ENVIRONMENTAL IMPLICATIONS OF RECLAIMED WATER IRRIGATION ON SOIL CHEMICAL PROPERTIES ON GOLF COURSES IN OKLAHOMA AND PUBLIC ACCEPTANCE OF RECLAIMED WATER USE IN OKLAHOMA

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Abstract: Golf course managers in arid and semi-arid regions of the United States are increasingly using reclaimed water for irrigation as freshwater supplies are decreasing due to drought and rapid population growth. Many municipalities are considering implementation of reclaimed water into regional water plans, for which public acceptance is a key factor in the success. The first objective of this research was to assess how reclaimed water irrigation affects soil chemical properties compared to other irrigation sources, including treated municipal water, untreated surface water, and groundwater on five golf courses in Oklahoma. A total of 90 samples from six holes on the greens, fairways, and irrigated roughs were taken along with irrigation water samples and analyzed. High levels of total soluble salts (~3000-3673 mg L^{-1}) were found in soils irrigated with untreated surface, reclaimed, and ground waters. Elevated and deficient levels of nutrients (Ca, Mg, NO_3, P, K, Fe, Cu, Zn, SO_4, Mn, and B) were found in the soil and water samples on all of the five courses in the case study. Reclaimed water can be effectively utilized for golf course irrigation if combined with regular soil and water quality monitoring and proper best management practices. The second objective of this research was to investigate Oklahomans' willingness to pay for reclaimed water as municipal supply as a hedge against drought driven shortages. An Internet survey of 486 Oklahomans indicated that respondents were willing to pay for an additional fee on the standard price charged for water per 1000 gallons. Factors that influence this public acceptance and willingness to pay include: being male; have an annual income of $20,000-100,000+; rent their home; support reclaimed water use policy; and believe reclaimed water is not hazardous. Survey respondents were willing to pay an average fee of $4.19 and $4.20 per 1000 gallons. Providing basic educational information about the safety and quality of reclaimed water will help Oklahomans understand and accept reclaimed water use. Results of this research should aid golf course managers and municipalities interested in using reclaimed water for irrigation purposes, or to integrate reclaimed water use into regional water plans.

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LITERATURE REVIEW

Introduction

Reclaimed water, also referred to as recycled water, is “wastewater that has been through numerous treatment processes to meet specified water quality criteria with the intent of being used in a beneficial manner” (ODEQ, 2012). The terms reclaimed and recycled are often used interchangeably depending on the region but both refer to the reuse of water at least one time before it enters back into the natural water system. A growing number of municipalities across the United Stated began implementing reclaimed water systems in the 1960s because of the increased effect rapid development and population growth had on existing water sources (Asano et al., 2007).

Reclaimed water can be used for different purposes, either for potable use and non-potable use. Potable refers to water that has been treated and is safe to drink and non-potable refers to water that has not been treated and is not suitable for drinking purposes. The growing water management trend is to use water of the highest quality for drinking water purposes and to allocate reclaimed water for non-potable uses that have low health risks, such as irrigation. Reclaimed water has been historically used for non-potable applications for agricultural and landscape irrigation as well as urban and industrial use. Urban uses of reclaimed water include fire protection, toilet flushing, and air conditioning, while industrial applications include cooling tower water, process water, and heavy construction (Asano et al., 2007).

Direct potable reuse consists of processing reclaimed water through a tertiary treatment process and directly introducing this water to a potable water supply system prior to entering a water treatment facility (Asano et al., 2007). Indirect potable reuse involves introducing reclaimed water into storage, such as a reservoir or groundwater aquifer, before entering a water treatment plant, thus integrating the water through an environmental buffer (Asano et al., 2007). Indirect potable reuse systems have historically gained public acceptance more easily than direct potable reuse systems. Direct potable reuse systems have typically been implemented under extreme emergencies, and usually serve a temporary purpose.

Treatment processes, technology, and distribution

To ensure that reclaimed water is of high quality before use, effective and efficient treatment technologies, processes, and distribution are all necessary. Inspired by the increased adoption of reclaimed water regulations by many municipalities, the technology and treatment processes exist to produce high quality reclaimed water. Treatment technologies are constantly evolving and improving to allow for greater removal of contaminants. These treatment processes are required to produce reclaimed water that meets high quality standards to ensure environmental and public safety before use. Improved technologies have put an emphasis on removing higher levels of contaminants that have caused significant concern in the past, such as suspended and dissolved solids, pathogens, and trace components (Asano et al., 2007). After the proper treatment, reclaimed water is required to be distributed safely and through the proper piping systems.

The number of treatment steps that reclaimed water goes through depends on how the water will be used after treatment. Reclaimed water receives primary and secondary treatment like municipal and industrial treated wastewater, but must also receive tertiary treatment to further remove contaminants before reuse. Primary treatment is the mechanical process, removing the crude, floating solids as sewage first enters the treatment facility through screening. Primary treatment removes about 60% of the suspended solids from the influent that comes into the treatment facility (USGS, 2014). Secondary treatment is known as the more biological treatment process, using microbes to consume organic matter and convert to carbon dioxide, water, and energy for their own use.

Tertiary, or advanced, treatment is the highest level in the wastewater treatment process and is considered any treatment process beyond those used in primary and secondary. Advanced treatment technologies have the capabilities to remove 99% of contaminants from wastewater, creating an effluent comparable to, or exceeding, drinking water quality (World Bank Group, 2015). Tertiary treatment employs various biological, physical, and chemical processes to remove or reduce the concentrations of nutrients, organic constituents, and pathogens (USEPA, 2008). Advanced treatment methods include, but are not limited to, membrane filtration (microfiltration, nanofiltration, reverse osmosis), advanced oxidation processes (AOP), and ultraviolet radiation (Zhou and Smith, 2002). Natural systems are an option for advanced treatment of reclaimed water in the forms of wetlands and soil aquifer filtration. Natural systems provide filtration and storage for the unwanted nutrients and microorganisms in reclaimed water. In addition to treatment processes, natural systems provide environmental benefits, such as increased stream flow, but also reduce the energy intensive input that is required of conventional advanced treatment technologies.

Reclaimed water can be distributed through dual piping systems. Dual piping systems consist of two completely separate piping systems, one pipe to deliver potable water and a separate pipe to deliver reclaimed water, or untreated wastewater, to the specified service area (Asano et al., 2007). To avoid cross contamination with potable water lines, piping systems used to distribute reclaimed water must be properly identified. Purple pipes are required by regulation to be used for distribution of non-potable reclaimed water. If the purple pipe is not used for distribution of non-potable reclaimed water, proper signage must be implemented to notify the public to avoid contact.

Reclaimed regulations and standards

Currently, no federal regulations exist for water reclamation and reuse in the United States, leaving states responsible for enforcing their own regulations (Asano et al., 2007). The United States Environmental Protection Agency (USEPA) has released guidelines for reclaimed water use, first in 1992 and again in 2004 and 2012, to provide advisory information and best practices for reclaimed water use. Numerous states, such as California, Florida, Texas, and Arizona, have developed reclaimed water regulations. Reclaimed water regulations ultimately have to ensure water quality that is safe to the public and environment.

Oklahoma's Relationship with Water

The history of water in Oklahoma is irrefutably intertwined with climate, and more specifically, drought. Drought is a normal and repetitive climate condition in Oklahoma. The statewide precipitation trend in Oklahoma from 1895 to 2011 has been a consistent and cyclical occurrence of wet and dry periods of about 5 to 10 years (Oklahoma Water Survey, 2011). Available water supply in Oklahoma has been concurrently affected in these wet and dry periods. The most prominently known drier periods in Oklahoma history include the 1910s, 1930s, 1950s and the late 1960s (Oklahoma Water Survey, 2011). These drier periods experienced various levels of drought, where surface water is decreased to dangerously low levels.

Dry periods and water shortages

Since 2010, Oklahoma has been in the midst of another dry period, setting records for high temperatures and low precipitation. Throughout the last four years of drought (2010-2014), Oklahoma has endured rainfall patterns less than those of the Dust Bowl in the 1930s (Parker, 2014). According to the USGS, the water year of 2011 (October 1, 2010 to September 30, 2011) was the second driest year (precipitation) recorded since 1925 (Shivers and Andrews, 2013). Reduced rainfall patterns, drier temperatures, and decreased stream flows have prompted communities all across Oklahoma to enforce more stringent water conservation measures. At the beginning of September in 2011, 40 of the 113 public water supply systems that had been surveyed by the Oklahoma Department of Environmental Quality (ODEQ) had implemented mandatory water restrictions, while 45 had called for voluntary conservation amongst customers (Shivers and Andrews, 2013). Many municipalities have carried out these water use restrictions, some to a lesser degree based on surface water levels, throughout the remaining and current years of drought. In early January 2013, one of the primary drinking water sources for the Oklahoma City metro area, Lake Hefner, was sitting at 17 feet below maximum capacity, the lowest in the lake's 66-year history. Decreasing surface water reservoir levels has increased groundwater pumping for municipal, industrial, and agricultural purposes across the state. This increase in groundwater demand has put a strain on groundwater aquifer levels and recharge. In 2011, the estimates of drought-related losses in the agricultural production sector in Oklahoma totaled $1.6 billion (Stotts, 2012). In January 2013, the United States Department of Agriculture designated 76 of 77 counties in Oklahoma as disaster areas due to drought and heat (USDA, 2013).

Water conservation legislation

The Oklahoma Water Resources Board (OWRB), the state's agency for allocating and protecting Oklahoma's water resources, updates the Oklahoma Comprehensive Water Plan (OCWP) every five years. The OCWP is a comprehensive resource for management, technical, and regulatory information regarding Oklahoma's water resources. The most recent update of the OCWP was in 2012, and prioritized eight recommendations to focus on concerning water issues in Oklahoma. The 2012 OCWP included a rigorous and bold water conservation strategy, known as the Water for 2060 Act (House Bill 3055). The Water for 2060 Act was passed by the Oklahoma Legislature in 2012 and establishes a "statewide goal of consuming no more fresh water in 2060 than consumed today" (OWRB, 2014). The OWRB partnered with the US Army Corps of Engineers and the Water for 2060 Advisory Council to establish and recommend various water conservation initiatives (reclaimed water use included) for communities across Oklahoma.

In 2010, the Oklahoma Municipal League (OML) stimulated a conversation about reclaimed water regulation in Oklahoma when a representative expressed an interest in using reclaimed water as an alternative water source. Representatives from the OML met with the ODEQ and members from other municipalities, engineering firms, and the general public to discuss the further development of reclaimed water regulations. On July 1, 2012, reclaimed water regulation focusing on non-potable uses was issued from the ODEQ. This regulation establishes four categories of reclaimed water for non-potable use (Categories 2 through 5). Each category indicates a different level of treatment and permitted use (ODEQ, 2012). Category 1 is reserved for potable reclaimed water use, which regulations have yet to be established (ODEQ, 2012). These categories reflect the end use of the reclaimed water, potential for human contact, and the technology required for treatment and public health safety. Each of the categories includes water quality requirements, testing frequencies, and treatments. In May 2014, the Oklahoma legislature passed Senate Bill 1187 to allow the ODEQ to design an efficient permitting process for reclaimed water projects. This legislation allows ODEQ to authorize permits for nonpoint source discharges into public and private waterways. These permits are issued on a case-by-case basis and will encourage the development of reclaimed water use projects in Oklahoma.

Research Objectives and Hypotheses

The overall purpose of my two research projects is to further explore the role of reclaimed water use in Oklahoma. The first portion of my research is an environmental profiling case study that assesses reclaimed water irrigation on soil chemical properties compared to three different water sources on golf courses in Oklahoma. The second portion of my research is an Internet survey of Oklahomans to evaluate the willingness to pay for reclaimed water use in Oklahoma.

Environmental Profiling Golf Course Case Study

The overall purpose of this research is to provide a scientific analysis about the environmental impact of using reclaimed water compared to other water sources for irrigation on golf courses in Oklahoma

The overall research objectives include:

1. Compare and examine the effects of irrigation water from four different sources on soil chemical properties.
2. Compare water quality of the four water sources.

Research Hypothesis:

The chemical properties of soil irrigated with reclaimed water will be different from the chemical properties of soil irrigated with the other three water sources.

Willingness to Pay for Reclaimed Water in Oklahoma Survey

The overall research purpose is to provide a scientific foundation for municipalities in Oklahoma interested in implementing reclaimed water systems and the public's involvement in these projects. The overall research objective is to investigate Oklahomans' hypothetical willingness to pay (WTP) for reclaimed water as municipal water supply as a hedge against drought driven shortages. The specific research objectives include:

1. To analyze how water quality data regarding reclaimed water and surface water standards affects WTP for reclaimed water use in Oklahoma.
2. To analyze how demographic characteristics and attitudes affect the WTP for reclaimed water.

Research Hypotheses:

Oklahomans with the following attributes will be more likely to choose to pay an extra fee per 1000 gallons of water for reclaimed water use in Oklahoma:

1. Education level of B.S. or higher (Dolnicar and Schafer, 2009)
2. Male (Tsagarakis et al., 2009)
3. Annual income of $80,000+ (Rock et al., 2012)
4. Own their home (Burfurd et al., 2011)
5. Support reclaimed water use policy
6. See provided surface water vs. reclaimed water quality data in survey

Environmental Implications of Reclaimed Water Irrigation on Soil Chemical Properties on Golf Courses in Oklahoma

Advances in technology and increased water quality regulations in many regions across the world have allowed treated municipal and industrial wastewater to become economically viable options for water supply augmentation compared to largely expensive and energy intensive water management measures, such as dams and reservoirs. Using reclaimed water for landscape irrigation has become a common practice, especially in semi-arid and arid regions. In 2010, total irrigation withdrawals in the United States accounted for 38% of total freshwater withdrawals (Maupin et al., 2014). Reclaimed water can be used for landscape irrigation purposes in place of freshwater resources, while also providing beneficial nutrients to plants.

Advantages and disadvantages of reclaimed water use for irrigation

Using reclaimed water for landscape irrigation can have many environmental and economic advantages. Reserving freshwater resources for potable uses, especially in periods of drought, is the most critical advantage of reclaimed water projects. Reclaimed water can serve as a reliable, safe, and continuous source of water. Environmental advantages include a decrease in wastewater discharge into sensitive ecosystems, decreased diversion of water from freshwater habitats, and decreased amount of pollutant load into water bodies (USEPA, 2013). Turfgrasses can typically consume large amounts of nitrogen (N) and other nutrients present in reclaimed water, and these grasses use this water continuously without interruption from cultivation (Lazarova and Bahri, 2005).

An economic advantage of using reclaimed water for landscape irrigation is the cost of fertilizer decreases as the nutrients in reclaimed water are absorbed and used by plants and turfgrass. Fertilizer costs have continued to increase over the years, a major concern for golf course management. In 2010, the United States price index for fertilizer was five times higher than it was in 1960 (Fan et al., 2014). If economically and financially feasible for a region, reclaimed water projects can provide additional revenue for water agencies, as well as decrease the amount of costs acquired from freshwater resource projects, such as pipelines.

Disadvantages to reclaimed water use should also be taken into consideration when implementing a reclaimed water project. The safety of public health is the most important concern when using reclaimed water for irrigation purposes. If not properly treated, or proper signage is not implemented, reclaimed water can pose a health threat to animals or humans.

Communities that lack reclaimed water regulation may be discouraged from implementing irrigation systems using reclaimed water. Public acceptance of reclaimed water use for irrigation is also considered a major deterrent for successful implementation. Costs of reclaimed water technologies and facilities can be expensive, and seasonal variations in use and demand of reclaimed water present a need for additional storage. Reclaimed water is of benefit when the costs to implement are less than securing a new supply. While reclaimed water can provide nutrient benefits to plants and turfgrasses, it can also negatively affect the soil through buildup of salts and organic matter. The use of reclaimed water for irrigation can be associated with "hidden costs" (Lockett et al., 2008). These "hidden costs" can involve deterioration in water quality and value of irrigation ponds or water attractions, degradation of equipment, and damage to ornamental plants. Benefits and constraints of reclaimed water projects vary by location and must both be effectively weighed and evaluated before implementation.

Examples of reclaimed water irrigation at golf courses

Reclaimed water use for irrigation purposes has rapidly developed in numerous regions across the globe over the last 20 years (Lazarova and Bahri, 2005). Golf courses use about 2,312,701 acre-feet of water annually, making reclaimed water an attractive option for irrigation purposes (Lyman, 2012). In the Mediterranean country of Tunisia, reclaimed water has been used for recreational purposes, specifically for golf course irrigation, since the early 1970s. In the United States, numerous states contain reclaimed regulations in their state water policy plans. States, such as Florida, Arizona, California, and Texas, all have multiple golf courses that use reclaimed water for irrigation. The majority of golf courses (roughly two dozen) in the city of Scottsdale, Arizona, have been using reclaimed water for irrigation since 1989 (City of Scottsdale, 2015).

In 1996, Gaillardia Country Club in Oklahoma City began receiving reclaimed water to irrigate their golf course. In conjunction with Veolia Water, the City of Oklahoma City constructed a 5-mile pipeline from the Deer Creek Wastewater Treatment Plant to the Gaillardia golf course to irrigate more than 600 acres of greens and landscape (Chavez, 2012). Recently, the Deer Creek facility upgraded their treatment procedures with ultraviolet technology, which further purifies the reclaimed water to a higher level. The City of Norman also supplies reclaimed water for irrigation to the Jimmie Austin OU Golf Course on The University of Oklahoma's campus. This golf course uses reclaimed water for 85% of irrigation needs on the course, while groundwater is used the remaining 15% of irrigation needs.

Previous research in reclaimed water irrigation on golf courses

The increasing water shortages in various areas across the world have prompted more golf courses to use reclaimed water for irrigation in place of potable water. Research has been conducted over the last three decades to study the long and short-term effects of reclaimed water on the chemical properties of soil and turfgrass. A study by Qian and Mecham in Colorado studied soil chemical properties at golf courses that irrigated with reclaimed water over a time increments of 4, 13, 19 and 33 years versus golf courses irrigated with surface water over the same amounts of time. The soils from these golf courses irrigated with reclaimed water exhibited soils with higher concentrations of sodium (Na), boron (B), and phosphorus (P) than courses irrigated with surface water (Qian and Mecham, 2005). In another study conducted in San Antonio over approximately two years, reclaimed water irrigation showed no adverse effects on the turfgrass species, 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy] and 'Jamur' zoysiagrass (*Zoysia japonica* Steud.), but showed an increase in electrical conductivity (EC) (Thomas et al., 2006). A study conducted in Tucson, Arizona over a 16-month period assessed the effects of reclaimed water on soil and leachate properties and found increases in various nutrient amounts accumulated in a short period of time (Hayes et al., 1990).

In the short time period, EC, nitrate (NO_3-N), P, potassium (K), and Na concentrations were elevated in the soil irrigated with reclaimed water compared to potable water irrigation (Hayes et al., 1990).

A study in the Las Vegas Valley monitored the soil and turfgrass parameters related to irrigation sources on nine golf courses, three using reclaimed water, three using potable water, and three transitioning from potable to reclaimed water for irrigation purposes (Lockett et al., 2008). The golf courses using reclaimed and potable water for irrigation were classified as long term users, while the transition courses were considered short term as they switched from potable to reclaimed water irrigation during the monitoring study. Of the three distinct categories (reclaimed, potable, and transition) the soil salinity was statistically higher on the reclaimed water course than the potable water and transition courses (Lockett et al., 2008). Although the soil salinity was statistically higher on the reclaimed water course, the plant (bermudagrass and ryegrass) responses on the reclaimed water courses were not statistically different than those on the potable water courses (Lockett et al., 2008). Recent greenhouse studies conducted over a one-year time frame indicated that nitrogen in reclaimed water sources could be beneficial to overall turfgrass growth and health if N concentrations are at least 5 mg/L (Fan et al., 2014). The theme across these research studies is that problems and opportunities can arise in using reclaimed water for golf course irrigation and that proper management can help mitigate the problems and enhance the opportunities.

