illustrates the boundaries for the LARK. Population estimates for the LARK are projected to grow more than 38% by the year 2040.[11] Figure 4.3 illustrates the population estimates by county for the LARK. Population is highest in the eastern section of the basin and decreases in the western section. In 2006, the LARK used an estimated 700,000 acre-feet (288,096 MG) of water.[11]

Figure 4.1: Kansas Water Plan Hydrologic Regions (Source: KWO,2009)

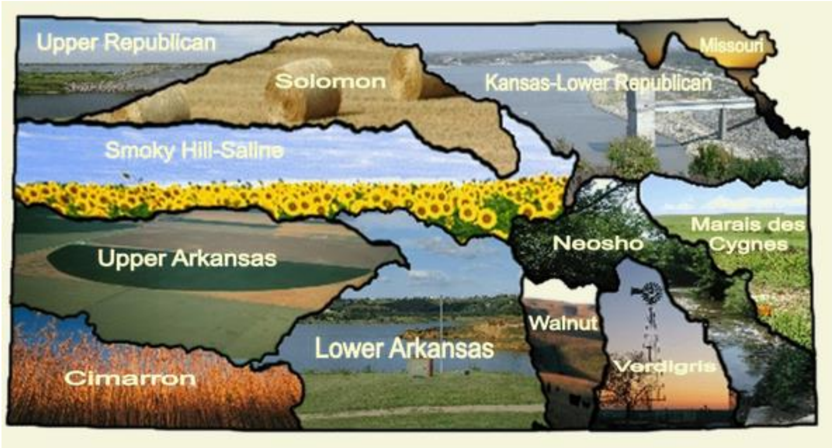


Figure 4.2: Kansas Water Plan Lower Arkansas River Basin (Source: KWO,2009)

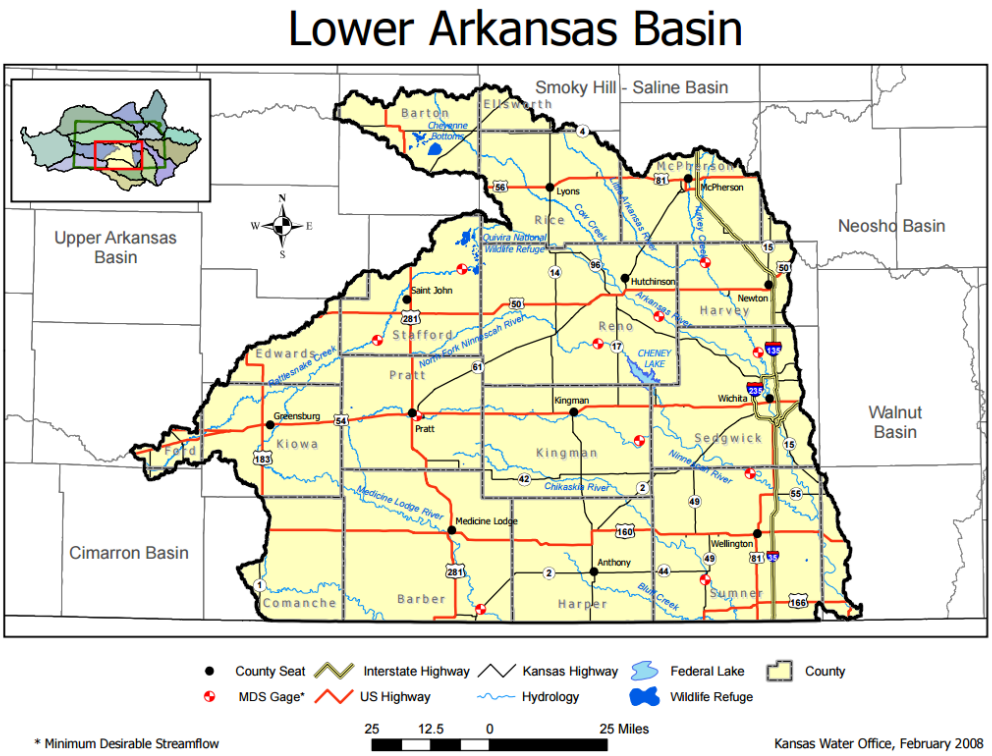
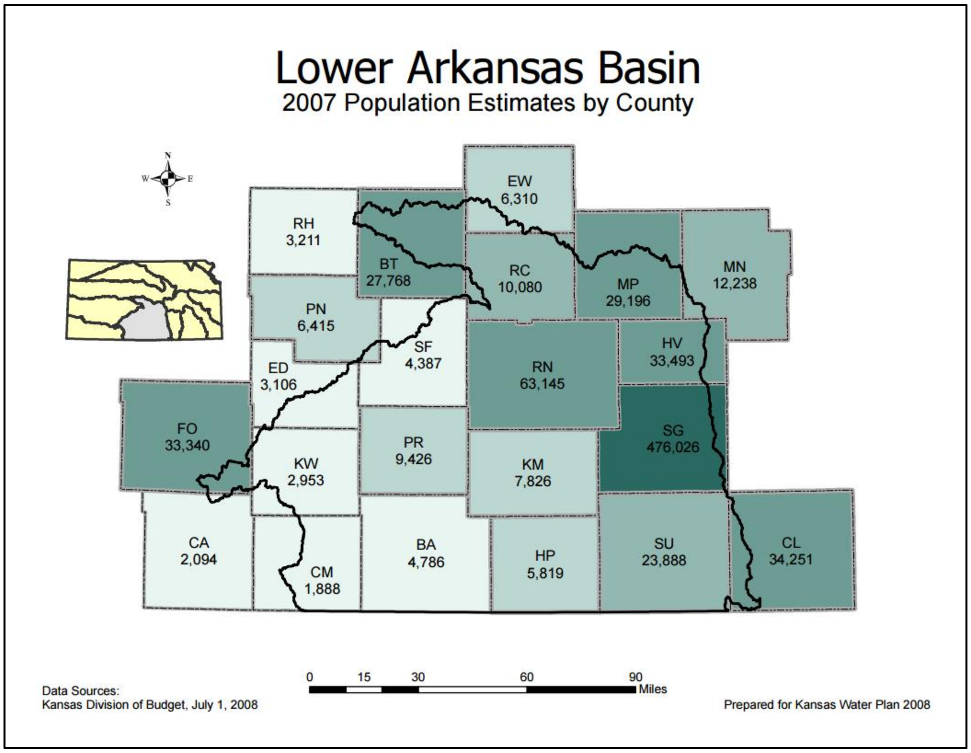


Figure 4.3: LARK Population Estimates (KWP, 2009)



4.2 Regulations and Guidelines for Reuse (Criteria 1)

Regulations in an area are extremely important and should be thoroughly researched as a first step as outlined in the Chapter 3. Kansas regulations need to be reviewed to determine what regulations and guidelines exist for reusing wastewater effluent for golf course irrigation in the LARK. Reuse for golf course irrigation is allowed by the Kansas Department of Health and Environment (KDHE) with very few documented restrictions. As discussed in Chapter 3 the EPA suggested guidelines should be reviewed for the specific application. The guidelines are meant as supplemental information to be considered in the absence of regulatory requirements. Reclaimed water monitoring is set through the permit on a case by case basis in Kansas; the EPA suggested guidelines have weekly, daily and continuous monitoring. While this does require labor, it is assumed the golf courses can use existing staff therefore no additional cost was added for this. Table 4.1 outlines the EPA suggested guidelines for urban reuse as found in the 2012 Guidelines for water reuse report. [22]

Table 4.1: EPA Suggested Guidelines for Urban Reuse (Source: EPA, 2012)

Reuse Category and Description	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring	Setback Distances
Urban Reuse				
Unrestricted: The use of reclaimed water in nonpotable applications in municipal settings where public access is not restricted.	Secondary Filtration Disinfection	pH = 6.0 – 9.0 ≤ 10 mg/l BOD ≤ 2 NTU No detectable fecal coliform / 100 ml 1 mg/l Cl2 residual (min.)	pH – weekly BOD – weekly Turbidity – continuous Fecal coliforms – daily Cl2 residual – continuous	50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media.
Comments for Unrestricted Reuse: At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g. secondary treatment and disinfection to achieve <14 fecal coli/100 ml may be appropriate. Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. The reclaimed water should not contain measureable levels of pathogens. Reclaimed water should be clear and odorless. Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. Chlorine residual > 0.5 mg/l in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements.				

The golf course will be required to post additional signage, install backflow preventers, and include proper markings of all wastewater reuse pipes and connections. Many golf courses have posted information on the score cards to ensure golfers are aware that the course is irrigated with wastewater effluent. Drinking fountains must be protected from irrigation spray. These anticipated regulations were included in the cost estimate under retrofit capital costs.

4.3 – Adequate Flow Ratio (Criteria 2)

Adequate flow ratio is an extremely important parameter when performing the regional study. After determining that the reuse will be feasible based on regulatory requirements, the next step is to determine the flow ratio for each wastewater treatment facility in the LARK. Water requirements for golf course irrigation vary by year depending on the rainfall and temperatures for the season. In Kansas, temperatures and rainfall can vary significantly year to year. The United States Golf Associated (USGA) has published data on the average acreage of irrigated turfgrass for an 18 hole golf course and the water-use in acre-feet for each agronomic region in the United States.[2] This published data was compared to reported water use data for an 18 hole golf course in the LARK to check for accuracy. Table 4.2 outlines the average water use in acre-feet for 9- and 18- hole golf facilities in the U.S. and by agronomic region.[2] Table 4.3 outlines the water use by two-month periods for an average 18-hole golf facility in the U.S. and within each agronomic region.[2]

Table 4.2: Average water use in acre-feet for 9- and 18- hole golf facilities in the U.S. and by agronomic region (Source: Environmental Institute for Golf, 2009)

		Agronomic region[1]						
	US	NE	NC	Trans	SE	SW	UW/Mtn	Pac
Facility Type	Acre-feet							
9-hole								
Avg. water use	48.2	13.8	52.5	24.9	54.0	99.7	89.9	66.3
18-hole								
Avg. water use [2]	152.5	42.4f	76.7e	78.9e	241.8c	459.0a	300.4b	158.0d

[1] Agronomic regions: NE = Northeast; NC = North Central; Trans = Transition; SE = Southeast; SW = Southwest; UW/Mtn = Upper West/Mountain; Pac = Pacific

[2] Within a row, values followed by the same letter are no significantly different from one another. Letters denote significance at the 90% confidence level.

Table 4.3: Water use by two-month periods for an average 18-hole golf facility in the U.S. and within each agronomic region. (Source: Environmental Institute for Golf, 2009)

	Agronomic region[1]							
	US	NE	NC	Trans	SE	SW	UW/Mtn	Pac
	% water use[2]							
January – February	2	0d	0d	1c	8a	6b	1c	1c
March – April	9	6d	5d	10c	15a	13b	10c	7c
May – June	26	27ab	27a	25bc	23d	24c	27ab	25bc
July – August	41	50a	49b	42d	26f	29e	41d	45c
September – October	18	16d	18c	19a	18bc	20a	19a	19ab
November – December	4	1e	1f	3c	10a	8b	2d	3cd

[1] Agronomic regions: NE = Northeast; NC = North Central; Trans = Transition; SE = Southeast; SW = Southwest; UW/Mtn = Upper West/Mountain; Pac = Pacific

[2] Within a row, values followed by the same letter are no significantly different from one another. Letters denote significance at the 90% confidence level.

Water usage is an important part of the cost evaluation and should be given careful consideration. Three golf courses within the LARK, Willowbend, Carey and Newton, provided adequate water use data for the purposes of this report; the average annual water use is 70 MG, 70 MG and 86 MG respectively. Published data from the USGA estimates an annual water usage of 78.9 MG, the average of the sample of golf courses in the LARK is 75.3 MG. For the purposes of this research study, the published annual water usage will be used for the adequate flow ratio and cost benefit analysis.

In Kansas the two highest usage months are typically July and August. During these months the water usage will be higher so the wastewater effluent needs to be able to adequately handle the higher usage months. The following equation was developed to determine what the water usage would be during the peak usage periods.

$$Q_i = \{[(AAWU * H) / 3.0689] / d\}*PF$$

Where Qi is the golf course irrigation water demand in MGD, AAWU is the annual average water use for the region from Table 4.2, H is the highest 2 month % water use from Table 4.3, 3.0689 is a conversion factor from acre-feet to million gallons, d is the number of days in the two month period, and PF is the peaking factor for LARK (based on golf course water use data).