Environmental effects of reclaimed water irrigation on turfgrass

As previously mentioned, reclaimed water can provide potentially beneficial nutrients to turfgrasses but can also provide some potentially harmful constituents. A “one size fits all” management strategy does not exist for golf courses using reclaimed water for irrigation, and management plans largely depend on treatment, water and soil chemistry, and climate. It is important to pair reclaimed water irrigation with a tolerable turfgrass, as in a species that can tolerate high salinity levels, or total concentration of soluble salts. Salinity levels of less than 3 deciSiemens per meter (dS/m) in soil water do not significantly influence the majority of turfgrasses (Asano et al., 2007). Warm-season grasses are known for their tolerance to drought and salt compared to cool-season grasses, but the tolerance can vary in each faction (Harivandi, 2007). Warm-season grasses, such as bermudagrasses, St. Augustine grass (*Stenotaphrum secundatum*), and seashore paspalum (*Paspalum vaginatum* Swartz), are all considered relatively tolerant of soil salinity (EC_e) levels of greater than 10 dS/m (Harivandi, 2004). Creeping bentgrass (*Agrostis stolonifera* L.) and annual bluegrass (*Poa annua*) has proven to be problematic to manage at an EC of water of approximately 1.5 to 2 dS/m (Duncan et al., 2009).

Environmental effects of reclaimed water on soil

In association with turfgrass selection, soil physical and chemical characteristics and drainage are both key components when considering a reclaimed water irrigation system. Soil characteristics, such as texture, mineral composition, and structure, can all affect salt accumulation from irrigation water. Soils with a high-water holding capacity contain small or fine particle sizes, such as silts and clays, and thus drain water at a slower pace than sandy soils that are made up of larger particles (Smith, 2008). Clay soils also have a lower infiltration rate compared to sandy soils due to their small pore spaces, which can cause runoff issues if too much water is applied at a rapid pace (Smith, 2008). It is important to consider the soil type used throughout the golf course when using reclaimed water for irrigation.

Total soluble salts

All reclaimed water sources will contain some level of soluble salts. Total soluble salts, or salinity, are the accumulation of salts in irrigation water, or soil water. Soluble salt ions that would be found in irrigation water include Na, Ca, K, Chloride (Cl), Bicarbonate (HCO_3), Carbonate (CO_3), Magnesium (Mg), Sulfate (SO_4). Salinity is typically reported as the EC of water, and as the concentration of salts increases, so does the water's ability to conduct electricity (Toor and Lusk, 2011). Electrical conductivity is measured as dS/m, or milli-mhos per centimeter (mmhos/cm). Electrical conductivity levels between 0.78 dS/m to 1.56 dS/m would be adequate for plants and soil to maintain productivity with few to no concerns (Toor and Lusk, 2011). Total soluble salt issues can occur most rapidly on sandy soils due to low cation exchange capacity (CEC) and the lack of ability to retain soil moisture in fine-textured soils (Carrow and Duncan, 2012). Salinity issues can sometimes be difficult to identify in turfgrasses but can cause detrimental issues. Accumulation of total soluble salts in the root zone of turfgrasses can obstruct water uptake, leading to water stress. Physiological drought stress can occur in some cases, where turfgrass can display drought stress symptoms even if soil appears to contain moisture (Duncan et al., 2009). Another symptom of a salinity problem is the discoloring of turfgrass (yellow, brown, or purple), with no response to nutrient applications. A white crust can collect on the soil surface due to salt buildup after water has already been taken up by turfgrass, or evaporated (Tusk and Loor, 2011). All of these issues can lead to a saline soil classification.

Sodicity

Sodicity, or the buildup of Na in the soil, is another important concern when using reclaimed water for irrigation. Sodium is commonly present in regions with hard water, and water softeners are used in water treatment facilities to reduce calcium and magnesium. These sodium-based chemicals and softeners remove Ca and replace it with Na. Irrigation water with moderate to elevated Na content would be considered >100 milligrams per Liter (mg L^{-1}) or 4.35 milli equivalents of solute per liter (meq L^{-1}) and is a major indicator of sodic or saline-sodic conditions in soil (Carrow and Duncan, 2012). Excessive Na accumulation in the soil can break down the soil structure, causing dispersion of soil particles and soil aggregates to separate (Toor and Lusk, 2011). The breakdown of the soil structure reduces infiltration rates and consequently water uptake. The impact of Na accumulation and infiltration issues is often referred to as the sodium permeability hazard. The sodium permeability hazard is the greatest when the sodium concentration is high in association with low Mg and Ca levels, and also when bicarbonates HCO_3 and CO_3 are at elevated levels (Toor and Lusk, 2011). Magnesium and Ca can displace Na in the soil due to their strong electrical attraction, while HCO_3 and CO_3 can combine with Mg and Ca, allowing Na to accumulate in the soil. Salt-effected soils can be classified by the exchangeable sodium percentage (ESP) or the sodium adsorption ratio (SAR). The ESP refers to the Na percentage that occupies the soil's CEC sites, expressed in the units of centimoles per kilogram (cmol/kg) or meq/100 grams (meq/100 g) (Carrow and Duncan, 2012). The SAR measures concentration of Na, Ca, and Mg cations in a saturated paste extract solution in the units of millimol of charge per liter ($mmol_c\ L^{-1}$) or meq L^{-1}. As the Na accumulation increases, the SAR increases. According to the United States Salinity Laboratory classification, if the ESP is >15% and/or the SAR is >12, then a soil would be considered sodic (Carrow and Duncan, 2012).

Bicarbonate and carbonates

Bicarbonates and carbonates can be commonly detected in reclaimed water sources. The specific levels of HCO_3 and CO_3 that are injurious to turfgrass is not definitive, rather the imbalance of these two ions with Na, Ca, and Mg is of more concern. When the combined levels of HCO_3 and CO_3 surpass the combined levels of Ca and Mg (meq L^{-1}), the Ca and Mg will precipitate out of the soil as insoluble lime. The first major concern of insoluble lime development is that if Na is at considerably high levels in the soil (>150 mg L^{-1} or 6.5 meq L^{-1}), the Ca and Mg precipitation frees up the Na^+ to take over the CEC sites and create a potentially sodic soil (Duncan et al., 2009). A general cause for concern would be when HCO_3 levels are >120 mg L^{-1} (1.97 meq L^{-1}) or when CO_3 levels are >15 mg L^{-1} (0.50 meq L^{-1}) and in combination with moderately high Na levels (Duncan et al., 2009). The second major concern related to excessive HCO_3 and CO_3 is that the precipitated lime (calcite) in sandy soils can seal off the macropores, therefore reducing water infiltration rates. This is typically a problem in arid climates with sandy soil profiles with high levels of HCO_3, CO_3, Ca, and Mg (Duncan et al., 2009). The residual sodium carbonate (RSC) value can be used to evaluate this situation and is the combination of Ca and Mg subtracted from the combination HCO_3 and CO_3, expressed in meq L^{-1}.

Chlorides, chlorine, and boron

High chloride (Cl) levels contribute to total soluble salt concentration in irrigation water but are not specifically toxic to turfgrass on golf courses. If Cl levels exceed 500 mg L^{-1} root tissues of turfgrass could be damaged. These excessive Cl levels can also restrict water and nutrient uptake in turfgrasses. Excessive levels of Cl are usually distributed to the growing leaves and regular mowing helps to limit this problem. Reclaimed water may contain high levels of residual chlorine (Cl_2), usually from chlorine disinfection chemicals. Chlorine toxicity typically occurs when sprayed directly on foliage, and can be a concern at levels over 5 mg L^{-1} (Harivandi, 2004). Residual free chlorine is relatively unstable in water, and will disperse quickly if stored (Harivandi, 2004). Boron is only necessary in small amount for essential plant growth. Boron can be toxic to ornamental plants at low concentrations in irrigation water (1 to 2 mg L^{-1}), but turfgrasses can typically tolerate higher levels of B on golf courses. Turfgrasses that can tolerate B levels as high as 10 mg L^{-1} are typically more sensitive to B than to Na or Cl toxicities (Harivandi, 2004).

Macro and micronutrients

Reclaimed water can contain a number of different macro and micronutrients that can have a negative impact on turfgrasses if present in excess. At certain quantities, some of these nutrients can prove to be advantageous as fertilizer to turfgrass. Macronutrients that may be important to consider include N, P, K, Ca, Mg, and Sulfur (S). Micronutrients that may be important to consider include Iron (Fe), Manganese (Mn), Zinc (Zn), Molybdenum (Mo), Nickel, (Ni), Ca, and B. The levels of these different elements in reclaimed water will vary in reclaimed water due to the previous use of the water and the treatment procedures at the reclamation facility.

The amount of N in the reclaimed water source will directly influence the nutritional needs of the turfgrass on golf courses, thus requiring adjustments to seasonal and annual N fertilization. High levels of N fertilization can lead to excessive growth on golf course greens, reduced hardiness, thatch accumulation, and heightened susceptibility to disease (Duncan et al., 2009). Excessive growth concerns can occur when annual N fertilization surpasses 4 to 6 lb. N/1000 ft^2 for annual bluegrass or creeping bentgrass, or 8 to 12 lb. N/1000 ft^2 for bermudagrass for most golf course locations across the United States (Duncan et al., 2009). Phosphorus can also be found in reclaimed water and can be beneficial to turfgrass if managed properly. Turfgrasses can endure P levels up to 2 lb. P_2O_5/1000 ft^2 annually from irrigation sources. Elevated P levels can cause eutrophication in surface waters, and therefore buildup of P in the soil should be monitored to avoid runoff events.

Potassium is beneficial to turfgrasses that encounter high traffic, such as golf courses. Excess K can contribute to general salinity issues, but is typically balanced by Ca and Mg if present in reclaimed water. Turfgrasses usually require supplemental K fertilization as K is immensely mobile and soluble in soil and can easily be leached out (Duncan et al., 2009). Calcium can be found in reclaimed water sources and should be monitored by turfgrass managers. Reclaimed water sources containing 60 mg L^{-1} of Ca would add 3.75 lb. of Ca/1000 ft^2/12 inches of irrigation water (Duncan et al., 2009). Turfgrass needs for Ca can generally be met through irrigation water sources. Magnesium usually exists in reclaimed water at lower concentrations than Ca. If Mg exists at higher levels in reclaimed water, this can decrease Ca on CEC sites; supplemental Ca may need to be added. It is more often the case that Mg is present in low concentrations in irrigation sources or is available at low levels due to excess Ca applications. A healthy balance of Ma and Ca in the soil is crucial to avoid long-term negative consequences for turfgrasses.

Sulfate is often present at comparatively high levels concentrations in reclaimed water. The major concern with elevated levels of SO_4 on turfgrass is that is can be converted to a reduced form of S when anaerobic conditions develop (Duncan et al., 2009). A reduced form of S can cause problems when combined with Fe or Mn, potentially contributing to black layer formation that can seal off soil pores. Annual nutritional needs of S for turfgrass are 2 to 3 lb. S/1000 ft^2 (Duncan et al., 2009). This amount can often be satisfied with the amount of SO_4 in irrigation water or with addition of sulfate based fertilizers. Irrigation water sources that contain SO_4^{2-} at 200 mg L^{-1} would provide 4.2 lb. of S/1000 ft^2 per acre-foot of reclaimed water (Duncan et al., 2009).

Iron levels in most reclaimed water sources are low, and a foliar application can be necessary. On the rare occasion when Fe levels are high, it can lead to Mn, Zn, and Cu deficiencies. High concentrations of Fe can also combine with sulfides to create anaerobic iron sludge or bacterial deposits, which can damage irrigation pipes and equipment (Duncan et al., 2009). Iron concentrations of 5 mg L^{-1} in 12 inches of irrigation water would contribute 0.31 lb. Fe/1000 ft^2 (Duncan et al., 2009).

Manganese found at levels of >0.20 mg L^{-1} in reclaimed water can be harmful to plant roots. This condition can be especially injurious in acidic soil with inadequate drainage. Reclaimed water typically contains a low amount of Mn, and supplemental Mn would only be needed for excessive salinity issues. Turfgrasses can endure comparatively high concentrations of Cu, Zn, and Ni with regular mowing since the toxicities from these ions occur in the leaf (Duncan et al., 2009). In the case that Cu and Zn are extremely high, Fe and Mn deficiencies can be created, affecting uptake in turfgrasses. Reclaimed water generally contains low levels of Mo, and toxicity is highly unlikely. Deficiency of Mo can sometimes occur in soil with low pH sites.

Fecal coliform and E.coli

Although not considered a chemical component in reclaimed water, total coliform bacteria can be present and easily identified and usually an indicator of a pathogenic presence. Total coliform bacteria are found in the intestinal tracts and waste of humans and animals. *Escherichia coli (E. coli)* is a species of the fecal coliform group and is considered generally harmless. Some strains of *E. coli* (O157:H7) exist that can cause gastric, respiratory and other illnesses if present in large concentrations in water. Fecal coliform bacteria and *E.coli* are typically removed through tertiary and disinfection treatment processes, but frequent monitoring of these bacteria are necessary when using reclaimed water for irrigation.

Management aspects of reclaimed water irrigation

The quality of the reclaimed water used for irrigation should be adjusted for the specifications of each golf course, or modified onsite (Asano et al., 2007). A management plan is essential to golf courses using reclaimed water for irrigation to maintain healthy soil, turf, and water. It is critical that water and soil sampling are a part of the management strategy on a regular basis. Many reclaimed water regulations require monitoring for certain constituents on a daily, weekly, or monthly basis to obtain permits for use. Saline reclaimed water will require continuous monitoring and testing of soil, water and tissue to maintain a balance in the nutritional needs and salinity aspects (Duncan et al., 2009). Monitoring of reclaimed water irrigation sources also serves as a proactive measure for groundwater protection.

Drainage and leaching systems

Implementing sufficient and effective drainage and leaching systems is another important management procedure when using reclaimed water for irrigation on golf courses. Leaching is the application of extra water in addition to normal irrigation needs to push nutrients and salts below the root zone. The overall goal of leaching is to provide a continuous downward movement of water and dissolved salts to prevent damage to the rootzone (Gross, 2008). Leaching strategies will vary on the turf and nature of the soil characteristics, and soil salinity should be monitored before and after leaching events to ensure the process was effective. Depending on location, leaching on greens, fairways, and roughs generally accounts for 10-20% additional water over normal irrigation requirements (Gross, 2008). Practical surface and subsurface drainage systems help to decrease puddling, which can lead to anaerobic circumstances, algae, or black layer formation (Duncan et al., 2009). Subsurface drainage systems are pivotal infrastructure components and allow for proper water infiltration and percolation of reclaimed water to the drains.

Cultivation programs, including coring and aeration, may be necessary where poor drainage is present or a heavy thatch accumulation has occurred in the turfgrass to assist salts in moving downward in the soil profile. The overall goal of cultivation is to increase water infiltration drainage, thus promoting further removal of dissolved salts from the rootzone (Gross, 2008). Cultivation can become difficult as the clay and silt content increase in the soil (Duncan et al., 2009). Aeration should occur in early spring and summer to prepare turf for high stress periods and increased salt build-up. Deep aeration has become a common practice on fairways at golf courses using reclaimed water for irrigation. This cultivation method effectively decreases soil compaction by creating channels for amendment applications to maintain soil structure (Gross, 2008). Other cultivation practices, such as coring and deep tine aeration, are performed in the spring and fall to maintain healthy soils and turfgrass. Topdressing is another common cultivation practice used on fairways to improve the quality of turf and enhance the removal of extra water. Topdressing is not a necessary practice, but assists in leaching salts.

Fertilizer

Fertilizer, or soil amendment applications, should be taken in to consideration when using reclaimed water for golf course irrigation. These applications should be adjusted based on the nutrient levels in the reclaimed water source, as expressed by the water and soil samples. As previously mentioned, reclaimed water can contain high amounts of certain nutrients, such as N, P, and K. It is important to factor these nutrient amounts into a fertilization program. Particular nutrients, such as P, can also be decreased from excessive leaching, and supplemental nutrient applications may be necessary following leaching events (Gross, 2008). If a considerable amount of Na is found in soil, it is advised to add a calcium-based amendment, such as gypsum, to the soil. Application of gypsum, along with cultivation and leaching programs, helps to maintain soil structure. Another popular fertilizer approach on golf courses using reclaimed water is to regularly apply a soil wetting agent. Soil wetting agents assist in managing water infiltration and drainage of dissolved salts and sodium from the rootzone (Gross, 2008). Properly calculated fertilizer programs are critical to maintaining a healthy golf course and to avoid nutrient runoff or seepage into surface, or ground waters.

Public Acceptance and Willingness to Pay for Reclaimed Water: A Case Study in Oklahoma

Public acceptance is a big barrier to successful implementation of reclaimed water projects. The negative public health perception that is associated with reclaimed water use is presumably the largest contribution to the public opposition of reclaimed water projects. The lack of public education regarding reclaimed water processes and technology, in combination with the absence of public involvement in reclaimed water project development, can also lead to public opposition. Surveying the general public about reclaimed water use and water conservation projects can significantly benefit municipal entities considering reclaimed water projects by providing direct insight in to public knowledge and perceptions on these topics. Incorporating the public in reclaimed water projects can lead to positive public acceptance and contribute to the success and longevity of these projects.

Public attitudes towards water conservation

Water scarcity, stress, and quality issues are considered to be major environmental threats in the 21st century (Corral-Verdugo et al., 2003). In order to combat these challenges, a combination of technological and socio-cultural systems needs to be established to encourage water conservation in communities. People participate in water conservation activities to protect water resources, comply with conservation programs, or to save money on their water bill (Corral-Verdugo et al., 2003). A compelling notion behind encouraging individuals to conserve water is to provide them with the skills and knowledge of conservation practices. If people know how to conserve water, they may be more willing to actual participate in water conservation activities.

Public attitudes towards reclaimed water

Public attitudes and beliefs toward reclaimed water use can vary drastically depending on numerous factors, such as location, climate, and education. A significant amount of research has been conducted regarding the correlation between public attitudes, perceptions, and public acceptance of reclaimed water since the early 1970s (Bruvold and Ward, 1970; Bruvold, 1972; Sims and Baumann, 1974; Kasperson et al., 1974). This research ignited numerous surveys and case studies in different regions across the world on what influences the public's acceptance and perceptions of reclaimed water projects. The overarching results from these studies are that public acceptance of reclaimed water is greater when the purpose of the reclaimed water is low human contact usage (i.e. flushing toilet), rather than personal human use (Bruvold, 1980; Marks, 2006; Dolnicar and Schafer, 2009; Dolnicar and Hurlimann, 2010). Public support for reclaimed water use has been shown to emanate from the desire to conserve water and protect environmental resources (Hartley, 2006).

Several other factors have been found to influence and contribute to the public's perception and acceptance of reclaimed water use. These influential factors include perceptions of risk, water quality, financial implications, public involvement in the development process, the "not in my backyard" movement, trust issues with water agencies and government, and the safety of public health (Rock et al., 2012; Menegaki et al., 2007). Trust in public entities has been in decline in the United States, including water agencies (Hartley, 2006). The public generally trusts university-accredited scientists, but tends to trust their own instincts and perceptions of water quality more than experts. Socio-demographic components also affect public acceptance of reclaimed water use. Male (Lohman and Milliken, 1985; Tsagarakis et al., 2007, Dolnicar and Schafer, 2009), highly-educated (Bruvold, 1972; Hurlimann, 2007; Dolnicar and Schafer, 2009), large annual income (Rock et al., 2012), and live in an urban area (Rock et al., 2012) are all factors that contribute to a higher acceptance and a positive attitude related to reclaimed water use.

Public health concern associated with reclaimed water

The potential threat of disease and harmful bacteria being transmitted through reclaimed water has divided the public on acceptance. To date, there have yet to be any confirmed cases of human illness directly related to reclaimed water systems (Rock et al., 2012). With treatment technology and treatment standards constantly improving, the possible spread of waterborne disease and bacteria will likely decrease. Advanced technology can deliver reclaimed water that meets and exceeds national drinking water standards (Ormerod and Scott, 2012). Health risk concerns related to reclaimed water use are largely associated with the origins of the water as waste or sewage. The majority of the public are unaware that in many parts of the United States, drinking water contains a percentage of treated wastewater that was discharged from another municipality's treatment plant and blended into surface water systems (Asano et al., 2007). This alludes to the idea that the general public has a strong cultural connection to water purity and lack the education of the urban hydrologic cycle, directly relating to a negative perception of reclaimed water. The marketing and advertising aspects of reclaimed water have played a large part in the public's perception, further emphasizing the connection between reclaimed water and sewage. Negative ad campaigns promoting the "yuck" or "ick" factor associated with reclaimed water projects have been generated by community groups to deter citizens and municipalities from supporting these projects. The terms "Toilet to Tap" and "Sewage Beverage" began circulating in mass media in the 1990s, during a time when a number of indirect potable reuse projects were being proposed (Hartley, 2006). This negative media attention further encouraged a strong public opposition to these reclaimed water projects.

Importance of public involvement in reclaimed water projects

When considering the implementation of a reclaimed water project in a community, it is critical to involve the public in the development of these projects from the beginning. There is no guarantee of success with the involvement of the public, but public outreach and education will only further establish public support and trust for water agencies and future projects. Communication, educational information, and open dialogue between the general public and water agencies could be key factors in encouraging positive public acceptance of reclaimed water projects (Dolnicar and Hurlimann, 2010). Since the public are the eventual bearers of the financial costs and exposure of water reclaimed water projects, public education about the benefits of these projects can help foster support. Studies in California have shown that providing public information about reclaimed water has increased public support but also further enhanced the extreme divided opinions (Hartley, 2006). Despite the opposition, research has shown that the general public has indicated an interest in participating in reclaimed water project development with water agencies (Hartley, 2006).

Public outreach and participation in reclaimed water projects

Public engagement allows for a two-way communication between the public and the water agencies, where both involved can learn about the different aspects and concerns related to reclaimed water projects (Asano et al., 2007). Public outreach involves distributing, or collecting, information and educating the public about reclaimed water projects. Examples of public outreach include surveys, workshops, and public information campaigns. Public participation is a more involved approach, employing task forces and community stakeholder committees to advise on reclaimed water projects (Asano et al., 2007). Public trust and transparency is an important

Contingent valuation method and willingness to pay

The contingent valuation method (CVM) estimates the economic value of an ecosystem or environmental service that lack value in the market. The CVM directly asks what people would be willing to pay, and how much, for the use of a nonmarket environmental service, or resource. The CVM approach has been used since the 1970s but gained widespread attention when used in appraising the environmental impact of the Exxon tanker oil spill in 1989 (Chieuh et al., 2011). The National Oceanic and Atmospheric Administration (NOAA) has since published guidelines for managing the use of the CVM in surveys. The CVM has been beneficial in valuing the direst use and indirect use values of reclaimed water, as well as the valuation of use and non-use values (Bakopoulou et al., 2009). Different formats can be used in a contingent valuation study, including an open-ended format, or single bound format. The open ended format asks survey participants to state the maximum amount of money they would be willing to pay, while the single bound format ask respondents if they would be willing to pay a specific price, referred to as a bid (Genius et al., 2008). The single bound format more accurately imitates the market situations in which consumers pay a specific price for a commodity and is widely used (Genius et al., 2008). Numerous studies have been conducted using the CVM to investigate the public acceptance and willingness to pay for reclaimed water use (Chiueh et al., 2011; Bakopoulou et al., 2009; Tziakis et al., 2009; Genius et al., 2008). These studies have provided critical data regarding the acceptability of these reclaimed water projects but also estimate the value of these projects to the community.

Case studies: Public acceptance and WTP for reclaimed water

Failed reclaimed water projects in communities all across the world have made it apparent that a lack of public acceptance can prevent reclaimed water projects implementation. The following paragraphs take a look at cases in the United States and Australia where public opposition and involvement played a large role in the successes and failures of reclaimed water projects.

San Diego, California

The City of San Diego, California originally imported 90% of its water supply from Northern California or the Colorado River during the 1990's. In 1993, San Diego constructed and tested a 1 mgd (million gallons per day) advanced treatment plant, with plans to integrate potable water reuse into their municipal water system. Extensive feasibility studies were conducted and combined with adequate monetary investments and unblemished science the treatment facility appeared a successful endeavor. The project was fully proposed in 1993, and if approved, would be on schedule to run by 2004 (DeSena, 1999). The media and local politicians were able to employ a negative ad campaign in reference to public health hazards and the famous "Toilet to Tap" slogan to generate mass opposition against the potable water reuse facility. The City of San Diego had failed to implement an effective public education campaign to explain the safety protocols and overall benefits of the reclaimed water project. The general public lacked the understanding of the science and treatment process behind reclaimed water and therefore latched on to the negative ad campaigns as the only source of public outreach and education. The project was finally eradicated in 1999. In 2004, another reclaimed water project was started, and a reclaimed water demonstration project was completed from 2009-2013. Pure Water San Diego is the City's program to equip the city with safe and reliable drinking water for the next 20 years (2035), part of which includes reclaimed water (City of San Diego, 2015). The Pure Water San Diego campaign has an extensive public education and involvement program, which includes tours of the Advanced Water Purification Facility, social media, community events and presentations, and testimonials.

Tampa, Florida

In 1984, the City of Tampa, Florida began developing the Tampa Water Resource Recovery Project (DeSena, 1999). This project planned to include mixing reclaimed water with conventional wastewater from a nearby wastewater treatment plant. After further treatment, this blended water would augment the drinking water supply for the Tampa Bay area. Much like San Diego, the pilot plant was heavily tested, reviewed, and applauded for the sound applied technology and science. The system was not enough to implement the project after the negative public backlash. Concerns about the public health hazards were the central focus of opposition from politicians, which became the general public consensus after the city of Tampa failed to include a public education element. The City of Tampa decided to invest in a desalination facility to treat seawater, instead of going forward with the reclaimed water plant. The City of Tampa Bay has plans to meet water demand needs from 2015-2035 by a combination of water projects, including reclaimed water use. The Southwest Florida Water Management District now has a comprehensive water education program that includes museum exhibits, community outreach events, and resource materials about water conservation for local communities, schools, and business (SWFD, 2015).

Toowoomba, Queensland, Australia

Another example of strong public opposition to reclaimed water systems occurred in Toowoomba, Queensland, Australia. Facing intensifying water shortages, the Toowoomba City Council proposed a referendum, called the Water Futures Initiative, which included augmenting the city's drinking water supplies through indirect potable reuse (Hurlimann and Dolnicar, 2010). Residents were concerned for the city's image, fearing this initiative would lead to a lack of attraction for industry and tourism. Residents also expressed concern over health risks and were unsure they could trust the science. A local public interest group called 'Citizens Against Drinking Sewage' (CADS) was able to effectively publicize the negative aspect of the reclaimed water project in Toowoomba, far exceeding the City Council's positive campaign efforts. Within six months of launching the Water Futures Initiative (August 2005-February 2006), the CADS group had effectively gathered 10,000 signatures on a petition against the reclaimed water portion of the proposal. After a referendum, the City of Toowoomba began a 10-week public information campaign in March 2006, distributing booklets about the water cycle, water supplies, and water resource alternatives. The CADS group was continuously active in encouraging citizens to vote against the initiative. In July 2006, the Water Futures Initiative was voted against implementation by 62% of Toowoomba residents (Dolnicar and Hurlimann, 2010). In January 2007, the Premier of Queensland, who is appointed by the Governor of Queensland, announced plans to not allow the public to vote on the installation of a reclaimed water project for the city of Brisbane. A pipeline was constructed to supply reclaimed water to Toowoomba from the Wivoenhoe Dam, Brisbane's main dam, in order to address the dire water situation.

Conclusion

The present and future challenges of water scarcity and stress, combined with drought conditions, will become increasingly relevant to every community across the world. Entering the fifth year of drought, Oklahoma will continue to face water resource issues. Considering reclaimed water as an additional water resource is an important topic that needs to be discussed in Oklahoma and in other regions facing water shortages. Using reclaimed water for municipal irrigation purposes is a sensible approach to conserving potable water. In order to successfully implement reclaimed water systems, engaging with the public through education and outreach is critical. The purpose of this research is to provide applicable data for municipalities in Oklahoma concerning the potential use of reclaimed water.

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CHAPTER II

ENVIRONMENTAL IMPLICATIONS OF RECLAIMED WATER IRRIGATION ON SOIL CHEMICAL PROPERTIES ON GOLF COURSES IN OKLAHOMA

Introduction

Drought conditions and increased population growth have put a strain on freshwater supplies in much of the middle to western portions of the United States. Municipalities, agriculture, industry, and recreation are competing for depleting water supplies and are being forced to reconsider how they use water. The competing demand for limited potable water supplies has encouraged many golf courses in these drought-stricken regions to utilize reclaimed water, or recycled wastewater, for irrigation purposes. Reclaimed water can serve as a safe and reliable alternative water source for non-potable uses, such as irrigation (USEPA, 2013).

Reclaimed water typically contains different levels of elements, such as nitrogen (N) and phosphorus (P), which can be beneficial to turfgrasses. Using the beneficial elements like N and P that already exist in reclaimed water can reduce the amount of fertilizers that golf courses use annually on their greens and fairways. In addition to these beneficial nutrients, reclaimed water can also contain high levels of total soluble salts, sodium (Na), and chloride, which can be damaging to plant and soil health. When using reclaimed water for irrigation, it is important to routinely monitor soil and water quality to properly manage the beneficial and harmful nutrients and elements.

Many of the studies that have been conducted on the use of reclaimed water for irrigation purposes have addressed use on golf courses in the southwest and arid regions of the United States (Hayes et al., 1990; Mancino and Pepper, 1992; Qian and Mecham, 2005; Lockett et al., 2008). Previous research has found that soil irrigated with reclaimed water contained elevated levels of soil electrical conductivity (EC), Na, macronutrients (N, P, K, Ca, P, Mg, and S), and micronutrients (Cl, Fe, Zn, B, and Mn) (Hayes et al., 1990; Mancino and Pepper, 1992; Qian and Mecham, 2005; Thomas et al., 2006; Lockett et al., 2008). Studies have also shown that proper irrigation management and soil and water monitoring can help balance out the excessive salts and nutrients. There is limited information regarding the effects of reclaimed water irrigation on soil chemical properties on golf courses in Oklahoma.

Currently in Oklahoma, reclaimed water is not used for golf course irrigation on a large scale. As drought conditions are frequent in Oklahoma, the use of reclaimed water for golf course irrigation is gaining interest from superintendents and municipalities. In this study, we examine the soil chemical properties of one golf course irrigated with reclaimed water in comparison to four other golf courses irrigated with different water sources (groundwater, untreated surface water, treated municipal water, and groundwater + reclaimed water mix).

Materials and Methods

Study sites

This case study was conducted at five golf courses located in the Oklahoma City Metropolitan in central Oklahoma. Four of the five golf courses (Lincoln Park, Gaillardia, Quail Creek, and Lake Hefner) are located within Oklahoma City limits, and one golf course (Jimmie Austin OU) is located 25 miles south in Norman, Oklahoma. Each of the five golf courses uses a different water source to supply irrigation to their courses, including reclaimed water, treated municipal water, groundwater, and untreated surface water. The main soil series and texture classifications for each of the study sites was acquired through the assistance of the United States Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS) Web Soil Survey located in Table 1. The average annual precipitation for the central Oklahoma region is approximately 36 inches (Oklahoma Climatological Survey, 2012).

Gaillardia Country Club is located at 5300 Gaillardia Boulevard, Oklahoma City, OK 73142. Gaillardia Golf Course is a private, 18-hole golf course that covers over 250 acres of land and opened in July, 1998. The golf course greens feature A4 creeping bentgrass (*Agrostis stolonifera* L.), and the fairways and roughs feature T-419 and U3 common bermudagrass (*Cynodon dactylon*) respectively. The City of Oklahoma City was unable to provide potable water for this course, prompting the country club to drill water wells to supply the course with irrigation water. The City of Oklahoma City and Veolia Water constructed a 5-mile pipeline to provide treated wastewater to irrigate the 600-acre property. In 1996, Gaillardia Country Club became the first customer to utilize reclaimed water from Deer Creek wastewater treatment facility (WWTF). The changing regulatory standards required Oklahoma City to update the WWTF to include ultraviolet (UV) treatment. According to the USDA-NRCS Web Soil Survey, Gaillardia contains various soil series with the majority being Ashport silt loam and Lawrie silt loam. The cultural management report is located in Appendix A.

Lake Hefner Golf Club is located at 4491 South Lake Hefner Drive, Oklahoma City, OK 73116. This course consists of two 18-hole courses, located on the North and South sides of the property and covering approximately 350 acres of land. The golf course greens feature Pennlinks creeping bentgrass (*Agrostis stolonifera* L.), and the fairways and roughs feature Variety Not Specified (VNS) common bermudagrass (*Cynodon dactylon).* The public course partially wraps around the southern edge of Lake Hefner. Lake Hefner Golf Club receives untreated water from Lake Hefner to irrigate both golf courses. The water is pumped via irrigation pump station and distributed through an above ground, automatic sprinkler system. When lake levels are extremely low, the course irrigation is supplemented with treated municipal water from the Oklahoma City Water Utilities Department. The majority soil series from the Lake Hefner course is Renthin-urban land complex with a silt loam soil texture. The cultural management report is located in Appendix A.

Lincoln Park Golf Course is located at 4001 North East Grand Boulevard Oklahoma City, OK 73111. This public golf course includes two 18-hole courses, located on the East and West sides of the property. The golf course greens feature 'Penncross' and 'L93' creeping bentgrass (*Agrostis stolonifera* L.), and the fairways and roughs feature VNS common bermudagrass (*Cynodon dactylon).* The Lincoln Park Golf Course is Oklahoma City's oldest public golf course, with the West course opening in 1921. This course is irrigated with treated municipal water from the Oklahoma City Water Utilities Department through an automatic and manual above ground sprinkler system. Lincoln Park contains Stephenville-Darsil-Newalla complex, which is a sandy loam soil. The cultural management report was not provided.

Quail Creek Golf Course and Country Club is located at 3501 Quail Creek Road, Oklahoma City, OK 73120. Quail Creek is a private, 18-hole course constructed in 1961 and uses groundwater sources for irrigation. The greens feature SR 1020 creeping bentgrass (*Agrostis stolonifera* L.) and the fairways and roughs feature VNS common bermudagrass (*Cynodon dactylon).* A groundwater well (OWRB ID: 32397) was completed in 1995 over the major bedrock aquifer, Garber-Wellington, of the Central Oklahoma aquifer system. This well encompasses a total depth (TD) of 500 feet (ft), with the first water zone of 162 ft. The estimated yield is 408 gallons per minute (gpm). Quail Creek has a majority soil series of Grainola-Urban land-Ironmound complex with a silty clay loam soil. The cultural management report is located in Appendix A.

Jimmie Austin OU Golf Course is located at 1 Par Drive, Norman, OK 73019. Jimmie Austin OU is an 18-hole, public golf course covering approximately 135 acres on the campus of the University of Oklahoma. The golf course greens feature a combination of A1/A4, G2, 007 creeping bentgrass (*Agrostis stolonifera* L.) and Champion Ultra-Dwarf bermudgrass (*Cynodon dactylon).* The fairways feature a combination of Astro, Midlawn, and U3 bermudagrasses, and the roughs feature U3 bermudagrass (*Cynodon dactylon).* This course is irrigated through an above ground automatic sprinkler system with 85% reclaimed water from the City of Norman Water Utilities Department and 15% groundwater from the Garber-Wellington aquifer, part of the Central Oklahoma aquifer system. This course has been receiving reclaimed water from the City of Norman for irrigation purposes since 1995. Teller-Urban land complex is the majority soil series with a sandy loam soil texture. The cultural management report it located in Appendix A.

Soil sampling and testing procedures

A total of 90 soil samples were collected to a depth of approximately 6 inches from the greens, fairways, and non-irrigated roughs to test soil chemical properties during September 2014. At each course six samples were taken from each of the greens, fairways, and adjacent non-irrigated roughs on holes 3, 6, 9, 12, 15, and 18. At each of the designated holes, 15-20 random samples were taken from the green, fairway, and adjacent non-irrigated rough with a soil probe. The samples were collected in a bucket, mixed, and approximately two cups were sent to the Oklahoma State University Soil, Water, and Forage Analytical Laboratory (SWFAL) in Stillwater, OK. The samples went through a soil fertility test, including the following parameters:

pH, Soil Test Phosphorus (STP), Soil Test Potassium (STK), Surface Nitrate (NO_3), Surface Sulfur (S), Calcium (Ca), Magnesium (Mg), Iron (Fe), Zinc (Zn), Boron (B), and soil organic matter content (OM%). The soil samples also received a salinity management test (1:1 extraction), including the following parameters: Electrical Conductivity (EC), Sodium (Na), Calcium (Ca), Magnesium (Mg), Potassium (K), Boron (B), Total Soluble Salts (TSS), Sodium Adsorption Ratio (SAR), and Exchangeable Sodium Percentage (ESP). Soil fertility test samples are initially dried at 65°C for 6, 10, and 12 hours. These samples are then ground to pass through a 2mm screen and submitted for chemical analyses. Salinity management soil samples are dried overnight at 65°C, then ground to pass through a 2mm gap between two ceramic discs. A 1:1 soil:water mixture is created and equilibrated for four hours then the solution is filtered for analysis. The SWFAL lab provided brief information about the soil testing parameters and testing procedures (Table 2).

Water sampling and testing procedures

A total of 36 four-ounce irrigation water samples were collected at the golf courses for the water quality and fecal coliform and *E.coli* tests. These samples were collected at the same time at each golf course on separate days during September 2014 and taken directly from the irrigation source at each of the golf courses: Lake Hefner at Lake Hefner Golf Course; the irrigation holding pond at Gaillardia Golf Course; the water hose at Lincoln Park Golf Course; the irrigation holding pond at Quail Creek Golf Course; and the pump house and above ground sprinkler head at Jimmie Austin OU Golf Course. Each of the four ounce plastic bottles used to take the water samples was thoroughly rinsed with each irrigation water source prior to collecting the representative samples. The samples were stored overnight at 40ºF in a refrigerator. Water samples were submitted to the SWFAL in Stillwater, OK. Once submitted to the SWFAL, the water samples were filtered through Fisher P-4 paper filters and analyzed for the basic irrigation water quality and salinity management tests. Parameters for the basic irrigation water quality and salinity management tests included pH, CO_3, HCO_3, EC, Na, Ca, Mg, K, B, NO_3-N, Cl, SO_4, Zn, Cu, Mn, Fe, NH_4-N, Hardness, Alkalinity, TSS, PAR, SAR, EPP, and ESP. The specific details about the SWFAL water testing procedures are located in Table 3.