A wastewater treatment facility in the LARK needs to be able to deliver 0.7 MGD for an 18 hole golf course and 0.22 MGD for a 9 hole golf course. Wastewater treatment facility data was gathered from the KDHE. Only wastewater treatment plants with National Pollutant Discharge Elimination System Data (NPDES) permits with flow data were considered for the study. Both mechanical and lagoon treatment facilities were considered as Kansas allows wastewater effluent reuse from both types of treatment. All existing 9 and 18 hole golf courses in the LARK were considered for the study. Golf course data was compiled using a combination of tools. The website www.geostat.org/KS was used to compile an initial list and general location of golf courses in the LARK. This website compiles golf courses by county and maps the locations. Locations and size (18 hole vs. 9 hole) were cross checked using www.golflink.com and www.golfdigest.com. In some cases, the municipality website had information available regarding golf course location and size. Wastewater treatment plants were located using permit data, www.geostat.org , and google earth. To verify the locations, wastewater and golf courses were located on a USGS quadrangle maps where available. The wastewater treatment facilities and golf courses were mapped using Google Maps. After analyzing the maps it was determined that a 5 mile radius would encompass most of the golf courses and appeared to be a reasonable distance to start the analysis with. The maps were downloaded from Google Maps into AutoCAD by county to map a 5 mile radius around the wastewater treatment facility. Results from the mapping were used to compile a list of golf courses that are within a 5 mile radius of a wastewater treatment facility with an NPDES permit. Figure 4.4 provides an overall view of the wastewater treatment design capacity in the region. It can be noted that Sedgwick County is an outlier due to Wichita and the surrounding areas. This is an important consideration and will be discussed further in the discussion section. Figure 4.5 illustrates all wastewater treatment facilities and golf courses in the LARK. Additional figures illustrating the golf courses that are within a 5 mile radius of a wastewater treatment facility by county can be found in Appendix A. Red markers indicate wastewater treatment facilities, blue markers indicate wastewater treatment facilities that are currently reusing wastewater effluent for golf course irrigation, and green markers indicate golf courses. Table 4.4 shows the flow ratio for all golf courses in the LARK that are within a 5 mile radius of a wastewater treatment facility. The flow ratio was calculated using the following equation as discussed in section 3.2.2 of this report:

$$\text{Flow Ratio} = Q_{ww} / Q_i$$

A flow ratio greater than 1 indicates the wastewater treatment facility has an adequate design capacity to supply the golf course with irrigation water. Wastewater treatment facilities with a flow ratio below 1 are considered inadequate and were removed from the list of feasible facilities. In the LARK there were wastewater facilities with a flow ratio below 1 who are currently reusing their effluent for golf course irrigation. Many golf courses decide to partially irrigate in an effort to conserve water. In this research study the wastewater facilities with a flow ratio below 1 are eliminated, however in reality these facilities may be well suited for the golf course needs. Golf courses who are currently using wastewater effluent to irrigate are marked with an * in Table 4.4.

Figure 4.4: Wastewater Treatment Design Capacity by County in the LARK

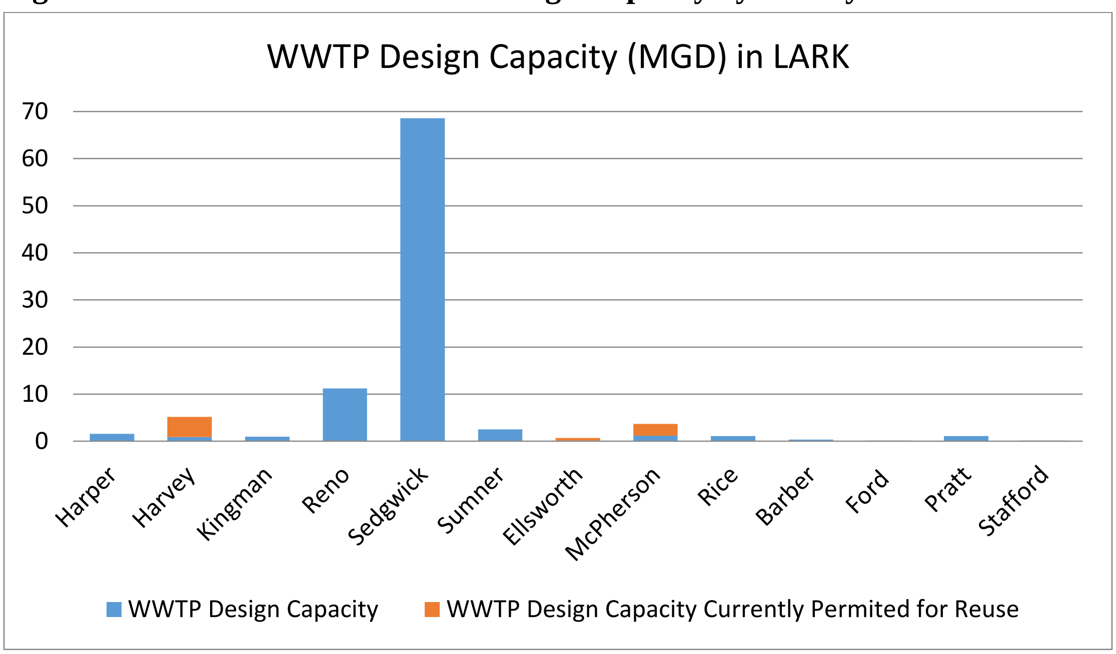


Figure 4.5: Wastewater Treatment Facilities and Golf Courses in the LARK

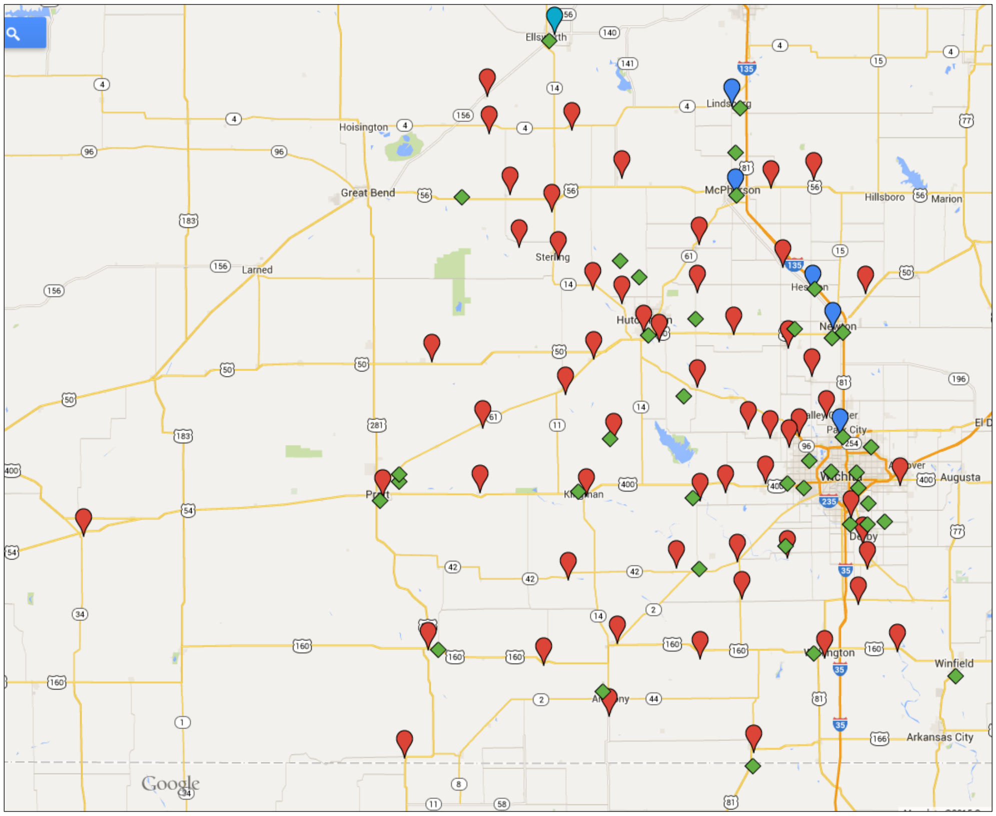


Table 4.4: Golf Courses within a 5 mile radius of a Wastewater Treatment Facility in the LARK

Golf Course	WWTP in 5 mile radius	Q_{ww} (MGD)	9 or 18 hole	Flow Ratio**
Anthony Golf Club	Anthony	0.3	9	1.4
Wedgewood Golf Course	Halstead	0.42	9	1.9
Fox Ridge Golf Course (Newton Country Club)	Newton	3	9	13.6
Kingman Country Club	Kingman	0.75	9	3.4
Suppesville Golf Course*	Norwich	0.103	9	0.5
Haven Golf Club	Haven	0.2488	9	1.1
Clearwater Golf Course	Clearwater	0.253	9	1.2
Pine Bay Golf	Wichita Plant #2	54	9	245.5
Pine Bay Golf	Derby	2.5	9	11.4
Caldwell Golf Course	Caldwell	0.15	9	0.7
Ellsworth Golf Course*	Ellsworth	0.5	9	2.3
Green Valley Golf Course	Pratt	1.1	9	5.0
Seidel Golf Course	Pratt	1.1	9	5.0
Medicine Lodge Golf Course	Medicine Lodge	0.35	9	1.6

Hesston Municipal Golf Course*	Hesston	1.3	18	1.9
Sand Creek Golf Course*	Newton	3	18	4.3
The Highlands Golf Club	Willowbrook	0.016	18	0.0
Carey Park Golf Course	Hutchinson	8.3	18	11.9
Cottonwood Hills Golf Course	Buhler	0.168	18	0.2
Links at Pretty Prairie	Pretty Prairie	0.103	18	0.1
Cherry Oaks Golf Course	Cheney	0.36	18	0.5
Auburn Hills Golf Course	Goddard	0.8	18	1.1
Reflection Ridge Golf Course	Wichita #3	2	18	2.9
Reflection Ridge Golf Course	Maize	0.5	18	0.7
Echo Hills Golf Course	Park City (CCUA)	2.16	18	3.1
Echo Hills Golf Course	Valley Center	0.7	18	1.0
Willowbend Golf Course*	Park City (CCUA)	2.16	18	3.1
LW Clapp Memorial Golf Course	Wichita Plant #2	54	18	77.1
Derby Golf Course	Wichita Plant #2	54	18	77.1
Derby Golf Course	Derby	2.5	18	3.6
Hidden Lakes Golf Course	Derby	2.5	18	3.6
Twin Lakes Golf Course	Wichita Plant #2	54	18	77.1
Wellington Golf Club	Wellington	1.71	18	2.4
Turkey Creek Golf Course*	McPherson	2	18	2.9
Lindsborg Golf Course*	Lindsborg	0.55	18	0.8
Park Hills Golf Course	Pratt	1.1	18	1.6

* Golf courses are currently using Wastewater Effluent for irrigation

** WWTP Capacity / 0.22 MGD for 9 hole; WWTP Capacity / 0.70 MGD for 18 hole

4.4 Cost Benefit Analysis (Criteria 3)

The cost benefit analysis is perhaps the most important consideration as it will determine if wastewater reuse is financially feasible in the LARK. All golf courses within a 5 mile radius of a wastewater treatment facility with an adequate flow ratio were examined using a cost benefit analysis. Economic feasibility is determined by developing payback periods to allow golf courses to easily understand how long it will take to recover their capital investment.

Distribution system capital cost is the largest item in the cost benefit analysis, pipe size influences this cost. Wastewater effluent will be delivered to the golf course via a distribution main that is gravity fed to the storage location on the golf course. As discussed in the methodology section 3.3, distribution main diameters were modeled using the Hazen Williams equation or using Table 3.9. Table 3.9 was used with an assumed decline of 3 ft per 100 feet of pipe. Required distribution main diameters for 9 and 18 hole golf courses in the LARK are listed in Table 4.5

Table 4.5: Diameter of distribution main for 9- and 18- hole golf courses

Golf course size	Q_i (MGD)	D (inches)
18 hole	0.70	10
9 hole	0.22	6

Many variables determine the construction cost for a pipeline, including the size and length of the pipe, the type of soil, number and type of crossings (i.e. road, creek, railroad, etc.), fittings, and many others. In more populated regions like the City of Wichita the cost of laying a distribution main could increase significantly. The US Environmental Protection Agency (USEPA) completed a nationwide survey to document the cost of infrastructure needs. Table 4.6 is a compilation of the data received from this study on the capital cost of distribution mains as a function of diameter and geographic region.[6] Values from this table were compared to local data obtained from recent bid tabs in the LARK. Two recent projects in Newton Kansas constructed 8" pipe at a cost of $45.36 and $45.49 per linear foot, this correlates extremely well with the cost of $45.14 in Table 4.6. From Table 4.6 the cost for a 10 inch and 6 inch distribution main respectively in the South region is $56.61 per foot and $39.41 per foot.

Table 4.6: Estimated capital cost of distribution mains as a function of diameter and geographic region (Source: Hertzler, 1997)

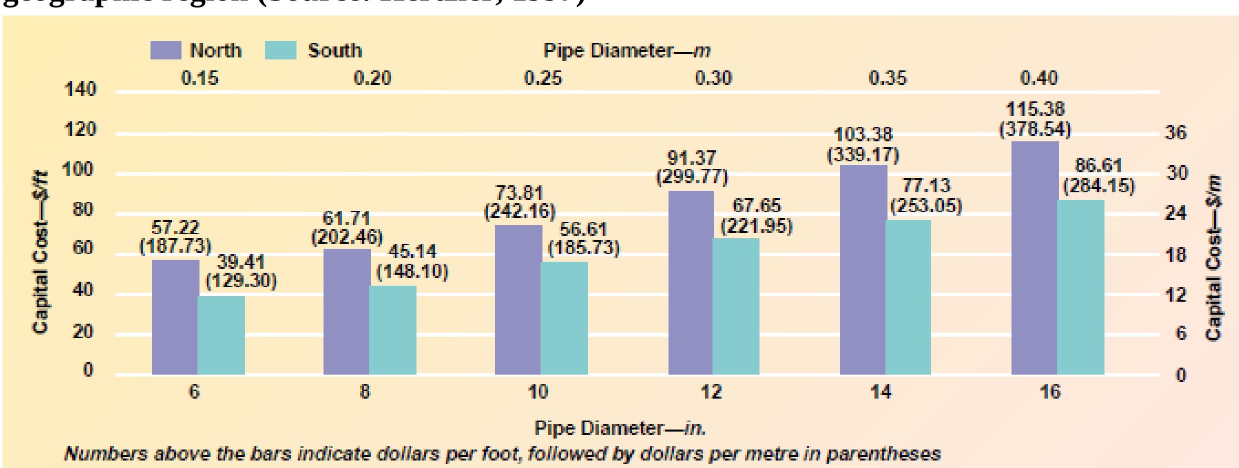


Table 4.7: Cost for 9 and 18 hole Golf Course Distribution Main in the LARK

Golf course size	Q_i (MGD)	D (inches)	Cost per ft.
18 hole	0.70	10	$56.61
9 hole	0.22	6	$39.41

A detailed routing study would need to be completed for an accurate length of pipe, however for the purposes of this study the length of pipe was taken from the shortest distance by road between the wastewater treatment plant and the golf course. While it is unlikely the pipeline would follow this exact routing, it is a place to start for cost estimation purposes. It will be assumed the pipeline can be routing in the existing easements along the road so no additional cost will be added for easement. Google map was used to determine the shortest distance by road from the wastewater treatment facility to the golf course. The distance by road in miles and estimated cost are compiled in Table 4.8.