E.coli and fecal coliform testing procedures

The *E.coli* and fecal coliform tests were conducted in the Biosystems and Agricultural Engineering Laboratory in Stillwater, OK with additional water samples. Three four-ounce water samples were collected from each water source at each golf course to conduct the *E.coli* and fecal coliform tests using the IDEXX Colilert sampling equipment and procedures. IDEXX has been approved and certified by the USEPA as a testing procedure for detecting *E.coli* and fecal coliform in water (IDEXX, 2007). IDEXX Colilert is used to simultaneously detect *E.coli* and fecal coliform concentrations within 24 hours using the most probable number per 100mL (MPN/100mL) method (IDEXX, 2007). The maximum detection limit is 2419.6 MPN/100 mL, and any sample that exceeds this limit must be re-sampled under dilution criteria. The MPN/100mL is a statistical estimate of the number of fecal coliform and *E.coli* bacteria present in the sample. Regulatory standards regarding fecal coliform and *E.coli* are typically provided in colony-forming units per 100mL (cfu/100mL). The values MPN/100mL and cfu/100mL are often used interchangeably to assess fecal coliform and *E.coli* concentrations. The MPN estimates are considered variable compared to CFU measurements, indicating that MPN measurements will result in higher concentrations than CFU measurements (Gronewold and Wolpert, 2008; Hwa Cho et al., 2008).

Pre-sterilized clear 120 mL sample bottles with declorination chemicals were weighed and calibrated prior to adding sample water. After calibration, 100 mL of sample water was added to each bottle and weighed again. One Colilert reagent packet was added to each sample bottle and vigorously shaken approximately 25 times to ensure reagent dissolves completely. The

100mL sample mixture was then poured into a Quanti-Tray/2000 seal tight packet, containing 97 wells, and placed in a cutout rubber insert. The rubber insert was then placed on the input shelf of the Quanti-Tray sealer then pushed into the sealer. Once sealed, the tray is incubated in an oven at approximately 35 +/- 0.5ºC for 24 hours. After the 24 hours of incubation, the tray was removed from the oven and the wells were quantified for *E.coli* and fecal coliform presence in MPN/100 mL. The presence of yellow small and large wells indicated a positive presence of fecal coliforms. Using an Ultraviolet lamp, inflorescent wells indicate a positive presence of *E.coli*. A chart containing the MPN values for the Quanti-Tray/2000 was used to find the corresponding MPN/100 mL for the quantification of large and small wells for the *E.coli* and fecal coliform concentrations.

The samples that exceeded the maximum MPN/100mL limit were diluted to various concentrations with deionized water to quantify better measurements. The dilution concentrations that were used included 90 mL of deionized water to 10 mL of sample water (90/10), 99 mL of deionized water to 1 mL of sample water (99/1), and a base sample of 100 mL of sample water (100/0). The dilution samples underwent the same procedure as the other water samples, yet the MPN/100 mL values were multiplied by a dilution factor. The dilution factor was calculated by dividing the volume of the total sample by the volume of the sample water included in the total sample (V_{total}/V_{sample}).

Statistical analysis

Statistical analysis was conducted to assess the interactions and effects of the independent variables (irrigation water sources and golf course greens, fairways, and non-irrigated roughs) on the dependent variables (soil chemical parameters) using Statistical Analysis Systems Software version 9.3 (SAS, Cary, NC, 27513) for the personal computer. An Analysis of Variance (ANOVA) procedure was performed using SAS 9.3 software, applying the General Linear

Models Procedure, PROC GLM. The two-way factorial ANOVA procedure included a main effects analysis of the treatment (water source) and location (greens, fairways, and non-irrigated roughs) as well as an interaction of the main effects, treatment by location. The mean values of the soil properties from the interaction of the main effects that were statistically different at a p-value of 0.001 indicate that the data are consistent with the hypothesis that all soil chemical parameter means are significantly different for reclaimed water irrigation sources compared to the other irrigation water sources.

Irrigation analyses

The irrigation water samples were analyzed by comparing the results of the water quality parameter tests. The varying concentrations of the water quality parameters were analyzed in reference to irrigation quality guidelines provided by Duncan et al. (2000), Duncan et al. (2009), and Carrow and Duncan, (2012). The water samples tested for fecal coliform and *E.coli* were analyzed in reference to the "Bacterial Water Quality Standards for Recreational Waters" provided by the US Environmental Protection Agency (EPA) and the "Testing Frequency and Limits for Water Reuse" provided the Oklahoma Department of Environmental Quality (ODEQ). The use of the MPN/100mL measurement reflects a probability of the number of fecal coliform or *E.coli* bacteria for each sample, therefore further testing would be necessary to count the exact colonies of each bacteria. The bacterial standards for recreational freshwaters in Oklahoma during May 1-September 30 require that no sample can contain more than 126 *E.coli* cfu/100mL or more than 200 cfu/100mL. Secondary criteria standards that apply for the rest of the year express that no more than 10% of samples can exceed a geometric mean of 400 fecal coliform bacteria per 100mL. For lakes and high use waterbodies, no single sample may exceed 235 cfu/100 mL and all other waters require no single sample exceed 406 cfu/100mL (USEPA, 2003). For Category 2 of reclaimed water, no detectable fecal coliform organisms can be found in the last four of seven daily samples, and the single sample maximum is 23 cfu/100mL (ODEQ, 2012).

Results & Discussion

Lincoln Park Golf Course

The irrigation water samples from Lincoln Park did not show any excessive levels of salts, sodium, or nutrients (Table 5). The dissolved P levels were considered in the high range for irrigation water (0.4-0.8 mg L^{-1}), which should be monitored for runoff as excess P can cause eutrophication of local water bodies. The results from the fecal coliform and *E.coli* tests indicated that there was < 1 MPN/100 mL detectable for both bacteria in the irrigation water samples from Lincoln Park. These results were to be expected for both the water quality and coliform bacteria tests as the source of the irrigation water is treated municipal water and all impurities and contaminants are removed at the water treatment facility prior to distribution.

Overall, the soil sample results from the greens, fairways, and non-irrigated roughs taken from Lincoln Park Golf Course did not exhibit excessive levels of salts or sodium (Tables 7-9). The mean Fe values for the soil samples from greens and fairways (41.2 mg L^{-1} and 62.27 mg L^{-1} respectively) were higher than the other golf courses. The medium sufficiency level for Fe is 10.00-15.00 mg L^{-1}. Iron is mainly stored in the new leaves of the turfgrass and frequent mowing can remove excess Fe. Iron is typically insoluble and unavailable to plants in the soil, therefore turfgrasses may respond differently to higher concentrations of Fe in the soil (Schmidt, 2004). Cool-season grasses responded to iron fertilization during times of high or low soil temperatures, while-warm season grasses responded best during periods of low soil temperature (Schmidt, 2004). Iron was not found in excess in the water samples, therefore the high levels could be a result of the soil type and management practices.

The mean NO_3-N levels for the soil samples from the greens and fairways (10 lbs./A or 5 and 14 lbs./A or 7 mg L^{-1} respectively) were lower than medium sufficiency level range of 11-30 mg L^{-1}. A low amount of NO_3-N was found in the irrigation water samples, therefore the deficiency could be associated with heavy leaching due to the highly soluble quality of NO_3-N. The mean STP value in the soil samples from the fairways (122 lbs./A or 61 mg L^{-1}) was above the medium sufficiency level of P by the Mehlich III test method of 26-54 mg L^{-1}. No additional P is required and should be monitored over time as over or misapplication of P fertilizer can be of concern for urban runoff into local surface waters.

Lake Hefner Golf Course

The mean value for pH from the Lake Hefner (8.60) irrigation water samples were above normal range for irrigation water, 6.5-8.4 (Duncan et al., 2009). This water is classified as alkaline (>7.0), and can cause a nutrient imbalance (Table 4). The higher pH of these samples could be caused by the higher concentration of bicarbonates in this lake water source. Lake water is typically adequately buffered that only minor pH changes occur. Since the water from Lake Hefner is not treated before it is used for irrigation on the golf course, using acidifying fertilizers could be used to negate some alkaline pH influence on the soil and turfgrass (Duncan et al., 2000). The Lake Hefner water samples expressed higher mean value for Mg than the other irrigation sources. Although this Mg value is still less than the Ca levels in this source, it should be regularly monitored as Mg can inhibit K availability and reduce Ca on cation exchange capacity (CEC) sites (Duncan et al., 2009).

The fecal coliform test results showed that the samples from Lake Hefner contained varying levels of the indicator bacteria, 501.2 and 159.7 MPN/100mL respectively (Tables 5-6). The geometric mean of these two samples is 282.92 MPN/100mL. According to the Bacterial Water Quality Standards for Recreational Water in Oklahoma, the geometric mean of the Lake Hefner samples does not exceed the second criteria standards for freshwater that no more than 10% of the samples may exceed a geometric mean of 400 fecal coliform bacteria. The *E.coli* test results showed that the samples from Lake Hefner (25.6 and 26.5 MPN/100mL) were in compliance with the standards for lakes and high use waterbodies that no single sample may exceed 235 cfu/100 mL or MPN/100mL.

The mean values for soil SO_4-S from the greens (104.88 lbs./A or 52.44 mg L^{-1}) and fairways (209.33 lbs./A or 104.67 mg L^{-1}) samples were above the suggested medium sufficiency level range of 10-20 mg L^{-1} according to the chemical extractant used in the soil samples (Carrow and Duncan, 2012) (Tables 7-9). The irrigation water samples from Lake Hefner also expressed high levels of SO_4, which could be the cause of the high SO_4-S levels found in soil samples. An effective leaching program can be applied to mitigate SO_4-S problems in the soil, or to adding lime to the soil surface to react with SO_4-S to create gypsum (Duncan et al., 2009). The mean values for soil EC (4548 µS/cm) and soil ESP (9.68%) from the fairways samples indicated saline soil conditions. The irrigation water could be the source of the saline conditions, but also could be contributed to by specific nutrient and ion imbalances in the soil or turfgrass (Carrow and Duncan, 2012). Some of the several management practices to ameliorate saline soil conditions include leaching, enhancing water infiltration and percolation, and adjusting fertilizer programs to balance nutrient and salt concentrations.

The mean NO_3-N levels for the soil samples from the greens and fairways (15 lbs./A or 7.5 mg L^{-1} and 16 lbs./A or 8 mg L^{-1} respectively) were lower than medium sufficiency level range of 11-30 mg L^{-1}. A low amount of NO_3-N was found in the irrigation water samples, therefore the deficiency could be associated with heavy leaching due to the highly soluble quality of NO_3-N.

Quail Creek Golf Course

The mean TSS value (3156. 45 mg L^{-1}) and the mean EC value (47823 µS/cm) for irrigation water samples from Quail Creek indicate a high salinity hazard (Duncan et al., 200) (Table 4). Saline irrigation water can cause slow accumulation of salts over time in soil layers, causing drought or water stress in the rootzone. To mitigate salt buildup in the soil, proper irrigation scheduling, leaching, sufficient drainage systems, and aerification are all management strategies that should be implemented. The Quail Creek irrigation samples contained the highest amount of HCO_3 than any of the other samples, with a mean value of 262.30.1 mg L^{-1}. The higher amount of HCO_3 could be attributed to the mineral content of the groundwater aquifer that Quail Creek uses for irrigation. Bicarbonate levels <500 mg L^{-1} can cause minimal damage to plants, it is the imbalance of HCO_3 and CO_3 to Ca, Na, and Mg measured by the SAR and Residual Sodium Carbonate (RSC) that is of greater concern for Na hazards (Duncan et al., 2009).

The irrigation samples from Quail Creek had the highest SAR mean value of 7.2 than any of the golf course irrigation water sources. According to the US Salinity Laboratory classifications, the SAR mean value of 7.2 is still considered a low sodium permeability hazard and can be used to irrigate the majority of soils with structure damage (Duncan et al., 2009). The mean calculated RSC value was 284 meq L^{-1} and classified as a high Na hazard. A high Na hazard from RSC values >2.50 meq L^{-1} indicates that most of the Ca and Mg has been removed as carbonate precipitates and the Na is able to build up. This RSC value provides beneficial information about Ca and Mg content as it relates to the need for additional soil amendments. The RSC does not include the Na concentration in the formula, therefore SAR and adjusted SAR values would be better indicators of sodium permeability hazards.

The values from the Quail Creek samples tested for fecal coliform bacteria were 870.5 and 1011.2 MPN/100mL (Tables 5-6). The geometric mean of these samples is 938.22 MPN/100mL, which exceeds the second criteria standards of 10 % of samples with a geometric mean of 400 fecal coliform bacteria. This high fecal coliform value could be contributed to human and animal influence in the irrigation pond where the water is stored prior to use. The values from the samples tested for *E.coli* bacteria were 13.4 and 13.5 MPN/100mL, which were below the standards for lakes and high use waterbodies (235 cfu/100mL *E.coli* bacteria).

The soil samples from the greens exhibited a mean EC value of 4786 μS/cm, a mean SAR value of 14.6, and a mean ESP value of 16.7%, indicated saline-sodic soil conditions (Tables 7-9). Drought stress caused by salts is the primary concern for saline-sodic soil conditions. To salvage plants and soil from saline-sodic conditions, gypsum should be applied prior to leaching to reduce the chances of converting the soil to sodic conditions (Carrow and Duncan, 2012). The high amount of total salts in the Quail Creek irrigation source could be contributing to the substantial salt accumulation in soil samples from the greens. The soil mean pH values for the samples from the greens and fairways, 8.27 and 7.85 respectively, and could be a result of the high pH levels in the irrigation water (8.19-8.2). The soil samples from the greens and fairways also contained the highest mean levels of Ca, 3495 and 9717 lbs./A respectively. Ample amount of Ca is necessary to remediate saline-sodic conditions to displace CEC-bound Na, and these high levels of Ca in the soil could be attributed to management practices as the irrigation water samples from Quail Creek did not contain high concentrations of Ca.

The mean NO_3-N level for the soil samples from the greens (12 lbs/A or 6 mg L^{-1}) was lower than medium sufficiency level range of 11-30 mg L^{-1}. A low amount of NO_3-N was found in the irrigation water samples, therefore the deficiency could be associated with heavy leaching due to the highly soluble quality of NO_3-N. The mean STP value in the soil samples from the fairways (206 lbs/A or 103 mg L^{-1}) was above the medium sufficiency level of P by the Mehlich III test method of 26-54 mg L^{-1}. No additional P is required and should be monitored over time as over or misapplication of P fertilizer can be of concern for urban runoff into local surface waters.

Jimmie Austin OU Golf Course

The irrigation water quality results from both the reclaimed water and groundwater samples did not exhibit many nutrients that were in excess or deficient, which may not have been expected from these water sources (Table 23). The groundwater samples contained the highest mean values of HCO_3, 341.90 mg L^{-1}, than the other irrigation water sources in this case study. This high HCO_3 concentration could be a result of the mineral composition of the source aquifer. As previously mentioned, the high levels of HCO_3 are of less concern compared to the imbalance of HCO_3 and CO_3 to Ca, Mg, and Na. The groundwater samples from Jimmie Austin OU also had the highest mean value for Ca. The mean RSC value for the groundwater sample results was 0.31 meq L^{-1}, which indicates a low Na hazard and only minimal removal of Ca and Mg from irrigation water (Duncan et al., 2009).

The salt and nutrient levels for the reclaimed water source at Jimmie Austin OU were all relatively within the medium sufficiency levels. Typically, reclaimed water sources contain elevated amount of salts and nutrients compared to other irrigation water sources (Duncan et al., 2000). The reclaimed water samples did contain the highest mean levels of NO_3-N, 14.03 mg L^{-1} compared to the other irrigation water sources, but were within the normal range for irrigation water, 5-50 mg L^{-1}. Higher nitrogen (N) levels are commonly found in reclaimed water sources, and can be incorporated into nutrient management plans and reduce N fertilizer applications (King et al., 2000). The reclaimed water samples had a mean value for dissolved P (2.08 mg L^{-1}), which is in the very high range (>0.8 mg L^{-1}) for irrigation waters. The reclaimed water from Jimmie Austin OU only receives secondary treatment, which does not remove as much dissolved P as tertiary treatment processes, which could be the reason behind the higher dissolved P values in these samples.

The groundwater samples had fecal coliform bacteria measurements of 285.1 and 478.6 MPN/100mL (Tables 5-6). The geometric mean of the groundwater samples fecal coliform bacteria results is 369.39 MPN/100mL, which is in compliance with the water quality standards second criteria for fecal coliform. The groundwater samples had *E.coli* measurements of 1 and 2 MPN/100mL, and were also in compliance for water quality standards for *E.coli*. The fecal coliform and *E.coli* measurements for the reclaimed water source both exceeded the maximum measurable value for the IDEXX tests, 2419.6 MPN/100mL, and had to be further tested with dilution factors.

The fecal coliform concentration for the diluted reclaimed water samples were 21430 and 22470 MPN/100mL with a dilution factor of 10 (Tables 10-11). The dilution factor is used to represent a multiplicative factor, and results in a lower concentration of fecal bacteria in the sample. The geometric mean of the diluted fecal coliform samples was 2193.84 MPN/100mL, which exceeds the second criteria standard of no more than 10% of samples can exceed a geometric mean of 400 cfu/100mL. The *E.coli* concentrations of the diluted reclaimed water samples were 816.4 and 579.4 MPN/100mL with a dilution factor of 1. The geometric mean of the diluted fecal coliform samples was 687.77 MPN/100mL, which also exceeds the *E.coli* standards for lakes, high use water bodies, and all other waters.

The soil samples were not tested separately for groundwater or reclaimed water irrigation, so the results would assume to reflect a combination of the two irrigation sources (Tables 7-9). The pH levels were a bit higher in the soil samples from the greens (7.2-8.3) than the fairways, which reflect the irrigation pH of the groundwater samples (7.85-7.94). The mean NO_3-N levels for the soil samples from the greens and fairways (9 lbs./A or 4.5 mg L^{-1} and 16 lbs./A or 8 mg L^{-1} respectively) were lower than medium sufficiency level range of 11-30 mg L^{-1}. A sufficient amount of NO_3-N was found in the reclaimed water irrigation samples, and the deficiency could be associated with heavy leaching due to the highly soluble quality of NO_3-N. The mean STP value in the soil samples from the fairways (242 lbs./A or 121 mg L^{-1}) was above the medium sufficiency level of P by the Mehlich III test method of 26-54 mg L^{-1}. No additional P is required and should be monitored over time as over or misapplication of P fertilizer can be of concern for urban runoff into local surface waters.