Table 4.8: Estimated Capital Cost of Pipeline in the LARK

Golf Course	WWTP in 5 mile radius	WWTP Capacity (MGD)	Pipe Diameter	Flow Ratio	Distance by Road (miles)	Estimated Cost [2]
9 holes						
Anthony Golf Club	Anthony	0.3	6	1.4	5.9	$1,227,700
Wedgewood Golf Course	Halstead	0.42	6	1.9	3.9	$811,531
Fox Ridge Golf Course (Newton Country Club)	Newton	3	6	13.6	1.7	$353,744
Kingman Country Club	Kingman	0.75	6	3.4	2.2	$457,787
Haven Golf Club	Haven	0.2488	6	1.1	0.7	$145,659
Clearwater Golf Course	Clearwater	0.253	6	1.2	2.6	$541,020
Pine Bay Golf	Wichita Plant #2	54	6	245.5	1.8	$374,553
Pine Bay Golf	Derby	2.5	6	11.4	5.9	$1,227,700
Ellsworth Golf Course[1]	Ellsworth	0.5	6	2.3	2	$416,170
Green Valley Golf Course	Pratt	1.1	6	5.0	7.8	$1,623,061
Seidel Golf Course	Pratt	1.1	6	5.0	5.6	$1,165,275
Medicine Lodge Golf Course	Medicine Lodge	0.35	6	1.6	1.9	$395,361
18 holes						
Heston Municipal Golf Course[1]	Hesston	1.3	10	1.9	1.8	$538,021
Sand Creek Golf Course[1]	Newton	3	10	4.3	1.2	$358,681
Carey Park Golf Course	Hutchinson	8.3	10	11.9	3.2	$956,483
Auburn Hills Golf Course	Goddard	0.8	10	1.1	5.3	$1,584,174
Reflection Ridge Golf Course	Wichita #3	2	10	2.9	7	$2,092,306
Echo Hills Golf Course	Valley Center	0.7	10	1.0	5.6	$1,673,844
Willowbend Golf Course[1]	Park City (CCUA)	2.16	10	3.1	6.6	$1,972,745
LW Clapp Memorial Golf Course	Wichita Plant #2	54	10	77.1	7.4	$2,211,866
Derby Golf Course	Wichita Plant #2	54	10	77.1	4.4	$1,315,164
Derby Golf Course	Derby	2.5	10	3.6	5.8	$1,733,625
Hidden Lakes Golf Course	Derby	2.5	10	3.6	9.1	$2,719,997
Twin Lakes Golf Course	Wichita Plant #2	54	10	77.1	9.6	$2,869,448
Wellington Golf Club	Wellington	1.71	10	2.4	2.7	$807,032
Turkey Creek Golf Course[1]	McPherson	2	10	2.9	1.2	$358,681
Park Hills Golf Course	Pratt	1.1	10	1.6	1.1	$328,791

[1] Golf courses are currently using Wastewater Effluent for irrigation
[2] Estimated Cost = distance by road * 5280 ft/mile * C_{pi} (capital cost input $/ft)

As discussed in the methodology section, storage is extremely important to offset peaks. A typical golf course in the LARK pumps water out of a pond or retention basin for irrigation.

After discussions with the golf courses in the region who are currently using wastewater treatment plant effluent for golf course irrigation, they typically gravity flow the wastewater treatment facility to the existing pond. Therefore no additional costs are being added for storage as the pond will act as a storage basin for the wastewater effluent. If the pond is currently not lined there is a possibility it will need to be lined when the golf course irrigation system is converted to wastewater effluent, however KDHE does not currently require a storage pond to be lined. If this changes in the future the cost for lining the storage unit would go into the cost benefit analysis under capital costs for retrofit.

Golf courses in the LARK who are currently reusing wastewater effluent for irrigation were contacted to discuss storage, treatment and any additional costs that were incurred for the project. In the category of additional treatment, two golf courses installed sulfur burners to treat the wastewater effluent prior to using it for irrigation; this is included in the cost analysis. Additional costs were incurred by one golf course in the form of a franchise fee because the wastewater treatment facility is not located in the same municipality as the golf course. This cost seemed to be an outlier and would not apply to enough golf courses so it is not included in the overall cost estimate. Table 4.9 outlines the categories used in the cost benefit analysis for the LARK.

Table 4.9: Cost and Benefits for Water Reuse

Category	**Formula**	**Comments**
Costs (C)		
Capital Costs for reuse water distribution	(F/P, 4.75%, n)	C_p
Capital Costs for reuse water treatment	(F/P, 4.75%, n)	C_t
Capital Cost for golf course retrofit	(F/P, 4.75%, n)	C_r
O&M		
O&M Costs for reuse water treatment	(F/A, 4.75%, n)	OM_t
Annual Savings		
Savings in water cost differential	(F/A, 4.75%, n)	A_w

Future worth for the project can be summarized using the following equation:

$$FW = -\Sigma C(F/P, 4.75\%, n) - OM_t(F/A, 4.75\%, n) + A_w\,(F/A, 4.75\%, n)$$

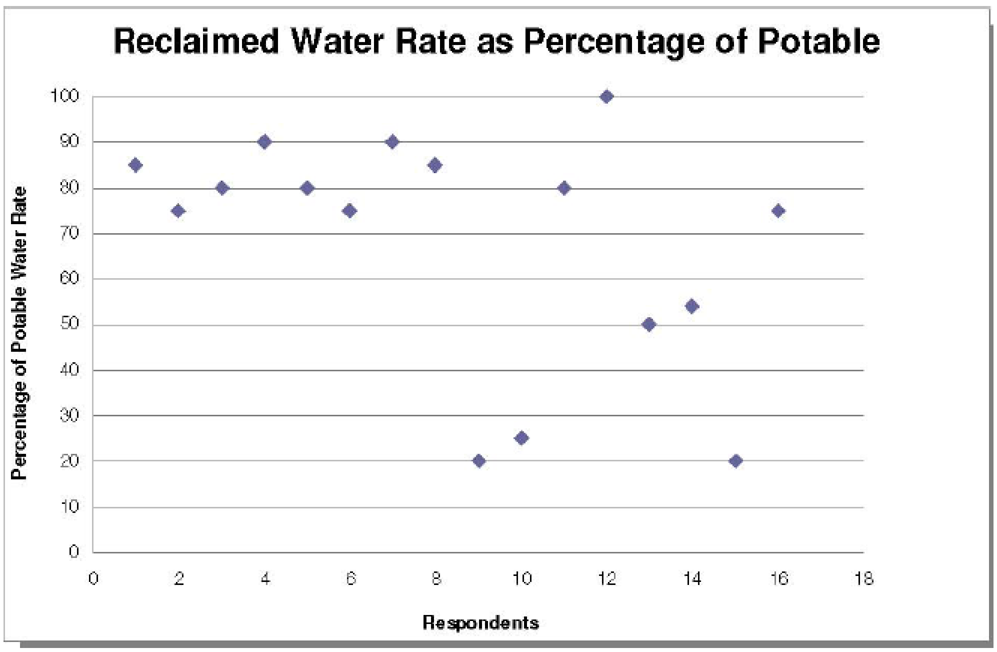
Capital Costs for the project include reuse water distribution, treatment and retrofit facility upgrade costs. Table 4.8 summarizes the cost for pipeline construction for each feasible golf course. The majority of golf courses in the region who are using wastewater effluent purchased a sulfur burner to protect the turf grass. These units typically cost $15,000 - $30,000 depending on the accessories required for the installation. A capital cost of $20,000 was used for the purposes of this research report. Facility upgrade costs include signage to inform golfers that wastewater effluent is being used to irrigate, backflow protection, and any labels that are needed to differentiate between potable and non-potable water. Assuming the golf course uses facility labor to complete this work the cost is estimated to be $20,000.[22]

Operation and Maintenance costs (O&M Costs) for reuse water treatment in the LARK are mainly from sulfur needed from the sulfur burner and the electrical costs of running the sulfur burner. It is estimated that golf courses in the LARK use approximately 7 tons of sulfur per year and the sulfur cost is $650 per ton for an annual cost of $4550. Power costs for sulfur burner are as follows:

24 hours = 1,000,000 gallons treated
18 hole golf course = 78.9 MG / yr
24*78.9 = 1894 hours per year
Assume a 150 gpm pump with a 15 hp motor
15 hp = 11.19 kWh per hour running
11.19*1894 = 21,194 kWh per year
21,194 * $0.10 / kWh = $2,119 per year for 18 hole golf course
24*24.9*11.19*.1 = $669 per year for 9 hole golf course

Each golf course was evaluated based on a 5 and 10 year payback period. The Future worth equation was used to calculate what the water cost differential needed to be for each payback period. An interest rate of 4.75% was used based on Wichita water and sewer utility municipal bond rates for 2014 and 2015 (www.municipalbonds.com). The AWWA published a study on how reclaimed water rates are established.[7] Figure 4.6 illustrates the results of survey completed by AWWA and published in their report. The graph depicts the cost of reclaimed water as a percentage of the cost of potable water. Establishing water rates for water reuse entails many variables and can vary significantly. In the LARK many of the golf course and wastewater facilities are owned by the municipality so the golf course is not charged for the reused water. For the purposes of the cost benefit analysis in this study, it was assumed the cost of reclaimed water is 80% the cost of potable water, this will provide a conservative cost analysis.

Figure 4.6: Reclaimed Water Rate as Percentage of Potable (Source: HDR Engineering, 2008)



Each golf course and corresponding wastewater treatment facility were evaluated using the future worth formula to determine what the current cost water would need to be for a 5 year and 10 year payback period. Using the 80% difference between the reclaimed and potable water, the cost of potable water was calculated for each of the pay periods. This represents what the cost of potable water would need to be to payback the capital and annual costs of converting the wastewater effluent reuse project. Five municipal water rates from the LARK are listed in Table 4.10 and provided data to calculate an average water rate of $3.93 for the region. The cost benefit analysis was performed using Microsoft EXCEL, Table 4.11 is the parameter table from the excel spreadsheet. Each of these parameters can easily be changed to accommodate other regions or other categories of reuse. In addition, the parameter values can easily be manipulated to create a sensitivity analysis for the cost benefit analysis results. All tables from the excel spreadsheet are listed in Appendix B of this report.

Table 4.10: Average water rates in the LARK

Municipality	Water Rate ($/1000 gallons)	Comments
Wichita	$4.09	Inside City Conservation Rate
Goddard	$3.00	Bulk Rate
Hutchinson	$2.57	Rate for above 5000 HCF
Derby	$6.03	Rate for more than 40,000 gal
Average	$3.92	

Table 4.11: Parameter Table from Cost Analysis Spreadsheet

Variable	**Description**	**Input Value**
Cost		
Capitol Cost		
C_p	6" pipeline cost ($/ft)	$39.41
	10" pipeline cost ($/ft)	$56.61
C_t	Sulfur Burner Cost	$20,000.00
C_r	Signage, Valves, Etc	$20,000.00
O&M Costs		
OM_t	Sulfur Burner Supplies & Power ($/yr)	$5,219.00
Annual Savings		
A_w	to be calculated	
Payback Periods		
n_1	1st payback period in years	5
n_2	2nd payback period in years	10
Other Parameters		
i	current municipal bond rate	0.0475
C_w	Avg. Cost of potable water per 1000 gal for region	$3.92
ΔC_w	anticipated cost of reclaimed water based on percent of potable water cost	0.80
Q_{9hole}	Annual Water Usage for 9 hole Golf Course (MG)	24.9
Q_{18hole}	Annual Water Usage for 18 hole Golf Course (MG)	78.9

Table 4.12 shows the calculations performed in the cost benefit analysis. Future Value from the pipeline, additional treatment, facility retrofit and O&M costs were summed for the FV Sum column. The water differential cost represents the amount of money that would need to be saved through reduced water cost to make the project have a 5 year payback. The cost per 1000 gallons was calculated using the following equation (this equation is for a 9 hole golf course):

$$\text{Cost per 1000 gallons} = \text{Water Differential Cost} / (Q_{9hole} * 1000 * n_1)$$

Where Q_{9hole} is the annual water usage for 9 hole golf course in MG, 1000 is a units conversion factor and n_1 is the payback period. The cost for current water is based on the following formula:

$$\text{Cost for Current Water} = \text{Cost per 1000 gallons} / (1-\Delta C_w)$$

Where ΔC_w is the anticipated reclaimed water cost based on a percentage of the potable water cost. This value was graphed with respect to the distance in miles between the wastewater treatment facility and golf course to illustrate what the golf course would need to be paying for potable water currently to make the project have a 5 year payback period. The average cost of potable water is also plotted as a reference point to help illustrate the feasibility of the reuse project. The 5 year and 10 year payback periods graphs are shown in Figures 4.7 and 4.8. These graphs provide useful information in how far away the golf courses could be from the wastewater treatment plants in this region to be considered a feasible facility for water reuse. In the 5 year payback graph, based on the average water cost in the region, a 9 and 18 hole golf course would need to be within 1.7 miles and 4.3 miles respectively of the wastewater treatment facility to have a 5 year payback period. In the 10 year payback period graph, based on the average water cost in the region, a 9 hole golf course would need to be within 6.9 miles of the wastewater treatment facility to have a 10 year payback period. The 18 hole golf course data was project forward to see where it intercepted the average water cost in the LARK. The results show based on the average water cost in the LARK, an 18 hole golf course needs to be within 15.9 miles of the wastewater treatment facility to have a 10 year payback period. This is useful information for the LARK region because it provides a guide to knowing when a golf course could feasibly reuse wastewater simply based on its location with respect to the wastewater treatment facility and what an acceptable payback period is for the input parameters. Regions with similar input parameters could use these results to guide their water resource planning. Input values can easily be changed in the excel spreadsheet to represent different cases.