Gaillardia Golf Course

The water quality test results for the reclaimed water source at Gaillardia produced salt and nutrient levels that were excessive compared to the other irrigation sources (Table 4). Mean values for EC and TSS, 1280.33 μS/cm and 845.02 mg L^{-1} respectively, would be classified as a medium to high salinity hazard according to water quality standards for irrigation water and reclaimed water. Adequate drainage and leaching are important management practices to reduce salt accumulation in the soil. It is important to choose turfgrasses that have a high salinity tolerance when using saline water sources, such as reclaimed water. Gaillardia has creeping bentgrass greens that begin to show signs of salt stress when EC_w reaches 1500 to 3000 μS/cm, and bermudagrass fairways and roughs that begin to degrade in quality due to salt stress around EC_w around 4000 to 15000 μS/cm (Duncan et al., 2009). The EC levels of the reclaimed water source from Gaillardia are not at levels of concern that would affect turfgrass health, but total salts should be monitored to maintain soil and turf health.

The mean CO_3 value (30.4 mg L^{-1}) in the reclaimed water source from Gaillardia was higher than any of the other irrigation sources. These CO_3 levels, in combination with HCO_3 Mg, Ca, and Na, were not high enough to cause a concern and the irrigation water samples produced SAR and RSC values that did not indicate a severe Na permeability hazard. The Cl concentrations (180.07 mg L^{-1}) were also the highest in the reclaimed water samples from Gaillardia. Chloride levels can cause toxicity concerns and restrict N uptake at 70-100 mg L^{-1}, but most Cl accumulation occurs in the leaf tips and can be removed by regular mowing. The mean pH value for this reclaimed water source (9.24) were the highest of the irrigation water sources in this case study. Water pH at this level can cause nutrient imbalances, and management practices should be altered to accommodate and reduce effects on turfgrass and soil. The mean value for dissolved P (0.59 mg L^{-1}) was within the high range for irrigation water (0.4-0.8 mg L^{-1}). The reclaimed water source from Gaillardia contained a significantly lower mean value for dissolved P compared to the reclaimed water source from Jimmie Austin OU. The difference in dissolved P mean values in these reclaimed water sources could be results in the difference in treatment processes; the reclaimed water source from Gaillardia receives tertiary treatment while the reclaimed water source from Jimmie Austin OU does not. The NO_3-N mean values were within the normal range for irrigation water, 5-50 mg L^{-1}.

The *E.coli* bacteria measurements were 1 and <1 MPN/100mL, which were in compliance with the water quality standards for *E.coli* (Tables 5-6). The fecal coliform bacteria measurements for the reclaimed water source from Gaillardia exceeded the maximum measurable value for the IDEXX tests, 2419.6 MPN/100mL, and had to be further tested with dilution factors. The fecal coliform concentrations of the diluted samples were 517.2 and 524.7 MPN/100mL with a dilution factor of 1(Table 10). The geometric mean of the diluted fecal coliform samples is 520.94 MPN/100mL, which exceeds the second criteria standard of no more than 10% of samples can exceed a geometric mean of 400 cfu/100mL.

There were salt and nutrient levels in the soil samples from Gaillardia that were above the medium sufficiency levels, but they were not the highest levels out of all of the soil samples in this case study as expected to be due to the reclaimed water irrigation (Tables 7-9). The mean EC and ESP values (5567 µS/cm and 7.72 % respectively) for the fairways soil samples indicates a saline soil condition. The best management strategies to remove excess salts is not by chemical amendments, but by leaching total soluble salts downward below the rootzone, implementing salt-tolerant turfgrasses, and adjusting fertilizer programs to counteract nutrient imbalances caused by salt accumulation (Carrow and Duncan, 2012).

The mean NO_3-N value for the soil samples from the greens (11 lbs./A or 5.5 mg L^{-1}) was lower than medium sufficiency level range of 11-30 mg L^{-1}. A sufficient amount of NO_3-N was found in the irrigation water samples, therefore the deficiency could be more associated with heavy leaching due to the highly soluble quality of NO_3-N. The mean STP value in the soil samples from the fairways (194 lbs./A or 97 mg L^{-1}) was above the medium sufficiency level of P by the Mehlich III test method of 26-54 mg L^{-1}. No additional P is required and should be monitored over time as over or misapplication of P fertilizer can be of concern for urban runoff into local surface waters.

The salts and nutrient concentrations were considerably higher for the soil samples from the greens and fairways at Gaillardia than the concentrations of the soil samples from the greens and fairways at Jimmie Austin OU. The difference in concentrations can be a result from a number of factors: soil type, cultural management practices, and turfgrass species. Another important factor to consider in the different salts and nutrient concentrations in the soil samples is that each of these reclaimed water sources receives different treatment processes at two different wastewater treatment facilities before distribution and use for irrigation. Different treatment processes can greatly impact the quality of reclaimed water, and vary on the intended end use and established regulations (Duncan et al., 2009). The Deer Creek Wastewater Treatment Plant that serves Gaillardia with reclaimed water has tertiary treatment processes, while the Norman Wastewater Treatment Plant that serves Jimmie Austin OU with reclaimed water currently only has secondary treatment processes with plans to add tertiary in the near future.

Treatment by location interactions

The interaction of treatment by location data specifically illustrates how the irrigation water sources interact with the soil parameters by location (greens, fairways, and non-irrigated roughs) and in comparison to each golf course (Tables 12-30). The mean values of the soil parameters that were similar were not statistically different at a p-value of 0.001. Since the irrigation water sources for Jimmie Austin OU were not separated for the soil tests, we have to assume the soil test results reflect a combination of effects that the groundwater and reclaimed water sources would have on the soil. At least two of the golf courses were not found statistically different from each other for every soil parameter at each of the locations. For TSS, the interaction of treatment by location at the greens is not statistically different for Gaillardia and Hefner, as well as for Lincoln Park and Jimmie Austin OU. This is interesting to see that mean concentrations of TSS on the greens for the groundwater and reclaimed irrigation water sources at Jimmie Austin OU are not statistically different from the treated municipal water at Lincoln Park. The results were the same for the location by treatment interaction for EC on the greens. These observations could be affected by soil type, management practices, and turfgrass type, but does show that the groundwater, untreated surface water and treated municipal water sources and the effects on the soil chemical properties are not all statistically different from the reclaimed water sources. These results actually disprove our hypothesis that the soil chemical properties of soils irrigated with reclaimed water would be different than soils irrigated with the other three water sources.

Conclusion

This case study evaluated the soil chemical properties and water quality properties of reclaimed water irrigation compared to untreated surface water, groundwater, and treated municipal irrigation on golf courses in Oklahoma. The results from the water quality tests were not statistically tested, but observations from the results showed that the highest concentrations of salts (TSS and EC) were found in the reclaimed water samples from Gaillardia, which was expected, but the reclaimed water source from Jimmie Austin OU contained half of the salt concentrations than that of Gaillardia's reclaimed water source. The nutrient concentrations varied amongst the water sources, with each of the water source results showing values above and below medium sufficiency ranges. Reclaimed water sources typically contain higher levels of P and NO_3-N, in which both of the reclaimed water sources contained the highest mean values for both of these nutrients The samples from the reclaimed water source from Jimmie Austin OU had the highest mean value for dissolved P, possibly resulting from only receiving secondary treatment before use. The samples from both of the reclaimed water sources had the highest mean values for NO_3-N, but both were within the normal range for irrigation water, 5-50 mg L^{-1}.

The fecal coliform and *E.coli* concentration tests showed the highest values were found in the reclaimed water irrigation samples for both Jimmie Austin OU and Gaillardia. The reclaimed water irrigation source from Jimmie Austin OU had higher values of both fecal coliform and *E.coli* concentrations than the reclaimed water irrigation source from Gaillardia, which could result from the difference in treatment processes each reclaimed water source receives. The MPN/100mL values from the fecal coliform and *E.coli* are estimates of bacteria concentrations and are typically estimated higher than cfu/00mL bacteria concentrations.

The results from soil quality tests suggest that the salts and nutrient concentrations from the interaction of water source and the location on each of the golf courses (greens, fairways, non-irrigated roughs) were not statistically different from each other for each soil chemical parameter for at least one of the golf course locations. The hypothesis for this case study that the chemical properties of soil irrigated with reclaimed water would be different from those chemical properties of soils irrigated from the other three water sources was proven false, as the soil chemical concentrations were different in value for all of the water sources, but not statistically different for the treatment by location interaction.

As the demand for potable water supplies increases among municipalities and industry, the use of reclaimed water for non-potable uses, such as landscape irrigation, will also increase. Golf courses are ideal candidates to use reclaimed water for irrigation purposes. Both opportunities and problems are evident when using reclaimed water for irrigation purposes. It is important to understand the constantly changing levels of soil chemical properties and water quality parameters when using reclaimed water for golf course irrigation. The results from this case study indicate that other water sources (treated municipal water, untreated surface water, and groundwater) are not different when discussing nutrient and salt concentrations, providing data that suggests reclaimed water can be beneficially used for golf course irrigation just as other water sources. Reclaimed water can be an effective source for golf course irrigation in Oklahoma in conjunction with supportive regulation and best management practices, such as aerification, leaching, choosing salt-tolerant turfgrass, applying proper applications of soil amendments, and consistently monitoring soil and irrigation water sources.

Table 1. Site, water source, soil series, and soil classifications from each of the five Oklahoma golf courses in the case study.

Golf Course	Location	Water Source	Year Water Source Est.	Majority Soil Series†	Soil Texture Classification†
Gaillardia	Oklahoma City, OK	Reclaimed water	1995	Ashport-Lawrie complex	Silt loam
Lake Hefner (N. Course)	Oklahoma City, OK	Untreated surface water	1994	Renthin-Urban complex	Silt loam
Lincoln Park (E. Course)	Oklahoma City, OK	Treated municipal water	1922	Stephenville-Darsil-Newalla complex	Sandy loam
Quail Creek	Oklahoma City, OK	Groundwater	1960	Grainola-Urban land-Ironmound complex	Silty clay loam
Jimmie Austin OU	Norman, OK	85% Reclaimed water; 15% groundwater	1996	Teller-Urban land complex	Sandy loam

†Information from USDA-NRCS Web Soil Survey

Table 2. Soil testing parameters and procedures.

Soil Test Parameters	†SWFAL Procedure
Soil Fertility	
pH	pH meter
P, K, Ca and Mg	M3, ICP reading
SO_4-S	$CaPO_4$, ICP reading
NO_3-N	Automated cadmium reduction
Fe, Zn, and B	DTPA-Sorbital, ICP reading
Salinity Management (1:1 Soil-water extraction)	
EC	Electrode reading
Na, Ca, Mg, K, and B	ICP reading
Total Soluble Salts (TSS)	Greater of Σ (anions + cations) or EC x 0.66
Sodium Absorption Ratio (SAR)	0.043498 x Na / [(0.04990 x Ca + .08229 x Mg)/2]1/2
Potassium Absorption Ratio (PAR)	0.025577 x K / [(0.0499 x Ca + 0.08229 x Mg)/2]1/2
Exchangeable Potassium Percentage (EPP)	(10.51 x PAR + 3.60) / [1 + (0.1051 x PAR + 0.036)]
Exchangeable Sodium Percentage (ESP)	(1.47 x SAR - 1.26) / (0.01475 x SAR + 0.99)

†Parameters from Procedures Used by OSU Soil, Water, and Forage Analytical Laboratory, PSS-2901.

Table 3. Water testing parameters and procedures.

Water Test Parameters	†SWFAL Procedure
pH	Electrode reading
NO_3-N	Automated cadmium reduction
CO_3	Titrate with 0.02 N H2SO4 to pH 8.3, CO3 = ml titrant x 0.02 x 6000/ ml sample
HCO_3	Titrate with 0.02 N H2SO4 from pH 8.3 to 4.5, HCO3 = ml titrant x 0.02 x 12,200/ ml sample
EC	Electrode reading
Na, Ca, Mg, and K	ICP reading
B	ICP reading
SO_4	ICP reading
Cl	Automated ferricyanide
Total Soluble Salts (TSS)	Greater of Σ (anions + cations) or EC x 0.66
Hardness	(0.04990 x Ca + 0.08229 x Mg) x 50
Sodium Absorption Ratio (SAR)	0.043498 x Na / [(0.04990 x Ca + .08229 x Mg)/2]1/2
Potassium Absorption Ratio (PAR)	0.025577 x K / [(0.0499 x Ca + 0.08229 x Mg)/2]1/2
Exchangeable Potassium Percentage (EPP)	(10.51 x PAR + 3.60) / [1 + (0.1051 x PAR + 0.036)]
Exchangeable Sodium Percentage (ESP)	(1.47 x SAR - 1.26) / (0.01475 x SAR + 0.99)

†Parameters from Procedures Used by OSU Soil, Water, and Forage Analytical Laboratory, PSS-2901.

Table 4: Water quality parameters for untreated surface water, reclaimed water, groundwater, and treated municipal water irrigation samples. Mean values from water samples

	Golf Course					
	Lake Hefner	**Jimmie Austin OU**	**Jimmie Austin OU**	**Lincoln Park**	**Gaillardia**	**Quail Creek**
	Water Source					
	Untreated Surface	**Groundwater**	**Reclaimed**	**Treated Municipal**	**Reclaimed**	**Groundwater**
pH	8.60	7.89	7.13	7.48	9.24	8.20
Electrical Conductivity (EC), µS/cm	1003.67	663.00	665.00	161.70	1280.33	716.00
Sodium Adsorption Ratio (SAR), meq L^{-1}	2.43	0.90	3.47	0.47	3.70	7.20
Total Soluble Salts (TSS), mg L^{-1}	749.24	551.07	443.45	109.31	845.02	567.60
Carbonate (CO_3), mg L^{-1}	10.50	0.00	0.00	0.00	30.40	0.00
Bicarbonate (HCO_3), mg L^{-1}	191.13	341.90	110.90	49.77	53.83	262.30
Residual Sodium Carbonate (RSC), meq L^{-1}	-3.27	-0.39	-0.70	-0.38	-3.72	2.92
Potassium (K), mg L^{-1}	8.00	1.00	14.00	3.33	15.00	3.00
Nitrate (NO_3-N), mg L^{-1}	0.17	1.35	14.03	0.40	11.33	0.17
Total Dissolved Phosphate, (P) mg L^{-1}	0.13	0.04	2.08	0.52	0.59	0.04
Sodium (Na), mg L^{-1}	103.00	89.67	36.50	8.00	142.33	138.67
Calcium (Ca), mg L^{-1}	75.00	80.00	26.67	17.33	61.00	16.00
Iron (Fe), mg L^{-1}	0.04	0.01	0.09	0.08	0.00	0.00
Zinc (Zn), mg L^{-1}	0.05	0.00	0.03	0.13	0.01	0.00
Magnesium (Mg), mg L^{-1}	36.00	24.00	14.33	4.00	30.67	7.00
Copper (Cu), mg L^{-1}	0.00	0.00	0.00	0.00	0.00	0.00

Table 4 Continued

	Golf Course					
	Lake Hefner	**Jimmie Austin OU**	**Jimmie Austin OU**	**Lincoln Park**	**Gaillardia**	**Quail Creek**
	Water Source					
	Untreated Surface	**Groundwater**	**Reclaimed**	**Treated Municipal**	**Reclaimed**	**Groundwater**
Manganese (Mn), mg L^{-1}	0.00	0.00	0.01	0.00	0.00	0.00
Boron (B), mg L^{-1}	0.20	0.20	0.40	0.00	0.40	0.80
Hardness, mg L^{-1} in $CaCo_3$	334.67	300.00	124.67	58.33	277.67	70.33
Alkalinity, mg L^{-1}	174.33	280.50	91.00	41.00	95.00	215.67
Sulfate (SO_4), mg L^{-1}	202.80	32.75	55.47	12.53	206.03	103.37
Chloride (Cl), mg L^{-1}	122.83	32.95	96.07	14.40	180.07	35.80
Ammonium NH_4-N, mg L^{-1}	0.22	0.00	0.00	0.74	0.11	0.11

†Water samples for each golf course taken during a single time period on separate days during September 2014.

‡Lake Hefner, Lincoln Park, Gaillardia, and Quail Creek Golf Courses located in Oklahoma City, OK.

§Jimmie Austin OU Golf Course located in Norman, Oklahoma.

Table 5: Fecal coliform bacteria concentrations for untreated surface water, treated municipal water, groundwater, and reclaimed water irrigation samples.

Irrigation Water Source	Golf Course	Large Cell Count	Small Cell Count	Value, MPN/100 mL
Groundwater	Quail Creek	48	45	870.5
Groundwater	Quail Creek	48	48	1011.2
Reclaimed Water	Jimmie Austin OU	48	48	>2419.6
Reclaimed Water	Jimmie Austin OU	48	48	>2419.6
Groundwater	Jimmie Austin OU	47	20	285.1
Groundwater	Jimmie Austin OU	48	32	478.6
Reclaimed Water	Gaillardia	48	48	>2419.6
Reclaimed Water	Gaillardia	48	48	>2419.6
Untreated Surface Water	Lake Hefner	48	33	501.2
Untreated Surface Water	Lake Hefner	48	7	159.7
Treated Municipal Water	Lincoln Park	0	0	<1
Treated Municipal Water	Lincoln Park	0	0	<1

†Water samples for each golf course taken during a single time period on separate days during October 2014.

‡Lake Hefner, Lincoln Park, Gaillardia, and Quail Creek Golf Courses located in Oklahoma City, OK.

§Jimmie Austin OU Golf Course located in Norman, Oklahoma.

Table 6: *E.coli* bacteria concentrations for untreated surface water, treated municipal water, groundwater, and reclaimed water irrigation samples.

Irrigation Water Source	Golf Course	Large Cell Count	Small Cell Count	Value, MPN/100 mL
Groundwater	Quail Creek	11	0	13.4
Groundwater	Quail Creek	12	1	13.5
Reclaimed Water	Jimmie Austin OU	48	48	>2419.6
Reclaimed Water	Jimmie Austin OU	48	48	>2419.6
Groundwater	Jimmie Austin OU	1	0	1
Groundwater	Jimmie Austin OU	2	0	2
Reclaimed Water	Gaillardia	0	0	<1
Reclaimed Water	Gaillardia	1	0	1
Untreated Surface Water	Lake Hefner	18	3	25.6
Untreated Surface Water	Lake Hefner	21	0	26.5
Treated Municipal Water	Lincoln Park	0	0	<1
Treated Municipal Water	Lincoln Park	0	0	<1

†Water samples for each golf course taken during a single time period on separate days during October 2014.

‡Lake Hefner, Lincoln Park, Gaillardia, and Quail Creek Golf Courses located in Oklahoma City, OK.

§Jimmie Austin OU Golf Course located in Norman, Oklahoma.

Table 7: Chemical properties of soil irrigated with surface water, treated municipal water, groundwater, and reclaimed water on golf course greens. Mean values from soil samples.

	Golf Course				
	Hefner	**Jimmie Austin OU**	**Lincoln Park**	**Gaillardia**	**Quail Creek**
	Water Source				
	Untreated Surface	**Reclaimed & Groundwater**	**Treated Municipal**	**Reclaimed**	**Groundwater**
Soil Fertility					
pH	7.38	7.98	6.73	7.55	8.27
Nitrate (NO_3-N), lbs./A	15	9	10	11	12
Soil Test Phosphorus (STP), lbs./A	103	99	73	72	94
Soil Test Potassium (STK), lbs./A	148	112	133	113	254
Soil Sulfate (SO_4-S), lbs./A	105	33	24	86	160
Calcium (Ca), lbs./A	1773	1395	1444	1419	3495
Magnesium (Mg), lbs./A	382	174	174	262	275
Iron (Fe), mg L^{-1}	24.53	13.73	41.20	18.04	9.32
Zinc (Zn), mg L^{-1}	11.05	5.73	49.43	8.95	3.96
Boron (B), mg L^{-1}	0.69	0.57	0.17	0.79	2.04
Copper (Cu), mg L^{-1}	1.12	0.65	5.57	0.81	0.69
Organic Matter (OM), %	2.62	0.77	2.57	1.37	2.87
Salinity Management					
Electrical Conductivity (EC), µS/cm	2036	918	745	2098	4783
Sodium (Na), mg L^{-1}	197.67	88.83	22.50	223	593.83
Total Soluble Salts (TSS), mg L^{-1}	1343.76	605.88	491.37	1384.35	3156.45
Sodium Adsorption Ratio (SAR)	5.42	3.95	0.85	6.53	14.57
Exchangeable Sodium Percentage (ESP), %	6.25	4.32	0.00	7.68	16.68

†Soil samples for each golf course taken on separate days during September 2014.

‡Lake Hefner, Lincoln Park, Gaillardia, and Quail Creek Golf Courses located in Oklahoma City, OK.

§Jimmie Austin OU Golf Course located in Norman, Oklahoma.

¶Jimmie Austin OU irrigation consists of 85% reclaimed water and 15% groundwater.

Table 8: Chemical properties of soil irrigated with surface water, treated municipal water, groundwater, and reclaimed water on golf course fairways. Mean values from soil samples.

	Golf Course				
	Hefner	**Jimmie Austin OU**	**Lincoln Park**	**Gaillardia**	**Quail Creek**
	Water Source				
	Untreated Surface	**Reclaimed & Groundwater**	**Treated Municipal**	**Reclaimed**	**Groundwater**
Soil Fertility					
pH	7.50	7.20	7.03	7.38	7.85
NO_3-N , lbs./A	16	15	14	22	24
STP, lbs./A	45	242	122	194	206
STK, lbs./A	674	586	509	878	956
SO_4-S, lbs./A	209	47	17	222	102
Ca, lbs./A	5970	2754	3331	8668	9717
Mg, lbs./A	1567	571	709	1317	886
Fe, mg L^{-1}	42.51	55.83	62.27	38.17	35.65
Zn, mg L^{-1}	5.60	3.32	7.18	8.21	6.57
B, mg L^{-1}	1.83	1.33	0.29	2.55	3.63
Cu, mg L^{-1}	1.30	0.73	1.15	1.73	1.65
OM, %	4.54	2.87	3.50	5.26	4.04
Salinity Management					
EC, µS/cm	4548	1633	1152	5567	3799
Na, mg L^{-1}	514.83	199.33	54.50	468.00	460.50
TSS, mg L^{-1}	3001.50	1077.78	760.32	3674.22	2507.10
SAR	8.20	6.97	1.27	6.57	10.07
ESP, %	9.68	8.20	0.00	7.72	11.82

†Soil samples for each golf course taken on separate days during September 2014.

‡Lake Hefner, Lincoln Park, Gaillardia, and Quail Creek Golf Courses located in Oklahoma City, OK.

§Jimmie Austin OU Golf Course located in Norman, Oklahoma.

¶Jimmie Austin OU irrigation consists of 85% reclaimed water and 15% groundwater.

Table 9: Chemical properties of soil from non-irrigated roughs. Mean values from soil samples.

	Golf Course				
	Hefner	Jimmie Austin OU	Lincoln Park	Gaillardia	Quail Creek
	Water Source				
	Untreated Surface	Reclaimed & Groundwater	Treated Municipal	Reclaimed	Groundwater
Soil Fertility					
pH	7.10	7.62	6.42	8.03	8.07
NO_3-N, lbs./A	9	5	5	4	3
STP, lbs./A	102	17	20	26	7
STK, lbs./A	625	362	369	426	594
SO_4-S, lbs./A	20	14	22	18	11
Ca, lbs./A	5737	4616	2955	8848	10577
Mg, lbs./A	1231	597	628	764	1133
Fe, mg L^{-1}	35.93	11.58	23.63	6.79	12.16
Zn, mg L^{-1}	3.62	0.84	2.00	0.54	0.65
B, mg L^{-1}	0.72	0.32	0.34	0.52	0.66
Cu, mg L^{-1}	1.31	0.32	0.72	0.34	0.61
OM, %	3.41	2.01	2.37	1.85	1.58
Salinity Management					
EC, µS/cm	920	740	656	959	940
Na, mg L^{-1}	36.17	18.17	20.00	42.00	25.67
TSS, mg L^{-1}	607.20	488.40	433.13	632.94	620.07
SAR	1.03	0.57	0.65	1.15	0.70
ESP, %	0.42	0.00	0.00	0.64	0.00

†Soil samples for each golf course taken on separate days during September and October 2014.

‡Lake Hefner, Lincoln Park, Gaillardia, and Quail Creek Golf Courses located in Oklahoma City, OK.

§Jimmie Austin OU Golf Course located in Norman, Oklahoma.

¶Jimmie Austin OU irrigation consists of 85% reclaimed water and 15% groundwater.

Table 10: Fecal coliform concentrations and dilution factors for reclaimed water irrigation samples.

Golf Course	Large Cell Count	Small Cell Count	Value, MPN/100 mL	Dilution Factor
Jimmie Austin OU	49	11	21430	10
Jimmie Austin OU	49	12	22470	10
Gaillardia	49	27	517.2	1
Gaillardia	48	34	524.7	1

Table 11: *E.coli* concentrations and dilution for Jimmie Austin OU reclaimed water irrigation samples.

Golf Course	Large Cell Count	Small Cell Count	Value, MPN/100 mL	Dilution Factor
Jimmie Austin OU	49	35	816.4	1
Jimmie Austin OU	49	29	579.4	1

Table 12: Treatment by location interaction for the mean values of soil parameter pH.

	Golf Course				
	Quail Creek	Jimmie Austin OU	Gaillardia	Hefner	Lincoln Park
	Water Source				
	Groundwater	Reclaimed + Groundwater	Reclaimed	Untreated Surface	Treated Municipal
Greens	8.27a	7.98a	7.55b	7.38b	6.73c
Fairways	7.85a	7.22bc	7.38b	7.50b	7.03c
Non-Irrigated Roughs	8.07a	7.62b	8.03a	7.08c	6.42d

†Means within rows followed by the same letters are not statistically different at $P= 0.001$.

Table 13: Treatment by location interaction for the mean values of soil parameter Zn.

	Golf Course				
	Quail Creek	Jimmie Austin OU	Gaillardia	Hefner	Lincoln Park
	Water Source				
	Groundwater	Reclaimed + Groundwater	Reclaimed	Untreated Surface	Treated Municipal
Greens	3.96c	5.73c	8.95b	11.04b	49.43a
Fairways	6.57a	3.32c	8.21a	6.61b	7.18a
Non-Irrigated Roughs	0.65b	0.84b	0.54b	3.62a	2.00b

†Means within rows followed by the same letters are not statistically different at $P= 0.001$.

Table 14: Treatment by location interaction for the mean values of soil parameter TSS.

	Golf Course				
	Quail Creek	Jimmie Austin OU	Gaillardia	Hefner	Lincoln Park
	Water Source				
	Groundwater	Reclaimed + Groundwater	Reclaimed	Untreated Surface	Treated Municipal
Greens	3156.45a	605.88c	1384.35b	1343.76b	491.37c
Fairways	2507.01c	1077.78d	3674.22a	3001.35b	760.32e
Non-Irrigated Roughs	620.07a	488.40a	632.94a	607.20a	433.13a

†Means within rows followed by the same letters are not statistically different at $P= 0.001$.

Table 15: Treatment by location interaction for the mean values of soil parameter NO_3-N.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	12.33a	8.67b	10.83ab	14.5a	9.83b
Fairways	24.17a	15.17b	21.67a	15.83b	13.83b
Non-Irrigated Roughs	3.00b	5.00b	3.67b	8.67a	4.83b

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 16: Treatment by location interaction for the mean values of soil parameter SO_4-S.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	159.50a	33.21c	85.83b	104.88b	23.79c
Fairways	102.00b	47.05c	222.17a	209.33a	16.52d
Non-Irrigated Roughs	11.00a	13.67a	18.33a	20.23a	22.19a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 17: Treatment by location interaction for the mean values of soil parameter SAR.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	14.57a	3.95d	8.95b	5.42c	0.85e
Fairways	10.67a	6.97c	6.57c	8.20b	1.27d
Non-Irrigated Roughs	0.70a	0.57a	1.15a	1.03a	0.65a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 18: Treatment by location interaction for the mean values of soil parameter PAR.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	3.29a	1.11b	0.97b	1.08b	49.43b
Fairways	1.27a	1.51a	0.75c	0.45d	1.05b
Non-Irrigated Roughs	0.31a	0.47a	0.35a	0.30a	0.44a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 19: Treatment by location interaction for the mean values of soil parameter STP.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	93.50a	98.67a	71.83a	102.50a	73.33a
Fairways	205.50a	242.17a	193.50a	44.50c	122.00b
Non-Irrigated Roughs	6.50b	17.00b	25.67b	101.67a	20.00b

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 20: Treatment by location interaction for the mean values of soil parameter OM.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	2.87a	0.77c	1.37b	2.61a	2.57a
Fairways	4.04b	2.87c	5.26a	5.54a	3.49b
Non-Irrigated Roughs	1.58c	2.01c	1.85c	3.41a	2.37b

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 21: Treatment by location interaction for the mean values of soil parameter Na.

	Golf Course				
	Quail Creek	Jimmie Austin OU	Gaillardia	Hefner	Lincoln Park
	Water Source				
	Groundwater	Reclaimed + Groundwater	Reclaimed	Untreated Surface	Treated Municipal
Greens	593.83a	88.83c	223.00b	197.67b	22.50c
Fairways	460.50a	199.33b	468.00a	514.83a	54.50c
Non-Irrigated Roughs	25.67a	18.17a	42.00a	36.17a	20.00a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 22: Treatment by location interaction for the mean values of soil parameter Mg.

	Golf Course				
	Quail Creek	Jimmie Austin OU	Gaillardia	Hefner	Lincoln Park
	Water Source				
	Groundwater	Reclaimed + Groundwater	Reclaimed	Untreated Surface	Treated Municipal
Greens	275.00a	173.67b	261.67a	381.83a	173.67b
Fairways	886.33c	570.83d	1316.50b	1566.33a	709.00d
Non-Irrigated Roughs	1133.00b	596.50d	764.17c	1231.33a	627.83d

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 23: Treatment by location interaction for the mean values of soil parameter STK.

	Golf Course				
	Quail Creek	Jimmie Austin OU	Gaillardia	Hefner	Lincoln Park
	Water Source				
	Groundwater	Reclaimed + Groundwater	Reclaimed	Untreated Surface	Treated Municipal
Greens	253.67a	111.83b	113.17b	148.00b	132.67b
Fairways	956.17a	586.00b	878.00a	674.00b	509.17c
Non-Irrigated Roughs	594.17a	362.00c	425.83b	634.67a	369.00c

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 24: Treatment by location interaction for the mean values of soil parameter Fe.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	9.32c	13.73c	18.04b	24.53b	41.20a
Fairways	35.65b	55.83a	38.17b	44.51b	62.27a
Non-Irrigated Roughs	12.16c	11.58c	6.79c	35.93a	23.63b

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 25: Treatment by location interaction for the mean values of soil parameter ESP.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	16.68a	4.32d	7.68b	6.25c	0.10e
Fairways	11.82a	8.20c	7.72c	9.68b	0.70d
Non-Irrigated Roughs	0.13a	0.08a	0.53a	0.35a	0.00a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 26: Treatment by location interaction for the mean values of soil parameter EPP.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	27.57a	13.83b	12.15b	13.25b	12.95b
Fairways	14.48a	16.23a	10.25c	7.65d	12.73b
Non-Irrigated Roughs	6.35a	7.85a	6.78a	6.37a	7.60a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 27: Treatment by location interaction for the mean values of soil parameter EC.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	4782.50a	918.00c	2097.50b	2036.00b	744.50c
Fairways	3798.50c	1633.00d	5567.00a	4547.50b	1152.00e
Non-Irrigated Roughs	939.50a	740.00a	959.00a	920.00a	656.25a

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 28: Treatment by location interaction for the mean values of soil parameter Cu.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	0.69b	0.66b	0.81b	1.12b	5.57a
Fairways	1.65a	0.73b	1.73a	1.30a	1.15b
Non-Irrigated Roughs	0.61b	0.32c	0.34c	1.31a	0.72b

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 29: Treatment by location interaction for the mean values of soil parameter Ca.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	3494.50a	1394.67b	1418.50b	1772.83b	1444.17b
Fairways	9716.83a	2753.67c	8668.00b	5970.33b	3331.17c
Non-Irrigated Roughs	10577.00a	4615.50c	8848.33b	5736.50c	2955.00d

†Means within rows followed by the same letters are not statistically different at *P*= 0.001.

Table 30: Treatment by location interaction for the mean values of soil parameter B.

	Golf Course				
	Quail Creek	**Jimmie Austin OU**	**Gaillardia**	**Hefner**	**Lincoln Park**
	Water Source				
	Groundwater	**Reclaimed + Groundwater**	**Reclaimed**	**Untreated Surface**	**Treated Municipal**
Greens	2.04a	0.57b	0.78b	0.69b	0.17c
Fairways	3.63a	1.33d	2.55b	1.83c	0.29e
Non-Irrigated Roughs	0.66a	0.32c	0.52a	0.72a	0.34c

†Means within rows followed by the same letters are not statistically different at *P*= 0.001

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CHAPTER III

PUBLIC ACCEPTANCE AND WILLINGNESS TO PAY FOR RECLAIMED WATER: A CASE STUDY FOR OKLAHOMA

Introduction

Increased human consumption of water supplies and intensified drought conditions in certain regions have increased demand for water while also decreasing the surface flow of natural water systems and increasing the depletion of groundwater aquifers. Through the four years of drought (2010-2014), Oklahoma has endured precipitation deposition patterns less than those of the Dust Bowl in the 1930's (Parker, 2014). In January 2013, the United States Department of Agriculture designated 76 of all 77 counties in Oklahoma as disaster areas due to drought and heat (USDA, 2013). In early January 2013, one of the primary drinking water sources for the Oklahoma City metro area, Lake Hefner, was at 17 feet below maximum capacity, the lowest in the lake's 66-year history. Due to dangerously low lake levels, the City of Oklahoma City released water from Canton Lake, to which it owned the water rights, in order to raise Lake Hefner (Layden, 2013). To combat future water supply shortages, the City of Oklahoma City, like many other communities in Oklahoma, is considering using alternative water sources, such as reclaimed water and additional pipelines for water transfers. This study examines Oklahomans' willingness to pay (WTP) for reclaimed water to ensure future municipal water supplies.

Reclaimed water use may be a sound strategy to combat decreasing fresh water resources. Reclaimed water, also referred to as recycled water, can provide economic and environmental benefits to communities through various applications that replace potable water, including groundwater recharge, landscape irrigation, agricultural irrigation, and potable water supply augmentation (USEPA, 2013). Reclaimed water use projects are often met with public opposition due to the connection of reclaimed water to sewage, creating a negative public health perception (Hartley, 2006). Communities, such as San Diego, California; Tampa, Florida; and Queensland, Australia had to shut down reclaimed water use projects due to failed community outreach and heavy pushback from citizens regarding the safety of public health (DeSena, 1999; Hurlimann and Dolnicar, 2009).

This chapter will provide 1) an overview of reclaimed water use for municipal water supplies, 2) literature about public acceptance of reclaimed water, and 3) a case study on the willingness to pay for reclaimed water use in Oklahoma.

Definition of Reclaimed Water

According to the Oklahoma Department of Environmental Quality (ODEQ), reclaimed water is "wastewater that has gone through various treatment processes to meet specific water quality criteria with intent of being used in a beneficial manner" (ODEQ, 2012). Also referred to as recycled water, reclaimed water can be used for non-potable purposes, such as irrigation and power plant cooling. Reclaimed water can also be used for potable purposes, such augmenting drinking water supplies. Potable reclaimed water use projects can be further categorized as direct potable and indirect potable reuse. Direct potable reuse projects introduce reclaimed water directly into potable water distribution systems without prior storage. Indirect potable reuse projects introduce reclaimed water into an environmental buffer, such as a lake or reservoir, before entering potable water distribution systems. De facto, or indirect, potable reuse has been in existence for centuries, in which drinking water is drawn from river systems where treated wastewater has been discharged from wastewater treatment plants from cities upstream.

Treatment processes for reclaimed water vary according to state regulations and the intended end use, but the primary goal is to disinfect the wastewater to ensure the protection of the public's health and the environment. Reclaimed water undergoes primary and secondary treatment, just as traditional wastewater, but also typically receive tertiary and disinfection treatment processes prior to use. Tertiary, or advanced, treatment technology and processes are constantly evolving and are used to remove additional organic, chemical, and biological contaminants from wastewater leftover after conventional primary and secondary treatments.

Public Acceptance and Willingness to Pay for Reclaimed Water

A substantial amount of research has emerged regarding public acceptance and willingness to pay for reclaimed water use since the early 1970's (Bruvold and Ward, 1970; Bruvold, 1973; Sims and Baumanm, 1974; Kasperson et al., 1974). One finding remains consistent across previous reclaimed water research: public acceptance of alternative water resources is greater for purposes that involve low human contact than for purposes of a closer personal contact, such as bathing (Dolnicar and Hurlimann, 2010). The public's support for environmental stewardship related to reclaimed water use reaches a tipping point when the end use becomes too personal, thus support decreases (Hurlimann and McKay, 2006).

The potential threat of disease and harmful bacteria being transmitted through the use of reclaimed water has notably been the most common public concern. To date, research has shown that there has yet to be a confirmed case of human illness related to reclaimed water systems (Rock et al., 2012). Advanced treatment technology can deliver reclaimed water that meets and exceeds national drinking water standards (Ormerod and Scott, 2012). Municipalities often make decisions regarding reclaimed water use projects based on public acceptance rather than scientific research due to the influence and impact of negative ad campaigns and public opposition. The general public may also struggle with relying on government or academic institutions and studies have shown that people are more apt to trust their own intuition than peer-reviewed scientific research, also referred to as cognitive dissonance (Rock et al., 2012). If public opposition to reclaimed water use is greater than the public education and communication efforts of municipalities, then reclaimed water projects are unlikely to succeed.

Health risk concerns related to reclaimed water use stem from the connection of reclaimed water to dirty water, or sewage. The majority of the public is unaware that in parts of the United States, drinking water contains a percentage of treated wastewater that was discharged from another municipality’s treatment plant upstream and blended into surface water systems (Asano et al., 2007). The general public appears to have a strong cultural connection to water purity and a lack of education about the urban hydrologic cycle, directly relating to a negative perception of reclaimed water. The terms “Toilet to Tap” and “Sewage Beverage” began circulating in mass media in the 1990s, during a time when a number of indirect potable reuse projects were being proposed (Hartley, 2006). The negative media attention regarding reclaimed water projects further promoted an “ick” or “yuck” factor associated with reclaimed water use, increasing public opposition to these projects.

The incorporation and widespread use of public education and outreach campaigns are important components to successfully implementing reclaimed water projects. Educating the public about how reclaimed water systems work can lead to a positive acceptance of these projects (Dolnicar et al., 2011). Allowing the public to provide input and opinions can also have a significant impact on the success or failure of reclaimed water use projects. Public involvement should be integrated from the early stages through the completion of reclaimed water use planning for every reclaimed water use project (Asano et al., 2007). The public should participate in the planning of reclaimed water use projects because they are directly affected as customers and because utilities are highly regulated as natural monopolies (Asano et al., 2007). In 1993, the City of San Diego, California attempted to implement a potable reclaimed water use project into their municipal water system (DeSena, 1999). The City of San Diego failed to implement a public education and outreach program about the reclaimed water use project, and the project was eventually eradicated due to the public backlash and excessive negative media attention, although interest has been renewed in 2015 due to historic drought conditions in California (Morin, 2015).