Table 4.12: 5 Year Payback Cost Benefit Analysis

FV of C_p	FV of C_t	FV of C_r	FV OM_t	FV Sum	Water Differential Cost	Cost per 1000 gallons	The Cost for Current Water
9 holes							
$1,548,320.93	$25,217.70	$25,217.70	$28,694.60	$1,627,450.93	$296,002.24	$2.38	$11.89
$1,023,464.51	$25,217.70	$25,217.70	$28,694.60	$1,102,594.52	$200,540.88	$1.61	$8.05
$446,122.46	$25,217.70	$25,217.70	$28,694.60	$525,252.46	$95,533.39	$0.77	$3.84
$577,336.56	$25,217.70	$25,217.70	$28,694.60	$656,466.56	$119,398.73	$0.96	$4.80
$183,694.25	$25,217.70	$25,217.70	$28,694.60	$262,824.25	$47,802.71	$0.38	$1.92
$682,307.84	$25,217.70	$25,217.70	$28,694.60	$761,437.85	$138,491.00	$1.11	$5.56
$472,365.28	$25,217.70	$25,217.70	$28,694.60	$551,495.28	$100,306.46	$0.81	$4.03
$1,548,320.93	$25,217.70	$25,217.70	$28,694.60	$1,627,450.93	$296,002.24	$2.38	$11.89
$524,850.92	$25,217.70	$25,217.70	$28,694.60	$603,980.92	$109,852.59	$0.88	$4.41
$2,046,934.53	$25,217.70	$25,217.70	$28,694.60	$2,126,064.53	$386,690.53	$3.11	$15.53
$1,469,592.47	$25,217.70	$25,217.70	$28,694.60	$1,548,722.47	$281,683.04	$2.26	$11.31
$498,608.10	$25,217.70	$25,217.70	$28,694.60	$577,738.10	$105,079.53	$0.84	$4.22
18 holes							
$678,525.57	$25,217.70	$25,217.70	$28,694.60	$757,655.58	$137,803.08	$0.35	$1.75
$452,348.55	$25,217.70	$25,217.70	$28,694.60	$531,478.55	$96,665.80	$0.25	$1.23
$1,206,271.96	$25,217.70	$25,217.70	$28,694.60	$1,285,401.97	$233,790.07	$0.59	$2.96
$1,997,891.55	$25,217.70	$25,217.70	$28,694.60	$2,077,021.55	$377,770.55	$0.96	$4.79
$2,638,726.45	$25,217.70	$25,217.70	$28,694.60	$2,717,856.45	$494,326.18	$1.25	$6.27
$2,110,980.06	$25,217.70	$25,217.70	$28,694.60	$2,190,110.06	$398,339.19	$1.01	$5.05
$2,487,941.77	$25,217.70	$25,217.70	$28,694.60	$2,567,071.77	$466,901.32	$1.18	$5.92
$2,789,511.14	$25,217.70	$25,217.70	$28,694.60	$2,868,641.14	$521,751.03	$1.32	$6.61
$1,658,626.01	$25,217.70	$25,217.70	$28,694.60	$1,737,756.02	$316,064.63	$0.80	$4.01
$2,186,372.40	$25,217.70	$25,217.70	$28,694.60	$2,265,502.41	$412,051.61	$1.04	$5.22
$3,430,346.04	$25,217.70	$25,217.70	$28,694.60	$3,509,476.04	$638,306.66	$1.62	$8.09
$3,618,826.89	$25,217.70	$25,217.70	$28,694.60	$3,697,956.89	$672,587.73	$1.70	$8.52
$1,017,791.11	$25,217.70	$25,217.70	$28,694.60	$1,096,921.11	$199,509.00	$0.51	$2.53
$452,348.55	$25,217.70	$25,217.70	$28,694.60	$531,478.55	$96,665.80	$0.25	$1.23
$414,652.38	$25,217.70	$25,217.70	$28,694.60	$493,782.38	$89,809.58	$0.23	$1.14

Figure 4.7: 5 year payback for 9 and 18 hole Golf Course in the LARK

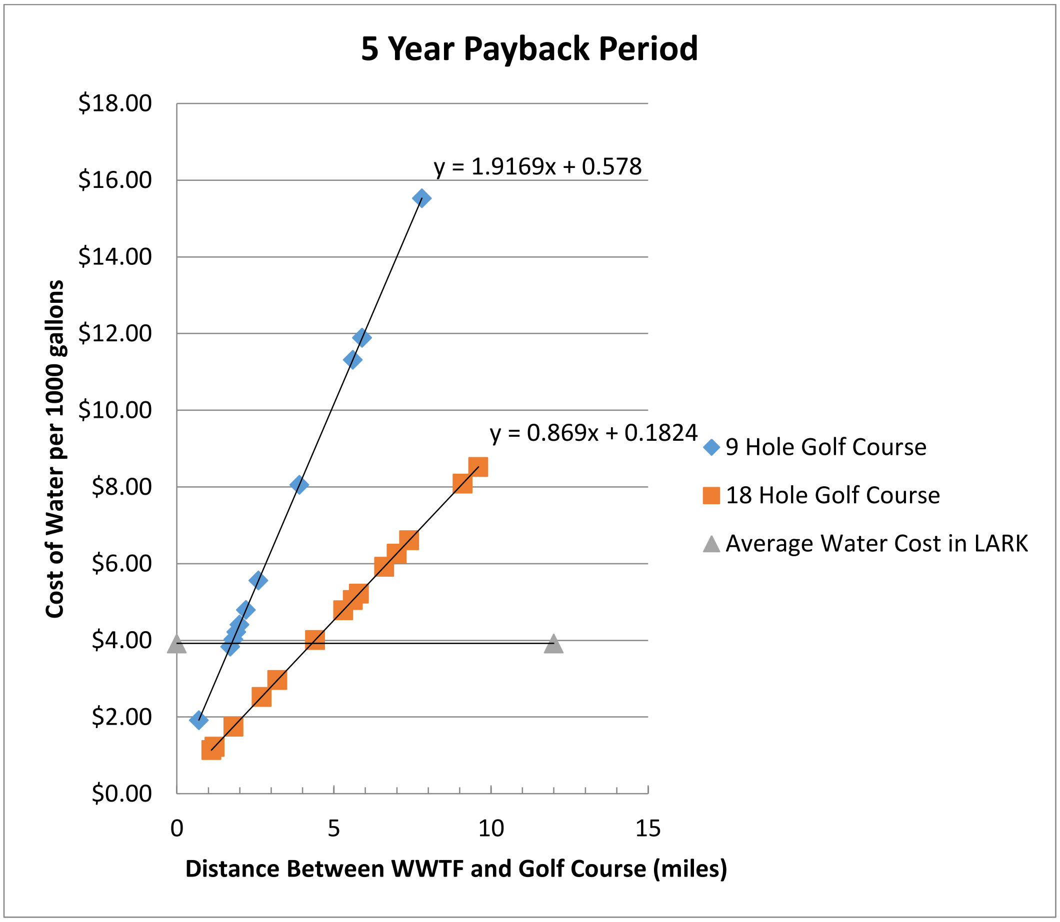
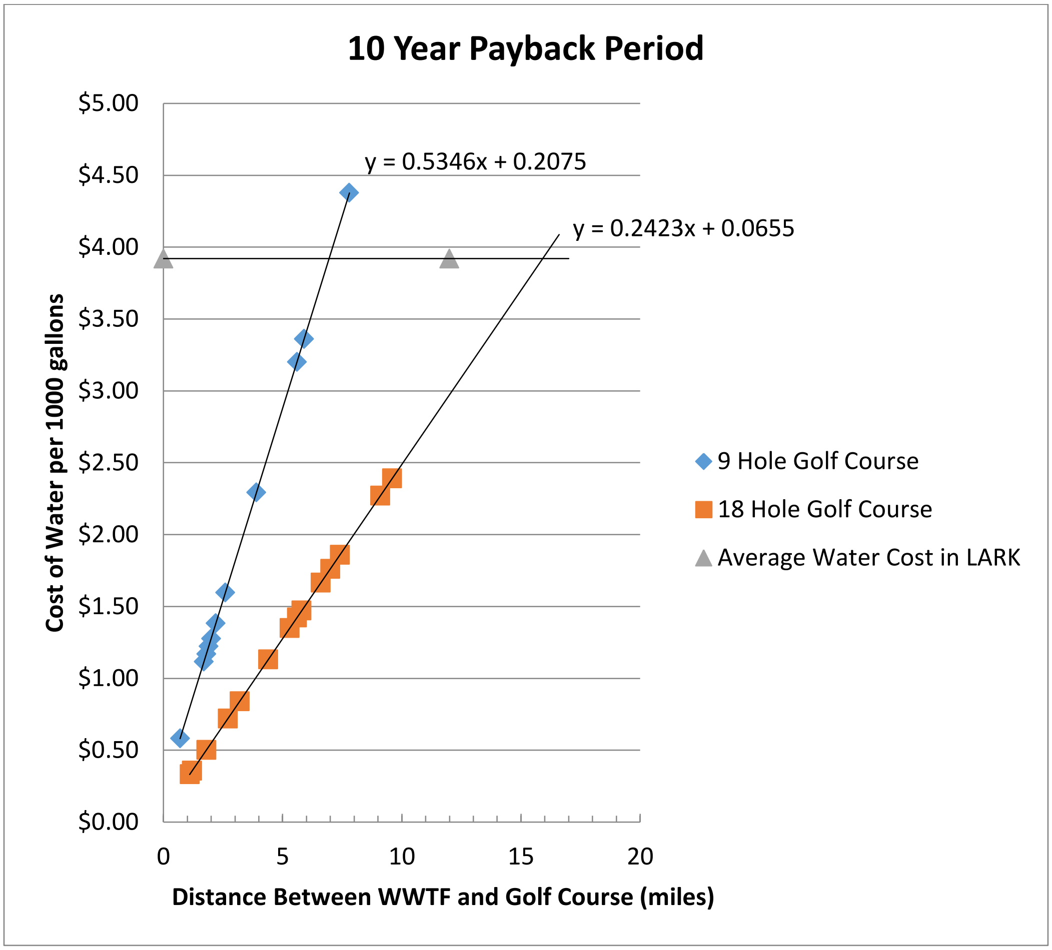


Figure 4.8: 10 year payback for 9 and 18 hole Golf Course in the LARK



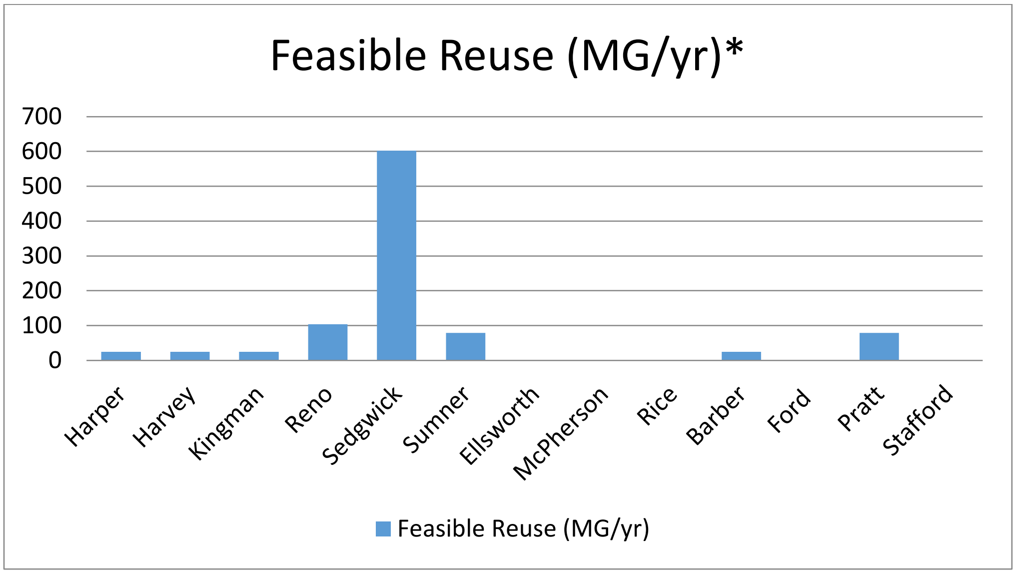
All golf courses that were below the average water cost line in the 10 year payback period graph are considered feasible; they are listed in Table 4.12. Corresponding wastewater treatment facility, county, and amount of water used in MG per year based on the size of the golf course are also listed in the table. Golf courses that are currently reusing wastewater effluent were not included in the table. If two or more golf courses corresponded with one wastewater treatment facility the wastewater treatment facility was evaluated based on its design capacity; when the capacity was not large enough for the golf courses the closest golf courses were included. The total estimated amount of wastewater effluent that could feasibly be used for golf course irrigation is 963.3 MG per year. The feasible wastewater quantity per county is illustrated in Figure 4.9. In 2006, the estimated water use in the LARK was 700,000 acre-feet or 288,096

MG, the potential wastewater effluent reuse for golf course irrigation accounts for 0.33 % of the total water usage.[11] These results will be discussed later in this chapter.