These studies exhibit the failure of reclaimed water projects due to lack of public acceptance but also that the public is willing to pay for reclaimed water to a certain degree on a global scale. Little or no qualitative research on reclaimed water acceptability exists in the semi-arid Midwest or in Oklahoma. This case study contributes insight on reclaimed water research in Oklahoma and estimates the public's willingness to pay for more widespread reclaimed water use given differing information on reclaimed water use safety and respondents' varied attitudes toward conservation.

Contingent Valuation Method and Willingness to Pay

Contingent valuation method (CVM) estimates willingness to pay for non-marketed or hard to value services such as ecosystems. The CVM is categorized as a stated preference method (Grafton et al., 2004; Bakopoulou et al., 2009). Different formats can be used in a contingent valuation study, for example, an open-ended format or single bound format. The open ended format asks survey participants to state the maximum amount of money they would be willing to pay, while the single bound format ask respondents if they would be willing to pay a specific price (bid) (Genius et al., 2008). The single bound format more accurately imitates the market situations in which consumers pay a specific price for a commodity and is widely used in comparison to the open-ended format (Genius et al., 2008). For water resources, the CVM has been valuable for analyzing use and non-use values of water. Numerous studies have been conducted using the CVM to investigate the willingness to pay for reclaimed water use (Chiueh et al., 2011; Bakopoulou et al., 2009; Tziakis et al., 2007; Genius et al., 2008).

The objective of this study was to investigate Oklahoman's hypothetical WTP for reclaimed water as a hedge against drought driven shortages. Since implementing reclaimed water projects will be costly, require cost recovery, and involve previously neglected infrastructures, this study uses WTP in addition to the current per 1000 water fee. When the WTP method is used, it is important to explain clearly what is being valued and provide respondents with realistic price choices. The WTP method can be beneficial in providing hypothetical prices for reclaimed water use and projects as determined by survey respondents that may otherwise be unknown to water managers and municipalities.

Survey Design

An Internet survey was designed in Qualtrics software and administered October 25 - November 1, 2014 to approximately 486 Oklahomans recruited by Survey Sampling International. Human subject research approval was obtained on October 15, 2014 (OSU IRB # AG-14-43). The survey methodology was quantitative and included 33 questions. At the beginning of each survey, definitions were provided for "reclaimed water use system" and "reclaimed water" sources from the ODEQ. Two versions of the survey were created to see how the inclusion of water quality data affected the willingness to pay for reclaimed water use.

One version of the survey contained precise water quality data concerning the standards for the common fecal coliform and E coli contaminant levels of surface waters and reclaimed water categories in Oklahoma. Half of the respondents saw water quality data as a comparison of the bacterial standards for fecal coliform and *E.coli* of recreational surface waters (126 cfu/100mL) and category 2 reclaimed water (23 cfu/100mL) according to the United States Environmental Protection Agency (EPA) and the ODEQ (EPA, 2003; ODEQ, 2012). The hypothesis was that participants who viewed the water quality data would be more likely to support more widespread reclaimed water use because the bacterial standard of fecal coliform for reclaimed water is much more stringent than allowed in surface waters (Figure 1).

The WTP question asked respondents if they were willing to pay an extra fee per 1000 gallons for reclaimed water use on top of what they currently pay per 1000 gallons for water (Figure 2). The bid amounts in the WTP question varied and were randomly distributed in each questionnaire at the values of $0.35; $0.85; $1.35; $1.85; $2.35; $2.85; $3.35. In addition to the reclaimed water WTP question, attitudinal questions about reclaimed water use were included in the survey. The survey asked the participant if he or she believed reclaimed water use was hazardous using a 5-level Likert scale format. Two questions in the survey were related to reclaimed water policy in Oklahoma, asking participants if he or she would support policy that encouraged more widespread reclaimed water use and more local widespread reclaimed water use in their community. These questions were included in the survey to assess participant's perception of reclaimed water use without the use of a monetary vehicle. An additional question asked participants whether he or she believed drought conditions in their community would increase over the next 25 years, using a 5-level Likert scale. This question was used to assess the participant's knowledge and response to drought conditions in their community.

Several socio-demographic and behavioral variables were also included in this survey, and the variables used in the models include: gender, education, household income, employment status, and if they rent or own their home. Summary statistics and variable descriptions for the models are presented in Table 1. Based on the literature, we hypothesize that participants who were males, owned their home, had an advanced degree, were employed, had an annual income over $80,000, and supported reclaimed water use policy in Oklahoma will choose to pay an extra fee per 1000 gallons of water for reclaimed water use (Tsagarakis et al., 2007; Dolnicar and Shafer, 2009; Burfurd et al., 2012; Rock et al., 2012).

Probit Model

A probit model was used to obtain the mean willingness to pay for reclaimed water in SAS 9.3 (SAS, Cary, NC, 27513). The probit model used the Maximum Likelihood Estimate (MLE) to provide a set of values of the model's parameters that maximize the likelihood, or probability, function. The survey data has been modeled using MLE where the likelihood of accepting the bid given for paying for reclaimed water is estimated as a dichotomous choice, 1 if accepted and 0 if not. We assume a type I extreme value distribution for the error terms, where the following expression results for the probability of saying yes (Grafton et al., 2004):

Eq. (1) $\Pr(\text{Yes}) = 1 - \frac{e^{(-\alpha + \beta B)}}{1+e^{(-\alpha+\beta B)}}$

If we assume a normal distribution, the probability that a respondent says yes to the reclaimed water bid question becomes:

Eq. (2) $\Pr(\text{Yes}) = 1 - \Phi(-\alpha + \beta B)$

The expected value for compensating variation is:

Eq. (3) $C = \int_{-\infty}^{0} F(B)dB + \int_{0}^{\infty}\big(1 - F(B)\big)dB$

The following probit model was estimated to empirically model the respondent's willingness to pay for reclaimed water use in Oklahoma:

(Eq. 4)

$$
\begin{aligned}
WTP_i = {} & \beta 0 + \beta_1 H20Bid_i + {} + \beta_2 Quality_i + \beta_3 Gender_i + \beta_4 Twenty_i + \beta_5 Forty_i \\
& + B_6 Sixty_i + \beta_7 Eighty_i + \beta_8 Hundred_i + \beta_9 Rent_i + \beta_{10} RegPol_i \\
& + \beta_{11} Drought_i + \beta_{12} Hazard_i + \varepsilon_i
\end{aligned}
$$

The Bid_i represents the random amount that the respondent was asked to pay; $Quality_i$ is a binary variable that represents one if the respondent received the water quality data, zero otherwise; $Gender_i$ is a binary variable that represents whether the respondent is a female (1) or male (0); $Twenty_i$ is a binary variable that represents whether the respondent has an annual income of $20,000-40,000; $Forty_i$ is a binary variable that represents whether the respondent has an annual income of $40,001-60,000; $Sixty_i$ is a binary variable that represents whether the respondent has an annual income of $60,001-80,000; $Eighty_i$ is a binary variable that represents whether the respondent has an annual income of $80,001-100,000; $Hundred_i$ is a binary variable that represents whether the respondent has an annual income of more than $100,000; $Rent_i$ is a binary variable that represents whether the respondent rents his or her home; $RegPol_i$ is a binary variable that represents whether the respondent supports reclaimed water use policy and regulation in Oklahoma; $Drought_i$ represents the respondent's perception of drought increase over the next 25 years with 1 being definitely yes to drought increase and 5 being definitely no to drought increase; $Hazard_i$ is a binary variable that represents whether the respondent believes reclaimed water use is hazardous; and ε_i is the error term.

The mean WTP estimates were calculated using a 'grand constant' (Giraud et al., 1999), which is determined by multiplying the variable coefficients by their respective mean then summing over all coefficients (without the bid) and dividing by the bid term (Loureiro and Umberger, 2003).

Eq. (4)

$$MeanWT\hat{P} = \frac{\widehat{\beta_0} + \sum_{j=2}^{12}(\widehat{\beta_J}\overline{x_l})}{\widehat{\beta_1}}$$

Results and Discussion

The coefficients for the WTP probit models with and without attitudinal variables are located in Table 32. The models are estimated using the maximum likelihood, and therefore the variable coefficients contribute to the likelihood of a "yes" response. In both the baseline and attitudinal variables models, the reclaimed water bid coefficients were significant at the 1% and 0.5% levels respectively and were also negative, indicating that the probability of a yes response for WTP decreases as the bid amount increases. According to demand theory, the higher the amount requested of the respondent to pay, the lower the probability that the respondent would be willing to pay the amount. The water quality information coefficient was statistically significant at the 0.01 percent level and negative in the baseline model, indicating that as respondents saw the water quality information at the beginning of the survey, the probability of a yes response decreased. This result could be related to the idea of cognitive dissonance, where the respondent chose not to believe the scientific data provided, but rather rely on their own judgment regarding the quality of reclaimed water. Also, the information may have been too complicated for the respondent to comprehend. The female coefficient was statistically significant and negative in the baseline and attitudinal variables models, meaning that the probability of a yes response is smaller if the respondent is a female. The female response supports previous research that males are more likely to pay for reclaimed water use.

The coefficients for the five income levels included in both models were statistically significant and were positive, which negates our hypothesis of income levels of $80,000 and over will contribute to a higher probability of yes responses. This significance suggests that Oklahomans from all income brackets are in favor of reclaimed water use compared to the lowest income group of less than an annual income of $20,000, not just those with a higher amount of discretionary funds. Municipalities that are considering implementing reclaimed water use in their communities but are concerned about the financial impact may find this income data beneficial.

The coefficients for the rent variable in the baseline and attitudinal variables models were both significant and positive at 0.05 level, indicating that the probability of a yes response WTP for reclaimed water use in Oklahoma is larger for renters than homeowners. Homeowners were hypothesized to be more willing to pay for reclaimed water use in Oklahoma, proposing that renters may not support reclaimed water use. Therefore, the results suggest that reclaimed water use can appeal to a larger market of citizens, i.e. renters. Homeowners may be concerned with the effect that reclaimed water use may have on their home property value, while renters may not experience this concern. As for dwelling type, neither coefficients for apartments nor homes were significant in either model. This suggests that water is viewed as a universal necessity, including reclaimed water, regardless of type of home. Age did not prove to be statistically significant for either model, suggesting that reclaimed water use is a relevant issue to all age groups. Education and employment status also proved not to be statistically significant in either of the model's results, contrary to the hypothesis. These findings suggest that employed and more educated citizens do not place a higher value on reclaimed water than those of a different status. Again, this broadens the public appeal and customer base that municipalities can reach when implementing reclaimed water use in their communities.

Three attitudinal variable coefficients were statistically significant in the attitudinal variables model: reclaimed water policy, drought increase, and safety hazard of reclaimed water. The reclaimed water policy coefficient was positive and significant at the 0.001% level, meaning that the probability of a yes response increases if the respondent supports reclaimed water policy and regulation in Oklahoma. Citizen's support for reclaimed water policy and regulation is a key driver for implementation of reclaimed water systems. In regards to drought, the coefficient was negative and significant, indicating that if respondents believed drought will not increase over the next 25 years in their region, the probability of a yes response decreases. The coefficient for the hazard variable, was positive and significant. This result indicates that if respondents believe that reclaimed water use is not hazardous to humans or animals, the probability of a yes response increases. If citizens do not believe reclaimed water is hazardous, then they may be comfortable if more widespread use of reclaimed water is implemented through municipalities into their local water systems in Oklahoma.

The results for the mean WTP estimates for the baseline model and the model with attitudinal variables are located in Table 3. The baseline model mean WTP estimate was $4.20 per 1000 gallons. The attitudinal variables model mean WTP estimate was $4.19 per 1000 gallons. These WTP estimates are higher than the bid amounts given in the survey and show that many respondents were willing to pay for reclaimed water use even when the bids were as high as an additional fee of $3.35 on top of what they currently pay per 1000 gallons of water. In the case for Oklahoma City, the summer 2012 average household water consumption was 10100 gallons (Boyer et al., 2015). The average household summer water consumption multiplied by the average price of water per 1000 gallons in Oklahoma $4.90 would equal $49.49 for a monthly bill (Mayors Counsel of Oklahoma, 2010). Adding the mean WTP estimate of $4.20 and $3.47 per 1000 gallons for reclaimed water use to the hypothetical monthly water bill for summer water consumption would bring the new monthly total to $91.91 and $84.54 respectively. Although price elasticity of demand is low, the higher prices for reclaimed water may spur water conservation behavior. In additions, the Oklahoma City Water Utilities Trust adopted an increasing block two-tier rate structure to encourage water conservation (City of Oklahoma City, 2014).

Conclusion

This case study assesses Oklahoman's willingness to pay for reclaimed water use given different attitudinal variables and water quality information for surface and reclaimed waters. The survey was conducted via the Internet to citizens across Oklahoma. Results indicate that respondents are generally supportive of reclaimed water use and are willing to pay an extra fee per 1000 gallons for more widespread use in Oklahoma.

In particular, our results suggest that Oklahomans who are males, have incomes of \$20,000-100,000+, rent their home, support reclaimed water use policy, and believe reclaimed water is not hazardous are more likely to support reclaimed water use in Oklahoma. The respondent's perception on drought indicated that as potential for drought over the next 25 years decreased, they were more willing to accept reclaimed water. Employment status, education status, age, and home ownership were not statistically significant for the estimated equations. Although the hypothesis stated that education, employment, and home ownership would all influence the support of reclaimed water use in Oklahoma, this suggests that they do not place any additional value to this alternative water source. Homeowners may be more concerned with a long-term stigma of recycled water on housing prices in a municipality than seasonal drought shortages. These findings can have favorable and practical implications for municipalities who have an interest in implementing reclaimed water use in their communities, implying that the supportive customer base is larger than expected.

Overall, public acceptance is an important part of reclaimed water use projects. Opposition to reclaimed water projects often stems from a lack of public education and a negative perception due to public health safety concerns. Incorporating the public when planning to implement reclaimed water projects can benefit the community as a whole. Public education and information that clearly explains the quality and safety of reclaimed water is important to establish support for reclaimed water projects. By using these survey results, water managers and city officials in Oklahoma can facilitate public support for reclaimed water use by educating and incorporating their communities in the development and implementation of reclaimed water projects, therefore alleviating the negative public acceptance. *Analysis of additional survey questions is located in Appendix B.

Table 31: Table 1: Descriptive statistics, variable descriptions, and expected effect on WTP. (Variables measured on a Likert Scale where 1 = Definitely Yes; 5 = Definitely No); RH2O: Reclaimed Water.

Variable	Description	Measure	Expected Effect on WTP	Mean	Std. Dev.	Min.	Max.	Frequency
QUALITY	Water quality data for Oklahoma surface vs. RH2O	1 if provided data, 0 otherwise	+	0.45	0.50	0	1	581
ACCEPTR	WTP for RH2O	1 if accept bid, 0 otherwise	+	0.58	0.49	0	1	491
HAZARD	Considered RH2O hazardous to humans and animals	1 definitely yes to 5 definitely no	-	3	1.05	1	5	503
BIDH20	Bid amount for WTP for RH2O		-/+	1.88	0.98	0.35	3.35	581
RENT	Rent or own their home	1 if renting, 0 if otherwise	-	0.44	0.5	0	1	494
DROUGHT	Drought will increase in region over the next 25 yrs.	1 if definitely yes to 5 if definitely no	+	2.66	0.98	1	5	491
RECUSE	Support RH2O use in their local municipal water system	1 if support more RH2O use, 0 otherwise	+	0.79	0.41	0	1	487
REGPOL	Support regs. to promote RH2O use in Oklahoma	1 if support regulations, 0 otherwise	+	0.8	0.4	0	1	479
AGE	Age in years		-/+	41.91	16.07	18	99	488
FEMALE	Gender	1 if female, 0 otherwise	-	0.71	0.45	0	1	487
APT	Live in an apartment	1 if live in apt., 0	-	0.16	0.37	0	1	486

		otherwise						
TWENTY	Household annual income of $21,000-40,000	1 if annual income is $21,000-40,000, 0 otherwise	-	0.3	0.46	0	1	481

Table 31: Continued.

Variable	Descriptions	Measure	Expected Effect on WTP	Mean	Std. Dev.	Min.	Max.	Frequency
FORTY	Household annual income of $41,000-60,000	1 if annual income is $41,000-60,000, 0 otherwise	-	0.2	0.4	0	1	481
SIXTY	Household annual income of $61,000-80,000	1 if annual income is $61,000-80,000, 0 otherwise	+	0.1	0.30	0	1	481
EIGHTY	Household annual income of $81,000-100,000	1 if annual income is $81,000-100,000, 0 otherwise	+	0.06	0.23	0	1	481
HUNDRED	Household annual income of over $100,000	1 if annual income is $100,000+, 0 otherwise	+	0.11	0.31	0	1	481
HS	Have high school degree	1 if have high school degree, 0 otherwise	-	0.23	0.42	0	1	486
BS	Have a bachelor's degree or higher	1 if have bachelor's degree or higher, 0 otherwise	+	0.32	0.47	0	1	486
UNEMPLOY	Unemployed	1 if unemployed, 0 otherwise	-	0.10	0.3	0	1	481
EMPLOYED	Employed	1 is employed, 0 otherwise	+	0.50	0.5	0	1	481
HOME2	Live in a house	1 is live in a house, 0 otherwise	+	0.7	0.46	0	1	486

Table 32: Probit Model Results of WTP for Reclaimed Water Use in Oklahoma

	Baseline Model			Model with Attitudinal Variables		
Variable	Coefficient	Std. Error	Pr > ChiSq	Coefficient	Std. Error	Pr > ChiSq
Intercept	0.1085	0.3795	0.7749	-0.7427	0.4892	0.129
BidH2O	-0.1132	0.0624	0.07*	-0.1777	0.0676	0.0085**
Quality	-0.2132	0.1257	0.0898*	-0.2138	0.1356	0.1149
Age	-0.00193	0.00446	0.6651	-0.00475	0.00486	0.3281
Gender	-0.304	0.1409	0.031**	-0.341	0.154	0.0268**
Employed	-0.1364	0.1458	0.3494	-0.0664	0.1554	0.6693
Unemploy	-0.208	0.2288	0.3633	-0.1084	0.2463	0.6597
Home2	0.2329	0.1906	0.2218	0.1765	0.2069	0.3938
Apt	0.2334	0.2321	0.3146	0.2379	0.2535	0.348
Twenty	0.4018	0.1749	0.0216**	0.3442	0.1886	0.0679*
Forty	0.7465	0.2054	0.0003***	0.8059	0.2208	0.0003***
Sixty	0.7324	0.248	0.0031**	0.6115	0.2668	0.0219**
Eighty	1.2352	0.3268	0.0002***	1.1499	0.3514	0.0011**
Hundred	1.0589	0.2708	<.0001***	0.9865	0.2898	0.0007***
H.S.	-0.1352	0.1588	0.3946	-0.0753	0.1721	0.6619
B.S.	-0.1548	0.158	0.327	-0.2726	0.1713	0.1115
Rent	0.3518	0.1598	0.0277**	0.3715	0.1703	0.0291**
Regpol				0.7662	0.2214	0.0005***
Recuse				0.2558	0.2291	0.2642
Drought				-0.1207	0.0687	0.0791*
Hazard				0.2225	0.0718	0.0019**

*,**,*** represent the 90%, 95%, and 99% confidence levels respectively

Table 33: Mean Willingness to Pay Estimates for Models

Model	Mean Willingness to Pay Estimate
Baseline	$4.20
Attitudinal Variables	$4.19

Figure 1: Water Quality Data for Surface vs. Reclaimed Waters in Oklahoma

EPA (2008a) reported that there were 549 reported impairments because of *E. coli*, enterococci, or fecal coliform for water bodies in Oklahoma in 2006. Only 10 of these impairments occurred in the IRW (one water body was considered impaired for both enterococci and fecal coliform). Oklahoma's 2008 report was approved by EPA on October 22, 2008 (ODEQ 2008a). The 2008 report lists twelve water bodies in the IRW impaired for PBCR as the result of bacteria. Of those twelve, a source of the bacteria for three water bodies is indicated as Confined Animal Feeding Operations but not specifying poultry (ODEQ 2008a). Possible other sources for all three water bodies include on-site treatment systems (septic systems), grazing in riparian zones, rangeland grazing, wildlife other than waterfowl, and "unknown" (State of Oklahoma VS. Tyson Foods Inc., Case No. 4:05-CV-329-GKF (SAJ)). One of the citizen concerns raised by reuse water is for water quality and public health.