Table 4.13: Feasible Golf Courses in the LARK

Golf Course	WWTF	County	Water Usage (MG/yr)
Anthony Golf Club	Anthony	Harper	24.9
Wedgewood Golf Course	Halstead	Harvey	24.9
Kingman Country Club	Kingman	Kingman	24.9
Haven Country Club	Haven	Reno	24.9
Clearwater Golf Course	Clearwater	Sedgwick	24.9
Pine Bay Golf	Wichita Plant #2	Sedgwick	24.9
Medicine Lodge Golf Course	Medicine Lodge	Barber	24.9
Carey Park Golf Course	Hutchinson	Reno	78.9
Auburn Hills Golf Course	Goddard	Sedgwick	78.9
Reflection Ridge Golf Course	Wichita #3	Sedgwick	78.9
Echo Hills Golf Course	Valley Center	Sedgwick	78.9
LW Clapp Memorial Golf Course	Wichita Plant #2	Sedgwick	78.9
Derby Golf Course	Wichita Plant #2	Sedgwick	78.9
Hidden Lakes Golf Course	Derby	Sedgwick	78.9
Twin Lakes Golf Course	Wichita Plant #2	Sedgwick	78.9
Wellington Golf Club	Wellington	Sumner	78.9
Park Hills Golf	Pratt	Pratt	78.9
Total			963.3

Figure 4.9: Feasible Reuse in the LARK



*Harvey, Ellsworth and McPherson counties have golf courses currently reusing wastewater effluent; these numbers are not included in the bar chart.

Other benefits, as listed in Chapter 3 Table 3.14, of reusing wastewater effluent in the LARK are to create or enhance golf courses in the LARK, improve groundwater resource, quality and/or quantity by reducing pumping demands, increase reliability and diversity of community water supply portfolio, and avoid or postpone investments for expanding water supply. Golf courses bring a variety of benefits to any community including high quality of living and increased housing value. If wastewater reuse is successful with existing golf courses, there lies a potential for future golf courses being developed. The City of Newton, Kansas specifically developed a municipal golf course to reuse wastewater from their existing wastewater facility. The golf course has brought additional revenue to the city through quality golf tournaments. Reusing wastewater effluent will improve groundwater resources in the LARK because a large percentage of water is withdrawn directly from groundwater. Using wastewater effluent instead of potable water or ground water will relive a percentage of withdrawal and potentially slow down the aquifer depletion being reported in the area. Many cities in the LARK, including Wichita are actively researching additional raw water resources. Although the quantity of water was not high when compared to the overall water use in the region, it could help in the water management plan for the future.

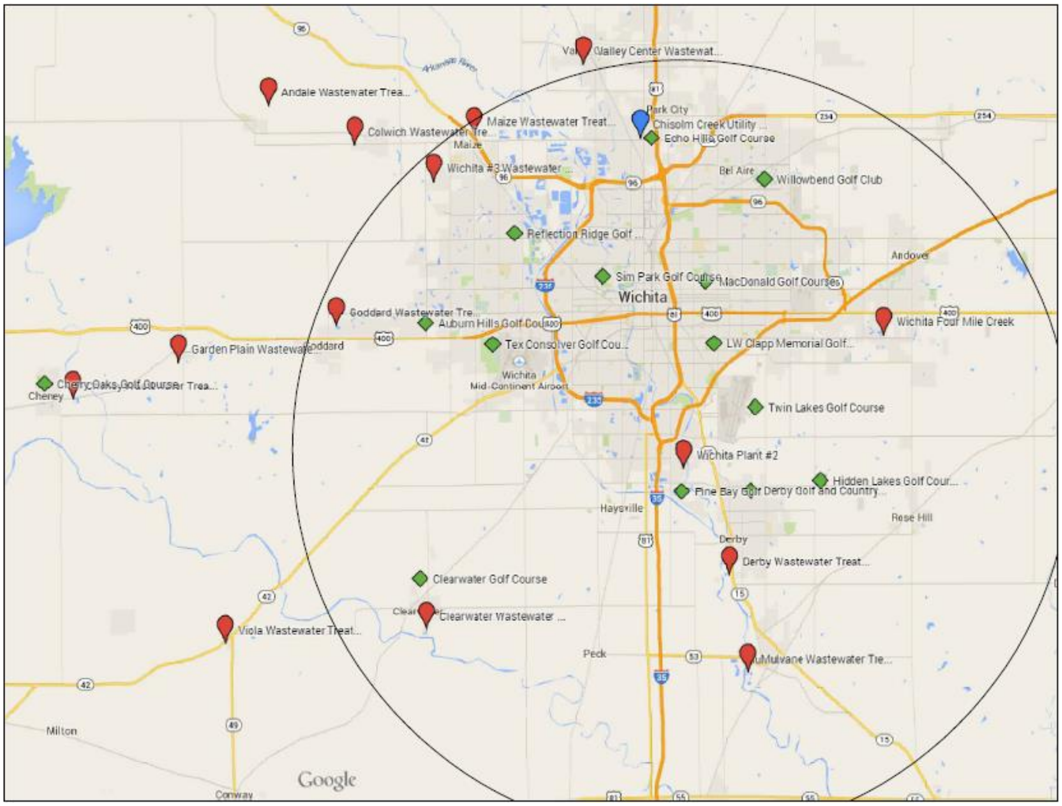
4.5 Discussion

Results from this study are helpful for planning agencies to determine how useful wastewater reuse could be in a region. Securing a safe and reliable water supply for the future is an issue most municipalities in the United States are struggling with. Water conservation has always been the highest priority, however despite concentrated efforts there are still water supply deficits in many parts of the country including the LARK. Populations are increasing which creates even more of a demand on a depleting resource. As the population increases so does the amount of wastewater produced, which could potentially provide some relief to the water supply shortage. Urban irrigation does not require potable water so an opportunity exists to use an alternative water source. This would allow potable water to be diverted to an end user that truly needs treated drinking water. Reusing wastewater for irrigation will help the water management plan in a region, however converting to reuse needs to be financially beneficial to the end user. The results from the study showed the financial feasibility for the region and the quantity of water that could be reduced from the overall water demand. In the LARK, all golf courses except one had less than a10 year payback period, making wastewater reuse a viable option to reduce overall water demand in the region. Project lifetime for the distribution mains far exceeds ten years making this a good investment for golf courses. Knowing that any 9 and 18 hole golf course within 1.7 and 4.3 miles respectively of a wastewater treatment facility will be able to payback the capital costs for converting to wastewater reuse for their irrigation within 5 years for the regional input values is a valuable planning tool. Similarly, knowing that a 9 hole and 18 hole golf course within 6.9 and 15.9 miles respectively from a wastewater treatment facility provides valuable insight for the region and similar regions.

After completing each step of the model it was determined that all 18 hole golf courses would be able to payback the initial project cost within 10 years. The main variables in this model are an 80% reduction in reuse water cost and an estimated construction cost for the distribution system. This is useful information for the region but did not provide the full picture of reuse potential. The linear relationship between cost of water and distance between wastewater treatment facility and golf course was projected past the 5 mile radius to determine the longest distance possible within a 10 year payback period. The conclusion is that any 18 hole golf course within 15.9 miles of a wastewater treatment facility would have a 10 year payback period for converting to wastewater reuse. For municipalities, this data provides a powerful tool when planning for future water supply in a region. City planners can use this information to guide future decisions. Municipalities in the LARK could use the results from this study to integrate wastewater reuse in their water and wastewater master plans.

The only wastewater facility in the LARK with an adequate design capacity to support multiple golf courses is Wichita Plant #2, with a design capacity of 54 MGD. Figure 4.10 illustrates a 15.9 mile radius around this wastewater treatment facility; it encompasses 13 golf courses in Sedgwick County. Willowbend golf course is currently reusing wastewater from the Chisolm Creek Water Authority so it was removed from the list of potential golf courses. Out of the potential 963.3 MG/yr of wastewater reuse in LARK, 946.8 MG/yr could come from one wastewater treatment facility. Golf courses in lower population areas within the LARK are currently reusing wastewater effluent for golf course irrigation but it was not because they were trying to conserve potable water or because it was a financial benefit for the golf course. In these municipalities wastewater effluent was the only water source available for golf course irrigation, without it the golf course would not be irrigated. Small towns can still benefit from the additional benefits wastewater reuse brings to a community, like a green golf course. Results from this study clearly show the larger impact from wastewater reuse will be in more densely populated areas where urban irrigation is a large water user. .

Figure 4.10: Golf Courses within 15.9 Mile Radius of Wichita Plant #2



In Kansas, and similar regions, golf courses already have an irrigation system in place which can be modified with few capital costs. Water storage is typically a lake or pond that acts as a water feature in the golf course landscape. The typical hot and windy summer conditions in Kansas promote turnover in the lake or pond and keep water moving, which means an aeration system is not needed further reducing retrofit costs. Pump stations were not added into the cost estimation because land is relatively flat allowing pipes to gravity feed wastewater to the golf course storage location. All of these conditions combine to keep the cost of a wastewater reuse project low resulting in a feasible payback period. Other similar regions would realize the same benefits. The hot, dry windy summer conditions in Kansas combine to create a large peak in water usage for urban irrigation; using wastewater effluent to irrigate golf courses would help lower a municipalities' water demand at the time when needed the most.

It was anticipated that reusing wastewater effluent for golf course irrigation would make a more significant impact than 0.33% of the total water use in the LARK. After carefully considering the results and the region of study, certain lessons can be learned that can be applied to similar regions. In Kansas 85% of the total water usage comes from irrigation, however agricultural irrigation makes up the majority of this percentage. By definition, large farming communities do not have the population to create enough wastewater effluent for reuse. While reuse can supplement agricultural irrigation, it likely will not serve as the primary source of water.

Samplings of golf courses in the LARK were interviewed to discuss their thoughts on using wastewater reuse for irrigation. Surprisingly there were no concerns about public perception, it was a matter of not considering it as a cost effective option for the golf course. Golf courses that are currently irrigating with wastewater were interviewed to discuss the costs of the project, any negative outcomes of the project, and general public perception. In every case there were no public perception issues with using wastewater effluent. Some golf courses mentioned minimal damage to the turf in extreme drought conditions, but overall there were not concerns with water quality. Most of the golf courses that are currently using wastewater for irrigation are municipal owned golf course, so that appears to play a role in getting the project off the ground. In most cases, the golf course was not paying for the irrigation water from the city, the project was started to help conserve water and allow the municipality to sell potable water to paying customers.

This study provides a model that uses regional input values to determine a relationship between cost of water and distance between wastewater treatment facility and end user. In the LARK region the relationship was linear because the highest impact was the cost of distribution mains which is a function of distance. For other regions this relationship could be significantly different if high treatment or storage costs dominate the project costs. The model allows users to input and change all values to determine what relationship there is between cost and distance. Sensitivity analyses can be performed using the model to determine what overall affect each variable contributes. Municipalities can use the model to determine how much they should charge for wastewater reuse. Golf courses can use the model to determine how long their payback period would be to convert to wastewater reuse. Developers can use the model to determine a location for their future golf course that would allow them to use wastewater reuse to save on irrigation costs. The model can also be adapted to any potential reuse category.

Industrial reuse could be studied in a region to determine the distance between wastewater treatment facility and industrial facility. If construction companies are bidding low on projects due to a bad economy the model can easily be updated to determine what would happen if the construction costs were reduced significantly. The potential use for the model is highly variable. Municipalities and golf courses in the LARK expressed an interest in the topic of using wastewater reuse for irrigation but they cited lack of knowledge and data as a reason for not pursuing it. A simple, user friendly tool could provide the needed data to begin the wastewater reuse conversation. It should be noted that there is a cluster of wastewater treatment facilities along Interstate 135 (Newton, Hesston, McPherson and Lindsborg) that are all using wastewater irrigation for reuse. In researching what the connection was between these facilities it was determined the municipalities observed the success of reuse in a nearby municipality and began to consider trying it themselves. Municipalities need to have some indication of success before beginning the wastewater reuse journey; this report provides the needed data. The model provides a tool that municipalities can manipulate to produce outcomes designed specifically with their input values.

Additional factors must be considered to ensure wastewater reuse success in irrigation applications. Water quality is discussed in section 3.1, however the salt tolerance should be a specific consideration when discussing wastewater reuse. Some types of turfgrass are known to not tolerate high salt content. In the LARK, golf courses using wastewater effluent did not notice a deterioration of turfgrass after changing their system to wastewater effluent; however most of them were using a sulfur burner to treat the water. These systems help alleviate the bicarbonate bonds that create salt buildup in soil. Specific types of turfgrass are more salt tolerant and can be considered as a solution to any negative effects caused from salt buildup.[22] Additional research could be needed to determine what effect wastewater reuse would have on the golf course soil and turfgrass in a specific region.

Results from this study show wastewater reuse for golf course irrigation in the LARK is a safe, reliable and economically feasible water source alternative. Integrating wastewater reuse into the overall water management plan is the key to successful projects. The results from this study provide a tool that can make this integration easier and more focused.

Conclusions

This study develops a set of evaluation criteria to quickly assess feasibility of wastewater reuse for irrigation needs. The theoretical framework for evaluating wastewater reuse was established and applied in this report using three main criteria; they are regulations and guidelines for reuse, adequate flow ratio, and a cost benefit analysis. Wastewater reuse regulations need to be researched in a region to establish whether or not a reuse project can be considered. In the absence of regulations, nationally established guidelines can be used to determine if a reuse project should be considered. Once it has been established that criteria 1 is met the region can be moved to criteria 2 which calculates a flow ratio. The flow ratio compares wastewater treatment plant design capacity to the end user water demands. A ratio greater than one indicates the wastewater treatment design capacity is sufficient for the end user water demands. Facilities passing through criteria 1 and 2 are moved into criteria 3 where they are assessed for economic feasibility. A model for calculating the cost benefit analysis was developed using Microsoft EXCEL. Input values from the region are entered into the model to determine what payback periods for converting urban and agricultural irrigation to wastewater reuse. The theoretical framework is developed in the methodology section for irrigation users and applied in the results section to a specific region for golf course irrigation.

Region specific data was gathered for the Lower Arkansas River Basin (LARK) to apply towards the theoretical framework and model developed for wastewater reuse. The Kansas Department of Health and Environment (KDHE) provided regulatory data and wastewater treatment facility data for the LARK. Golf courses and municipalities in the region currently using wastewater effluent for irrigation were contacted to discuss region specific parameters needed to successfully convert to wastewater reuse. Golf courses and municipalities in the region not using wastewater reuse for irrigation were also contacted to find out if any barriers exist in the region that would block wastewater reuse from being considered. Through a review of KDHE regulations and discussions with golf courses it was determined that few modifications were needed at the golf courses regarding additional treatment and storage. Several golf courses in the region were using sulfur burners to treat the wastewater effluent so the capital and O&M costs were included in the cost benefit analysis. All contacted golf courses used a water feature or lake for irrigation storage which can easily be converted to wastewater reuse storage. Distribution cost estimates were established based on research and local bid tabulations in the region. Regional factors led to low capital costs for wastewater reuse making it an economical option. There were no barriers to wastewater reuse in the LARK, the main reason for not considering it was lack of knowledge about the process and data showing if projects are feasible.

The theoretical framework and data were applied to assess water reuse in the LARK. The highest cost in wastewater reuse projects came from the cost of installing distribution mains from the wastewater treatment facility to the golf courses. The construction cost includes distance so a linear relationship exists between water cost and distance between wastewater treatment facility and golf course. Results from the cost estimate analysis showed that any 18 hole golf course within 15.9 miles of a wastewater treatment facility can payback the wastewater reuse project costs within 10 years. In Sedgwick County, 946.8 MG/yr of golf course irrigation water can be supplied by wastewater effluent. Based on the results from this study it can be inferred wastewater reuse for agriculture irrigation would not be feasible due to current regulatory requirements and inadequate flow ratios. Other wastewater reuse categories could be analyzed with the framework set up in this study.

The theoretical framework and criteria provide a methodology to assess water reuse projects in other regions and reuse categories. Criteria 1 and 2 are adapted to other regions and reuse by gathering data from local regulatory agencies and end users. Criteria 3 can be adapted to other regions through a model that was developed in this study. The model was set up to perform the cost benefit analysis based on input values from regional data. A relationship between water cost and distance between wastewater treatment facility and end user is established by the model to guide users in making a decision based on economic feasibility. For the LARK, the model was used to illustrate 5 and 10 year payback periods based on project costs and reduced water cost. Other regions could apply the model to any category of reuse by varying the input values. Input parameters include cost estimates, water cost reduction, municipal interest rates, and end user water demands. Other regions can easily update the input parameters to apply the model to different regions and end users. As regulatory frameworks and economic factors evolve over time the model can be updated to assess the affects these changes will have on reuse projects.

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Appendix A - **Wastewater Treatment Facility and Golf Course Locations By County**

Figure A.1: Wastewater Treatment Facilities and Golf Courses in Harper County

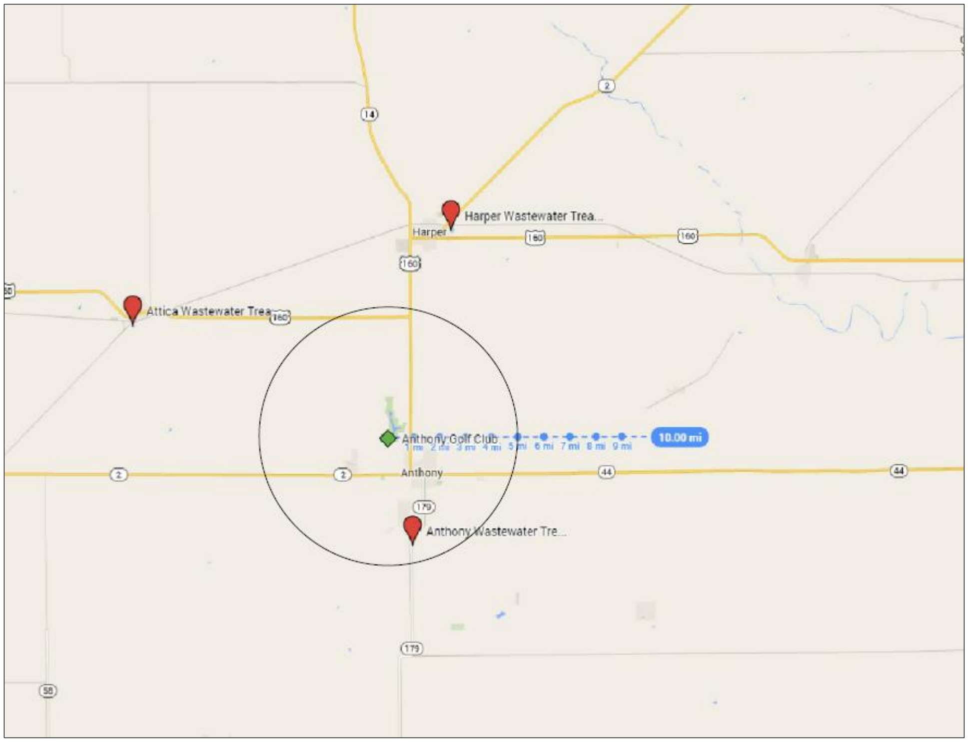


Figure A.2: Wastewater Treatment Facilities and Golf Courses in Harvey County

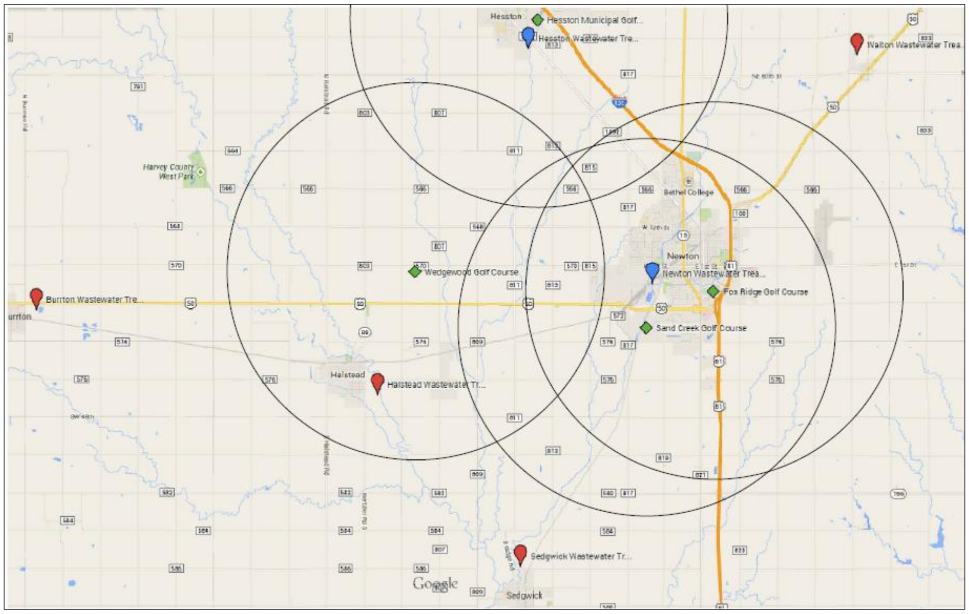


Figure A.3: Wastewater Treatment Facilities and Golf Courses in Kingman County

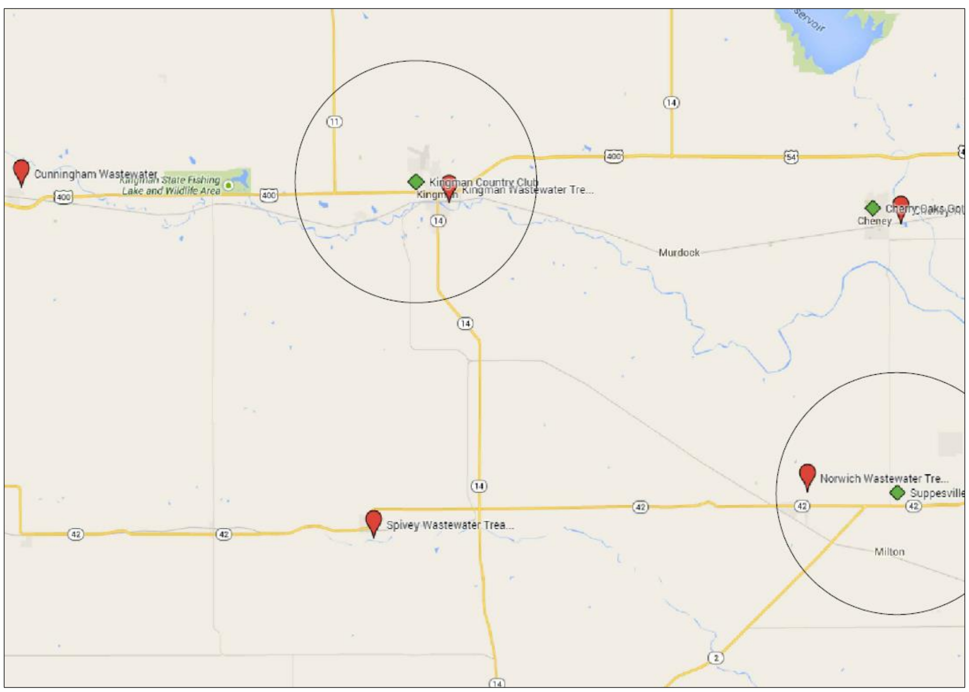


Figure A.4: Wastewater Treatment Facilities and Golf Courses in Reno County

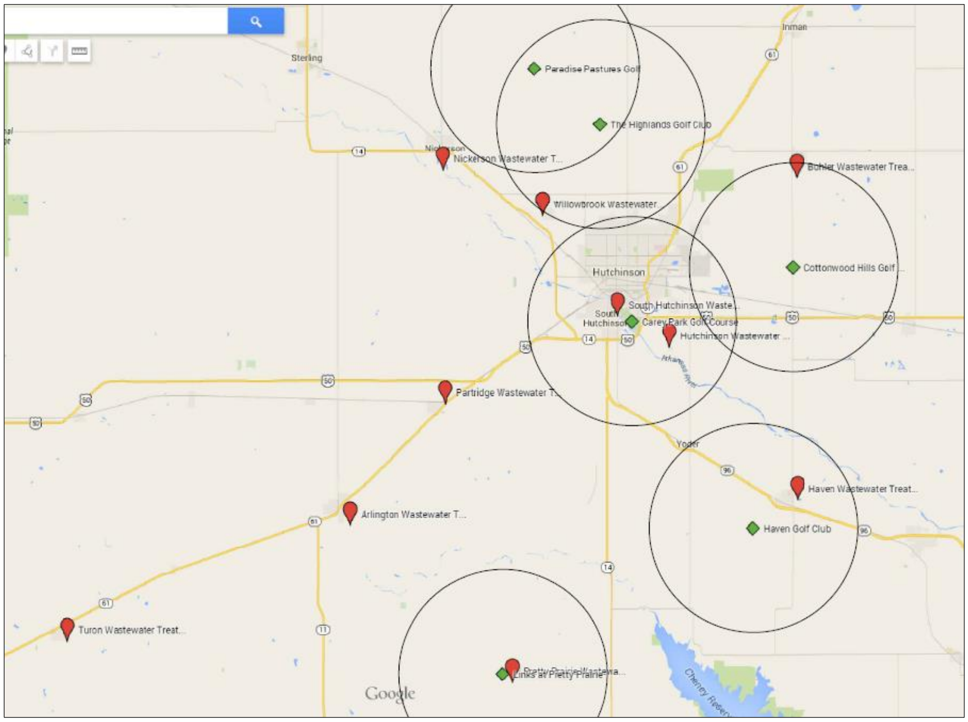


Figure A.5: Wastewater Treatment Facilities and Golf Courses in Sedgwick County

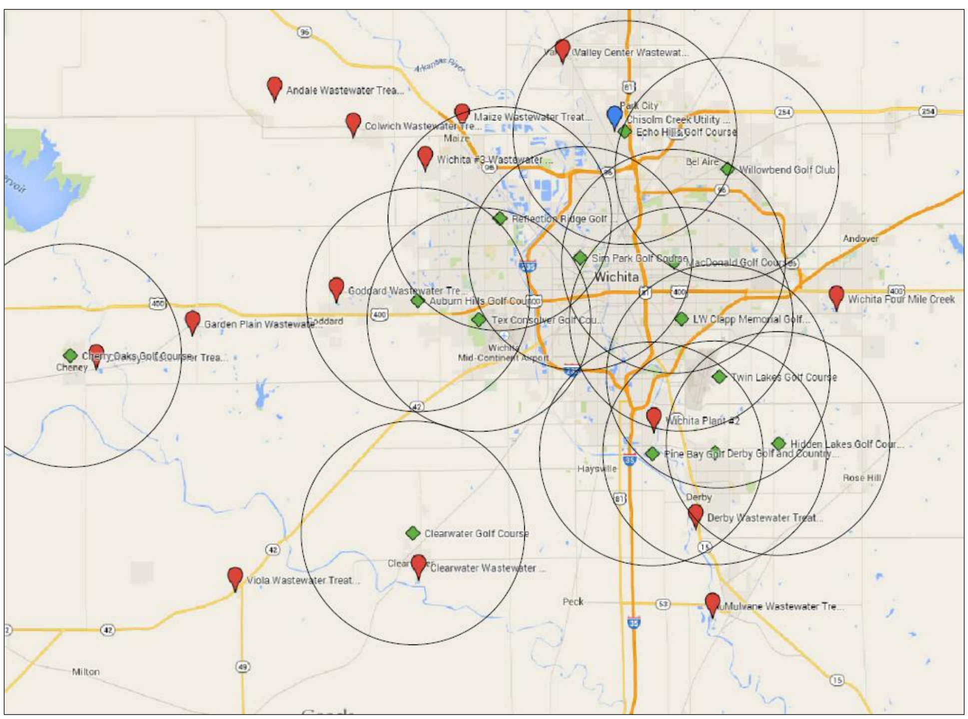


Figure A.6: Wastewater Treatment Facilities and Golf Courses in Sumner County

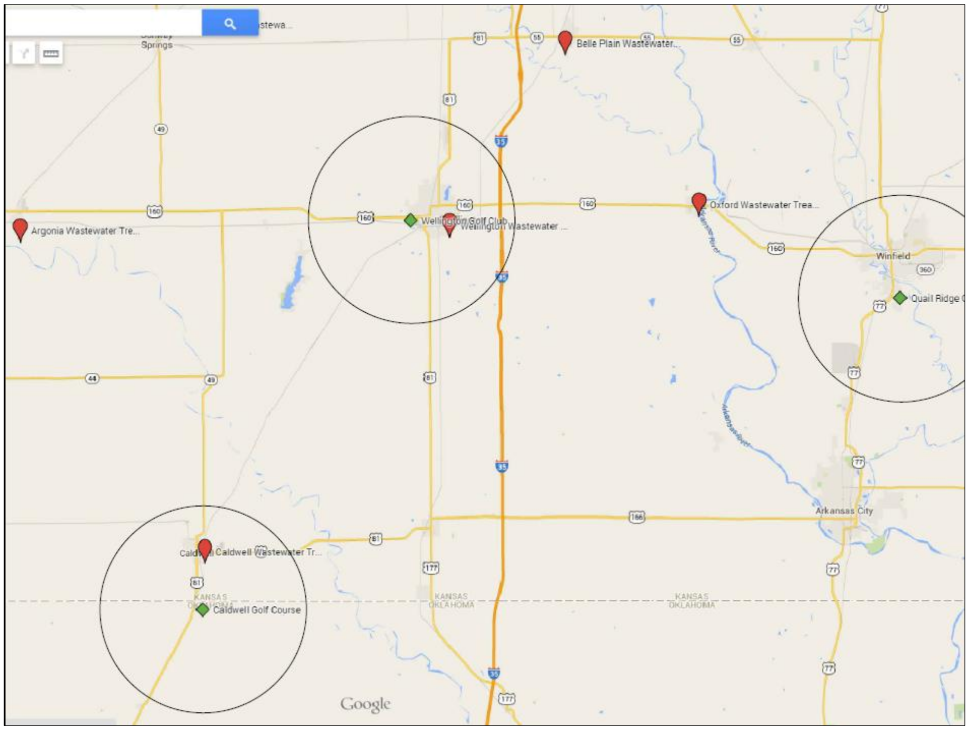


Figure A.7: Wastewater Treatment Facilities and Golf Courses in Ellsworth County

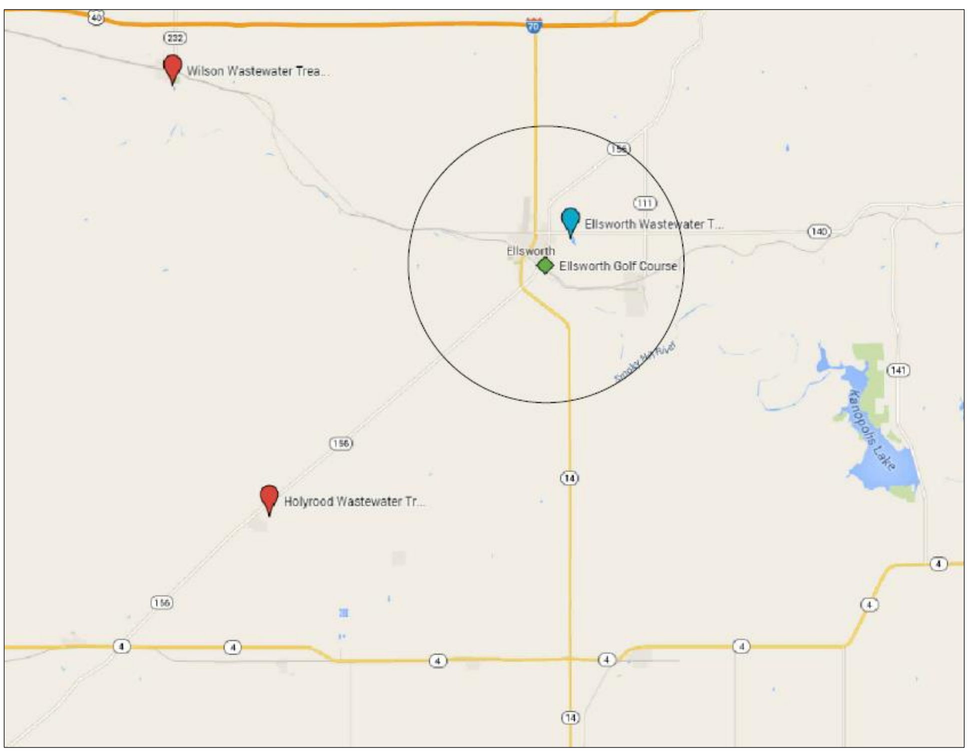


Figure A.8: Wastewater Treatment Facilities and Golf Courses in McPherson County

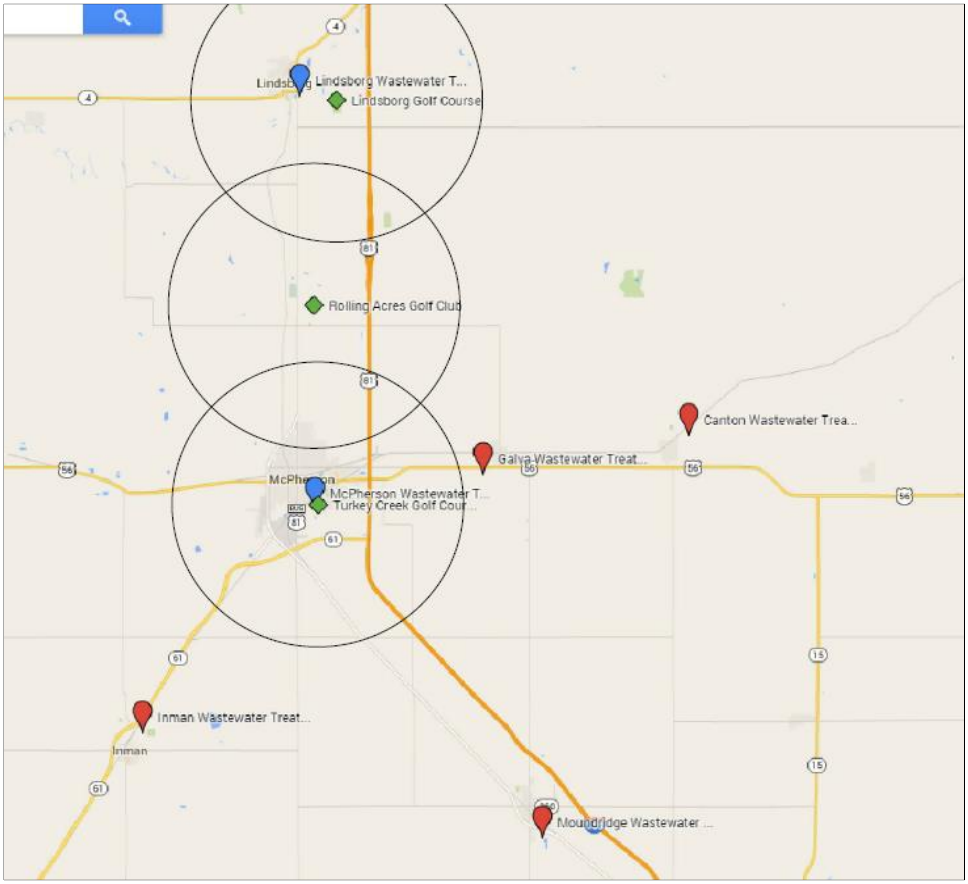


Figure A.9: Wastewater Treatment Facilities and Golf Courses in Rice County

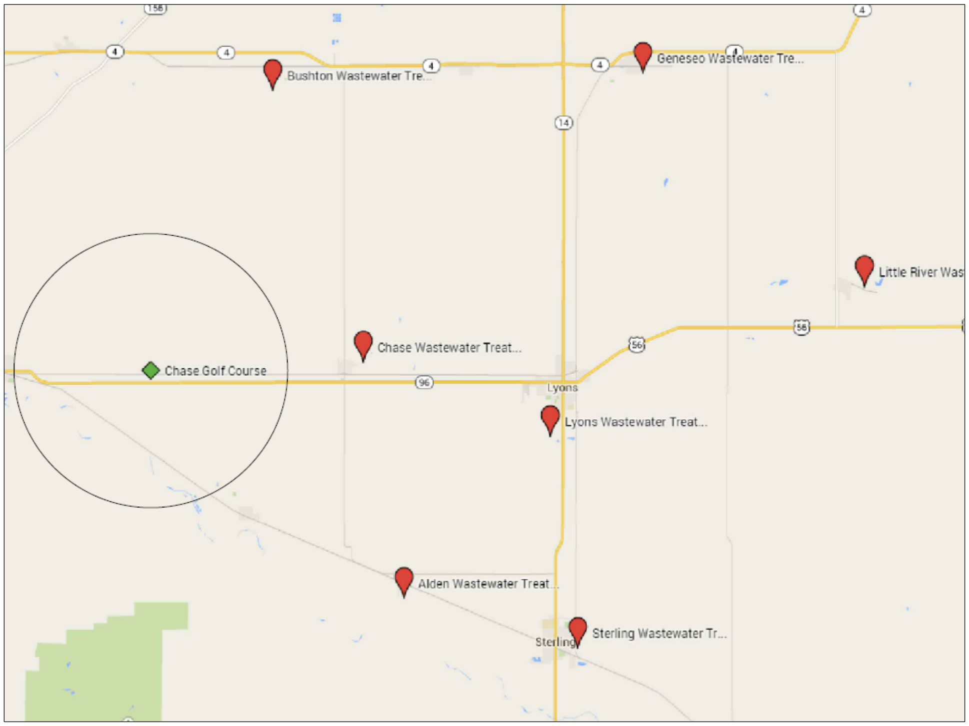
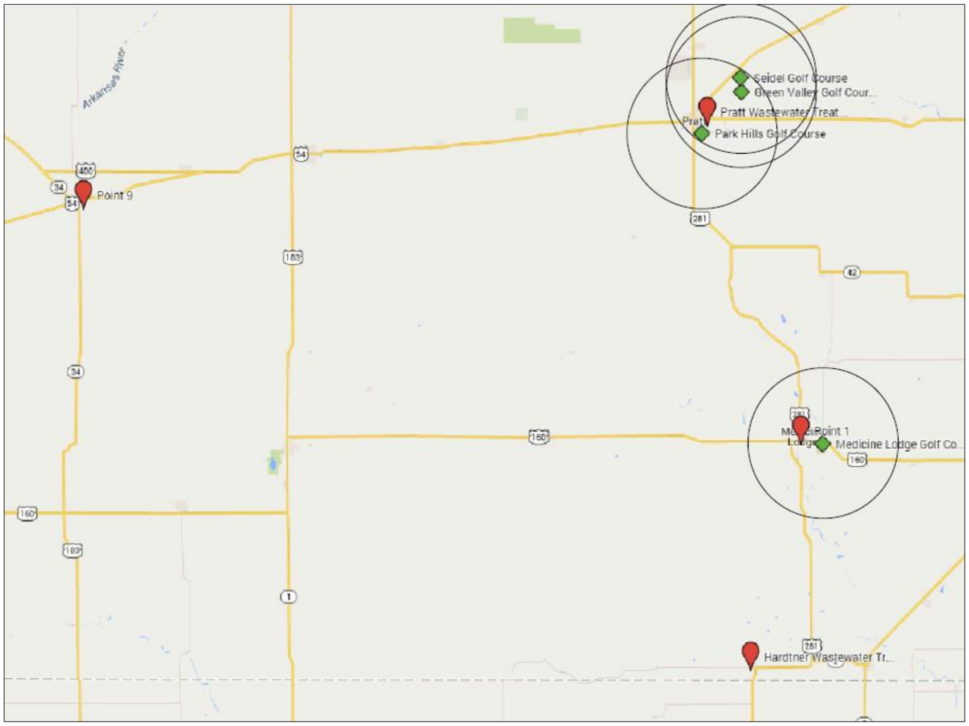


Figure A.10: Wastewater Treatment Facilities and Golf Courses in Barber, Ford, Pratt and Stafford Counties



Appendix B - **Excel Spreadsheet Tables**

Table B. 1: Parameters Table

Variable	Description	Input Value
Cost		
Capitol Cost		
C_{pi}	6" pipeline cost ($/ft)	$39.41
	8" pipeline cost (S/ft)	$56.61
C_{ti}	Sulfur Burner Cost	$20,000.00
C_{ri}	Signage, Valves, Etc	$20,000.00
O&M Costs		
OM_t	Sulfur Burner Supplies & Power ($/yr)	$5,219.00
Annual Savings		
A_w	to be calculated	
Payback Periods		
n_1	1st payback period in years	5
n_2	2nd payback period in years	10
Other Parameters		
i	current municipal bond rate (%)	0.0475
C_w	Avg. Cost of potable water per 1000 gal for region	$3.92
ΔC_w	anticipated cost of reclaimed water based on percent of potable water cost	0.80
Q_{9hole}	Annual Water Usage for 9 hole Golf Course (MG)	24.9
Q_{18hole}	Annual Water Usage for 18 hole Golf Course (MG)	78.9

Table B.2: Golf Course and Wastewater Treatment Facility Data

Golf Course	WWTP in 5 mile radius	WWTP Capacity (MGD)	Pipe Diameter	Flow Ratio	Distance by Road (miles)	Estimated Cost [2]
9 holes						
Anthony Golf Club	Anthony	0.3	6	1.4	5.9	$1,227,700
Wedgewood Golf Course	Halstead	0.42	6	1.9	3.9	$811,531
Fox Ridge Golf Course (Newton Country Club)	Newton	3	6	13.6	1.7	$353,744
Kingman Country Club	Kingman	0.75	6	3.4	2.2	$457,787
Haven Golf Club	Haven	0.2488	6	1.1	0.7	$145,659
Clearwater Golf Course	Clearwater	0.253	6	1.2	2.6	$541,020
Pine Bay Golf	Wichita Plant #2	54	6	245.5	1.8	$374,553
Pine Bay Golf	Derby	2.5	6	11.4	5.9	$1,227,700
Ellsworth Golf Course[1]	Ellsworth	0.5	6	2.3	2	$416,170
Green Valley Golf Course	Pratt	1.1	6	5.0	7.8	$1,623,061
Seidel Golf Course	Pratt	1.1	6	5.0	5.6	$1,165,275
Medicine Lodge Golf Course	Medicine Lodge	0.35	6	1.6	1.9	$395,361
18 holes						
Heston Municipal Golf Course[1]	Hesston	1.3	8	1.9	1.8	$538,021
Sand Creek Golf Course[1]	Newton	3	8	4.3	1.2	$358,681
Carey Park Golf Course	Hutchinson	8.3	8	11.9	3.2	$956,483
Auburn Hills Golf Course	Goddard	0.8	8	1.1	5.3	$1,584,174
Reflection Ridge Golf Course	Wichita #3	2	8	2.9	7	$2,092,306
Echo Hills Golf Course	Valley Center	0.7	8	1.0	5.6	$1,673,844
Willowbend Golf Course[1]	Park City (CCUA)	2.16	8	3.1	6.6	$1,972,745
LW Clapp Memorial Golf Course	Wichita Plant #2	54	8	77.1	7.4	$2,211,866
Derby Golf Course	Wichita Plant #2	54	8	77.1	4.4	$1,315,164
Derby Golf Course	Derby	2.5	8	3.6	5.8	$1,733,625
Hidden Lakes Golf Course	Derby	2.5	8	3.6	9.1	$2,719,997
Twin Lakes Golf Course	Wichita Plant #2	54	8	77.1	9.6	$2,869,448
Wellington Golf Club	Wellington	1.71	8	2.4	2.7	$807,032
Turkey Creek Golf Course[1]	McPherson	2	8	2.9	1.2	$358,681
Park Hills Golf Course	Pratt	1.1	8	1.6	1.1	$328,791

[1] Golf courses are currently using Wastewater Effluent for irrigation

[2] Estimated Cost = distance by road * 5280 ft/mile * C_p

Table B.3: 5 Year Payback Estimate

FV of C_p	FV of C_t	FV of C_r	FV OM_t	FV Sum	Water Differential Cost	Cost per 1000 gallons	The Cost for Current Water
9 holes							
$1,548,320.93	$25,217.70	$25,217.70	$28,694.60	$1,627,450.93	$296,002.24	$2.38	$11.89
$1,023,464.51	$25,217.70	$25,217.70	$28,694.60	$1,102,594.52	$200,540.88	$1.61	$8.05
$446,122.46	$25,217.70	$25,217.70	$28,694.60	$525,252.46	$95,533.39	$0.77	$3.84
$577,336.56	$25,217.70	$25,217.70	$28,694.60	$656,466.56	$119,398.73	$0.96	$4.80
$183,694.25	$25,217.70	$25,217.70	$28,694.60	$262,824.25	$47,802.71	$0.38	$1.92
$682,307.84	$25,217.70	$25,217.70	$28,694.60	$761,437.85	$138,491.00	$1.11	$5.56
$472,365.28	$25,217.70	$25,217.70	$28,694.60	$551,495.28	$100,306.46	$0.81	$4.03
$1,548,320.93	$25,217.70	$25,217.70	$28,694.60	$1,627,450.93	$296,002.24	$2.38	$11.89
$524,850.92	$25,217.70	$25,217.70	$28,694.60	$603,980.92	$109,852.59	$0.88	$4.41
$2,046,934.53	$25,217.70	$25,217.70	$28,694.60	$2,126,064.53	$386,690.53	$3.11	$15.53
$1,469,592.47	$25,217.70	$25,217.70	$28,694.60	$1,548,722.47	$281,683.04	$2.26	$11.31
$498,608.10	$25,217.70	$25,217.70	$28,694.60	$577,738.10	$105,079.53	$0.84	$4.22
18 holes							
$678,525.57	$25,217.70	$25,217.70	$28,694.60	$757,655.58	$137,803.08	$0.35	$1.75
$452,348.55	$25,217.70	$25,217.70	$28,694.60	$531,478.55	$96,665.80	$0.25	$1.23
$1,206,271.96	$25,217.70	$25,217.70	$28,694.60	$1,285,401.97	$233,790.07	$0.59	$2.96
$1,997,891.55	$25,217.70	$25,217.70	$28,694.60	$2,077,021.55	$377,770.55	$0.96	$4.79
$2,638,726.45	$25,217.70	$25,217.70	$28,694.60	$2,717,856.45	$494,326.18	$1.25	$6.27
$2,110,980.06	$25,217.70	$25,217.70	$28,694.60	$2,190,110.06	$398,339.19	$1.01	$5.05
$2,487,941.77	$25,217.70	$25,217.70	$28,694.60	$2,567,071.77	$466,901.32	$1.18	$5.92
$2,789,511.14	$25,217.70	$25,217.70	$28,694.60	$2,868,641.14	$521,751.03	$1.32	$6.61
$1,658,626.01	$25,217.70	$25,217.70	$28,694.60	$1,737,756.02	$316,064.63	$0.80	$4.01
$2,186,372.40	$25,217.70	$25,217.70	$28,694.60	$2,265,502.41	$412,051.61	$1.04	$5.22
$3,430,346.04	$25,217.70	$25,217.70	$28,694.60	$3,509,476.04	$638,306.66	$1.62	$8.09
$3,618,826.89	$25,217.70	$25,217.70	$28,694.60	$3,697,956.89	$672,587.73	$1.70	$8.52
$1,017,791.11	$25,217.70	$25,217.70	$28,694.60	$1,096,921.11	$199,509.00	$0.51	$2.53
$452,348.55	$25,217.70	$25,217.70	$28,694.60	$531,478.55	$96,665.80	$0.25	$1.23
$414,652.38	$25,217.70	$25,217.70	$28,694.60	$493,782.38	$89,809.58	$0.23	$1.14

Table B.4: 10 Year Payback Estimate

FV of C_p	FV of C_t	FV of C_r	FV OM_t	FV Sum	Water Differential Cost	Cost per 1000 gallons	The Cost for Current Water
9 holes							
$1,952,674.79	$31,798.05	$31,798.05	$64,883.08	$2,081,153.99	$167,401.76	$0.67	$3.36
$1,290,746.92	$31,798.05	$31,798.05	$64,883.08	$1,419,226.11	$114,158.28	$0.46	$2.29
$562,626.26	$31,798.05	$31,798.05	$64,883.08	$691,105.45	$55,590.44	$0.22	$1.12
$728,108.23	$31,798.05	$31,798.05	$64,883.08	$856,587.42	$68,901.31	$0.28	$1.38
$231,662.32	$31,798.05	$31,798.05	$64,883.08	$360,141.52	$28,968.70	$0.12	$0.58
$860,493.80	$31,798.05	$31,798.05	$64,883.08	$988,973.00	$79,550.01	$0.32	$1.60
$595,722.65	$31,798.05	$31,798.05	$64,883.08	$724,201.85	$58,252.62	$0.23	$1.17
$1,952,674.79	$31,798.05	$31,798.05	$64,883.08	$2,081,153.99	$167,401.76	$0.67	$3.36
$661,915.44	$31,798.05	$31,798.05	$64,883.08	$790,394.63	$63,576.97	$0.26	$1.28
$2,581,506.27	$31,798.05	$31,798.05	$64,883.08	$2,709,985.47	$217,983.08	$0.88	$4.38
$1,853,385.61	$31,798.05	$31,798.05	$64,883.08	$1,981,864.81	$159,415.24	$0.64	$3.20
$628,819.05	$31,798.05	$31,798.05	$64,883.08	$757,298.24	$60,914.79	$0.24	$1.22
18 holes							
$855,723.76	$31,798.05	$31,798.05	$64,883.08	$984,202.95	$79,166.32	$0.10	$0.50
$570,478.36	$31,798.05	$31,798.05	$64,883.08	$698,957.55	$56,222.04	$0.07	$0.36
$1,521,296.35	$31,798.05	$31,798.05	$64,883.08	$1,649,775.54	$132,702.98	$0.17	$0.84
$2,519,655.24	$31,798.05	$31,798.05	$64,883.08	$2,648,134.43	$213,007.96	$0.27	$1.35
$3,327,850.53	$31,798.05	$31,798.05	$64,883.08	$3,456,329.72	$278,016.76	$0.35	$1.76
$2,662,277.94	$31,798.05	$31,798.05	$64,883.08	$2,790,757.13	$224,480.11	$0.28	$1.42
$3,137,686.93	$31,798.05	$31,798.05	$64,883.08	$3,266,166.12	$262,720.57	$0.33	$1.66
$3,518,014.12	$31,798.05	$31,798.05	$64,883.08	$3,646,493.32	$293,312.95	$0.37	$1.86
$2,091,787.14	$31,798.05	$31,798.05	$64,883.08	$2,220,266.33	$178,591.54	$0.23	$1.13
$2,757,359.73	$31,798.05	$31,798.05	$64,883.08	$2,885,838.93	$232,128.20	$0.29	$1.47
$4,326,209.41	$31,798.05	$31,798.05	$64,883.08	$4,454,688.61	$358,321.75	$0.45	$2.27
$4,563,913.91	$31,798.05	$31,798.05	$64,883.08	$4,692,393.10	$377,441.98	$0.48	$2.39
$1,283,591.85	$31,798.05	$31,798.05	$64,883.08	$1,412,071.04	$113,582.75	$0.14	$0.72
$570,478.36	$31,798.05	$31,798.05	$64,883.08	$698,957.55	$56,222.04	$0.07	$0.36
$522,937.46	$31,798.05	$31,798.05	$64,883.08	$651,416.65	$52,398.00	$0.07	$0.33