For background, we explain Oklahoma regulations for common bacterial contaminants. The presence of coliform bacteria, including *E. coli* and fecal coliform in lakes, rivers, and streams is a signal of water contamination by human or animal feces. The Environmental Protection Agency maximum for E. coli in recreational water samples is exceeded when above 126 colony-forming units (cfu) per 100 mL of water This means an approximate risk of 8 per 1000 people contracting stomach illness, vomiting or diarrhea as result of contact. In 2012, 77 Oklahoma recreational water bodies went over the *E. coli* bacteria limit By contrast, for water to be considered a Category 2 for reclaimed water in Oklahoma, the Department of Environment Quality states there can be no detectable fecal coliform organisms in four of seven samples, with a maximum positive fecal coliform organism sample of 23 cfu/100mL in three of the samples. Reclaimed water at this level may be used for outdoor irrigation purposes. Water systems following the regulated standards will typically not have problems with treated reuse water.

A summary table of the standard is provided below:

Oklahoma Standards	**Recreational Water**	**Non-Potable Reclaimed Water, Category 2**
	Max 126 cfu/100ml	Max 23 cfu/100 ml

Figure 2: Willingness to Pay for Reclaimed Water Use in Oklahoma Question

In Oklahoma, water prices are increasing due to old infrastructure, urban growth, and the need for water conservation. New pricing rates are often based on usage. Currently water costs $4.90 per 1000 gallons across Oklahoma ($2.73 per 1000 gallons in OKC (Oct. 9); $3.18 per 1000 gallons in Tulsa). The average household uses 7000 gallons per month in the summer.

Would you be willing to pay an extra charge of $X per 1000 gallons to increase reclaimed water use, and thus maintain a sustainable water supply?

○	**Yes**
○	**No**

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CHAPTER IV

SUMMARY

Golf course case study

The irrigation water quality test results showed that the reclaimed water source from Gaillardia Golf Course contained the highest concentrations of total salts (TSS and EC) compared to the additional irrigation water sources. Each of the irrigation water sources contained nutrient concentrations that were above the medium sufficiency ranges. The two reclaimed water irrigation sources both differed in the amount of salts and nutrient concentrations, which could be attributed to treatment processes prior to distribution to each of the golf courses. The soil samples from Quail Creek Golf Course contained the highest amount of total salts (TSS and EC) for the soil samples from the greens, while the total salts concentrations were higher at Gaillardia for the fairways. The nutrient concentrations of the soil samples for the greens and fairways above medium sufficiency ranges varied across each of the golf courses. This can be associated with the quality of the irrigation water, soil type, and cultural management practices for each of these golf courses. The treatment by location data shows that the mean values for soil chemical properties were not statistically different for at least two golf courses for at least one of the locations (greens, fairways, and roughs) for each soil parameter. These results show that many of the soil chemical parameter and water quality issues that are typically connected to reclaimed water also occur with other irrigation water sources, just as groundwater or untreated surface water.

Reclaimed water can be considered a viable option for golf course irrigation if soil and water are properly monitored and best management practices are included in the cultural management plan.

WTP for reclaimed water case study

The public acceptance and willingness to pay survey results indicate that respondents are generally supportive of reclaimed water use and are willing to pay an extra fee per 1000 gallons for more widespread use in Oklahoma. The results suggest that individuals who are males, have incomes of $20,000-100,000+, rent their home, support reclaimed water use policy, and believe reclaimed water is not hazardous are more likely to support reclaimed water use in Oklahoma. Education, employment status, and home ownership were not found to be significant from the results. These findings suggest that reclaimed water use could potentially be valued by a diverse group of Oklahomans, not based upon income, education, employment status, or home ownership. Water quality data was significant when provided to survey respondents, but actually decreased the WTP amount by $0.01, indicating that the information provided may have been too complex for respondents.

Research Limitations and Future Considerations

Golf course case study

Due to the short time frame of this case study, multiple soil and water samples were not taken through different times of the year at these golf courses. A future consideration for this research would be to take soil and water samples during different times of the year to see the impact of reclaimed water irrigation compared to the other water sources over a short and long term. Multiple samples taken throughout the year and through multiple years would also provide data on how weather impacts the soil chemical properties and water quality. In addition to the limited time frame for sampling, the small number of golf courses that irrigate with reclaimed water in the Oklahoma City metropolitan area limited the number of comparisons to be made to other irrigation water sources. As regulations continue to be established to promote the safe use of reclaimed water for irrigation purposes, future research could address how different treatment methods affect the water quality and soil chemical parameters on golf courses that use reclaimed water and how these short-term and long-term effects differ from other irrigation sources.

Another research limitation for this case study was that there was a lack of comprehensive guidelines or standards for soil quality and irrigation water quality for golf courses in Oklahoma. A future consideration for OSU Extension or another research institution would be to create soil and water quality guidelines for golf courses much like the ones that are provided for the agricultural industry. These guidelines could factor in soil type, turfgrass type, fertilizer and soil amendment recommendations, and irrigation water source. These guidelines would be helpful not only for researchers, but also for golf course managers and superintendents who try to monitor their soil and water quality on a consistent and frequent basis.

WTP for reclaimed water survey case study

A limitation faced while conducting the Internet survey was that survey respondents came from an already established pool from Survey Sampling Inc., which limited the amount of accessible Oklahomans. A larger municipality or metropolitan area in Oklahoma interested in conducting a public acceptance or WTP survey in the future may be able to do so through their customer base, which would be more personal and most likely have a larger respondent pool. Future research could focus more on the public acceptance of the specific uses of reclaimed water, such as landscape irrigation or augmentation of drinking water supplies. If individual cities or towns in Oklahoma were interested in conducting a public acceptance survey, they would be able to customize the survey to accurately reflect the water prices and conditions in their community.

Outcomes and Impacts

Based on the results from both of the case studies, reclaimed water can be effectively used for golf course irrigation if properly managed, and there is support for reclaimed water use in Oklahoma. Soils irrigated with reclaimed water exhibited similarities in totals salts and nutrient concentrations with soils from golf courses that used other irrigation water sources. If proper management techniques are enforced, reclaimed water can be effectively utilized as an irrigation source for golf courses. The results from the survey indicate that there is support for reclaimed water use in Oklahoma. Certain behavioral and demographic variables influence this support and should be considered when implementing reclaimed water projects.

As wet and dry periods fluctuate in Oklahoma, so do the potable water supplies. Reclaimed water use could become a practice that municipalities have to implement, and these case studies can provide information regarding the environmental and social aspects related to reclaimed water use in Oklahoma. These case studies have increased the amount of research and data available about reclaimed water use in Oklahoma, regarding the effects on soil chemical properties and the public acceptance and willingness to pay. These findings should prove useful to golf course managers and superintendents as well as city officials, water managers, water regulatory agencies, and academic institutions. Using reclaimed water can help mitigate the effects drought can have on potable water supplies and efficiently utilize the potable water resources in Oklahoma.

APPENDICES

APPENDIX A: ENVIRONMENTAL IMPLCATIONS OF RECLAIMED WATER IRRIGATION ON SOIL CHEMICAL PROPERTIES ON GOLF COURSES IN OKLAHOMA.

Cultural Management Reports

Quail Creek

Annual Plans:

1. Fertilization: This past fall we converted from granular fertilization to fertigation. So, in a perfect world (without all of this rainfall) we should use between 3 and 4 pounds of nitrogen.

2. Aerification: We DryJect (water / dry sand injection) in March and September, then utilize ¼" solid tines in May, June, July and August.

3. Herbicide/Pesticide Application: We spray Greens preventatively throughout the growing season (May-Sept.)

Maintenance Information:

4. Average size of greens? 7500 ft^2

5. Do your greens have internal drainage? Yes

6. Were your greens built according to USGA standards? Yes

7. On average, how many rounds of golf are played at your course annually? 24,000 rounds

8. What is the average mowing height of your greens? Fairways?
   Greens height- .130"
   Fairway height- .5"

9. If applicable, well ID Number: Water right No. – 19940642

Gaillardia

Annual Plans:

1. Fertilization:
   15-0-15 50% slow release spring and fall apps of .65lbs N
   Spray applications of P.Nitrate at .05-.1 N/1000sqft through the year
   Total N around 2.5lbs. 0-0-50 10lbs K/yr. 20lbs of gypsum/yr
2. Aerification:
   ½ cores on 1.5by1.5 spacing in April. Air2G2 machine 3 times/yr 1/2inch crosstines 3 times per year
3. Herbicide/Pesticide Application:

Acelepryn 10oz/Acre last week of April

Maintenance Information:

4. Average size of greens? _____4900____ ft^2
5. Do your greens have internal drainage? Yes

6. Were your greens built according to USGA standards? Yes

7. On average, how many rounds of golf are played at your course annually?13,000

8. What is the average mowing height of your greens? Fairways?
   Greens .110, fwys .400

9. If applicable, well ID Number ________

Jimmie Austin OU

Annual Plans:

1. Fertilization:

Our fertilization plans are adjusted based on environmental conditions. We manage the fertility on Greens, Tees and Fairways very similar, and can adjust our fertility based on the amount of growth we need and/or want to discourage. Typically, N-P-K (**in pounds**) amounts at our facility are usually around 6-2-8 for Fairways, 6-2-8 for Tees and 3-3-9 for Greens.

2. Aerification:

With the qualities of our irrigation water, the excessive and aggressive growth habit of our turf types and the amount of traffic that our facility receives, aerification is very necessary. It is our goal to remove around 20-25% during these aerifications.

3. Herbicide/Pesticide Application:

Herbicide/Pesticide Applications are scheduled and performed when conditions are favorable for the target pest (**whether it is insect, fungal or weed pests**). We schedule applications to be made based on historical data, but have the flexibility to apply and/or not apply based on the impact of environmental conditions.

Maintenance Information:

4. Average size of greens?
   62,000 ft^2

5. Do your greens have internal drainage?
   Yes

6. Were your greens built according to USGA standards?
   Yes

7. On average, how many rounds of golf are played at your course annually?
   22,000

8. What is the average mowing height of your greens? Fairways?
   0.100” Greens, 0.450” Fairways, 0.250” Tees

9. If applicable, well ID Number ________

Hefner

Annual Plans:

1. Fertilization:

Greens about 3# N per year. Biweekly spray applications in season usually two granular applications in spring and one or two in fall.

2. Aerification:

Greens aerification in March try and remove 15%

Greens aerification in September try and remove 5-10%

3. Herbicide/Pesticide Application:

Herbicides are applied twice a year once in spring and once in fall. I use Bensulide and I have used the Anderson goose and crab which is Ronstar and Bensulide. Biweekly Fungicide applications starting in April ending in September "depending on the year and situation". I usually do a grub application in April and a follow up application for grubs and cut worms in June. I am only talking about greens here.

Maintenance Information:

4. Average size of greens? 6,000 ft^2

5. Do your greens have internal drainage? Yes

6. Were your greens built according to USGA standards? Yes

7. On average, how many rounds of golf are played at your course annually? 85,000 this is for two golf courses so probably 40,000 to 45,000 per course

8. What is the average mowing height of your greens? Fairways?

   Greens = .115"
   Fairways = .500"

9. If applicable, well ID Number N/A

Lincoln Park

Annual Plans:

1. Fertilization:

Greens --- 0.5 lbs of N/1000 sq ft per month in March, April, May, Sept, and Oct Fwys and Tees --- 1.5 lbs of N/1000 sq ft in March, 1 lb of N/1000 sq ft in June

2. Aerification: Greens only--- 1x in March with 3/8" tines ~4" deep in 2"x2" pattern, spiked with sand pro spiker 1x/month April through Sept

3. Herbicide/Pesticide Application:

Bensulide, Daconil Action, Appear, Heritage, Headway, Subdue Maxx on greens Ronstar, Glyphosate, 2,4---D amine on west fwys and tees

Barricade, Glyphosate, and 2,4---D on East Course fwys and tees

Maintenance Information:

4. Average size of greens? _________2150 ft

5. Do your greens have internal drainage?

Yes

6. Were your greens built according to USGA standards?

Yes, west built with 5% OM due to decreased recommended value in USGA specs at the time

7. On average, how many rounds of golf are played at your course annually? 65000 approx 37000 on west course 28000 on east course

8. What is the average mowing height of your greens? Fairways? 100/1000" greens and 3/8" fwys

9. If applicable, well ID Number __ N/A

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Lake Hefner Soil and Water Preliminary Analysis Report:

Soil:

Greens:

pH= 6.6-7.6: This is within and slightly above the normal pH range (6.0-7.0) for bermudagrass putting greens. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)= 102.5 lbs/A or 51.25 ppm: This is within the medium sufficiency level range for P (26-54 ppm, Mehlich III).

Potassium (K)= 148 lbs/A or 74 ppm: This is slightly below the medium sufficiency level range for K (75-176 ppm, Mehlich III). As a general rule, potassium (K_2O) requirement is approximately 75-100% of the nitrogen rate applied, although higher levels of potassium are sometimes desirable. Spring and late summer-early autumn are times when potassium applications are commonly made. Lights amounts of potassium also can be applied at 20- to 30-day intervals during heat, drought, and wear stress periods. Potassium sulfate (48 to 53% K_2O), potassium chloride (60 to 62% K_2O), and potassium nitrate (44% K_2O) are the water-soluble potassium carriers most commonly used.

Calcium (Ca)=1772.83 lbs/A or 886.42 ppm: This is above the medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Soil Sulfur (SO_4-S)= 104.88 lbs/A or 52.44 ppm: This is above the medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$). The major concern is that SO_4 can be reduced to forms of S under anaerobic conditions and contribute to black layer formation. SO_4 ions is readily leachable, another method of reduction is application of lime to soil at low rates, which can help “scrub” SO_4 from the system.

Iron (Fe)= 24.53 ppm: This is above the medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA). Fe toxicity can occur in very acidic soils.

Magnesium (Mg)= 381.83 lbs/A or 190.91 ppm: This is slightly above the medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Zinc (Zn)= 11.04 ppm: This is within the medium sufficiency level range for Zn (>2.0, DTPA).

Boron (B)= 0.69 ppm: This is within the suggested medium sufficiency level range for B (0.1-2.0 ppm).

Nitrate (NO_3-N)= 14.5 lbs/A or 7.25 ppm: Supplemental N will need to be applied. Creeping bentgrass greens require about 4 to 6 lbs N/1000 ft^2 or 175 to 262 lbs N/acre annually.

Sodium (Na)= 197.67 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to promote leaching to displace Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 6.25%: This is below the percentage of significant concern for sodic conditions (15%)

Electrical Conductivity (EC)= 2036 umhos/cm or 2.036 mmhos/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

Fairways:

pH= 7.3-7.7: This is within and slightly above the normal range (6.0-7.0) for bermudagrass fairways, and significant turfgrass growth problems would not be expected. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)= 44.5 lbs/A or 22.25 ppm: This is slightly below the suggested medium sufficiency level range for P (26-54 ppm, Mehlich III).

Potassium (K)= 674 lbs/A or 337 ppm: This is above the suggested medium sufficiency level range for K (75-176 ppm, Mehlich III). Supplemental K may be above the adequate level indicated by soil test results. This approach is used to enhance heat, cold, drought, and wear tolerance on fairways. As a general rule, the K requirement is approximately 75-100% of the nitrogen rate being applied; assuming the K soil test is in the high range.

Calcium (Ca)= 5970.33 lbs/A or 2985.17 ppm: This is above the suggested medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Magnesium (Mg)= 1566.33 lbs/A or 783.17 ppm: This is above the suggested medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Soil Sulfur (SO_4-S)=209.33 lbs/A or 104.67 ppm: This is above the suggested medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$). The primary problem of high SO_4 additions onto turfgrass sites occurs when anaerobic conditions (upper surface layering from compaction or salt deposition layering in the soil profile that seals in a particular zone) develop, which transforms SO_4 into reduced S. Reduced S can react with reduced forms of Fe and Mn to create FeS and MnS compounds in the soil that are contributors to black layer, and this condition results in additional anaerobic conditions, leading to the sealing of soil pores. Remediation involves cultivation for better aeration, limiting S additions, and leaching SO_4 as a preventative measure (Carrow & Duncan, 2012).

Iron (Fe)= 42.51 ppm: This is above the suggested medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA).

Zinc (Zn)= 5.6 ppm: This is within the medium sufficiency level range for Zn (>2.0 ppm, DTPA).

Boron (B)= 1.83 ppm: This is within the medium sufficiency level range for B (0.1-2.0 ppm).

Nitrate (NO_3-N)= 15.83 lbs/A 7.92 ppm: Supplemental N may be required. Bermudagrass fairways require 4-5 lbs/1000 ft^2 or 175-218 lbs/acre per year.

Sodium (Na)=514.83 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to move the displaced Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 9.68%: This is below the percentage for significant concern for sodic conditions (15%).

Electrical Conductivity (EC)=4547.5 umhos/cm or 4.5475 mmhos/cm or dS/m: In conjunction with the ESP, this value indicates that the soil is classified as saline (>4000μmhos/cm). The only effective way to reduce salts in the soil is to remove them. Applying the sufficient volume of water to allow net downward movement of salts would be the best management practice.

Irrigation Water:

pH=8.59-8.6: This is slightly above the normal range (6.5-8.4) for irrigation water. A high pH can be a warning that you need to evaluate the water for other chemical constituents. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. To bring the pH down, you can mix sulfuric acid with the irrigation water. By lowering the pH to slightly below 7 (about 6.5), there is little danger of excessively lowering the soil pH to a degree that could harm the turf. One disadvantage to note with this method is that irrigation systems are not completely uniform in distribution, which results in some areas receiving greater acidification than others.

Electrical Conductivity (EC) =1003.67 umhos/cm or 1.0037 mmhos/cm or dS/m: This is within the desired range for EC for irrigation water (0.40-1.20 dS/m).

Sodium Adsorption Ratio (SAR) = 2.43: This is within the preferred range or limit (<6.0) for irrigation water quality.

Hardness= 334.67 ppm: This water is considered "hard" (150-300 mg/l or ppm of $CaCO_3$). Hard water can lead to scaling in pipes, but is usually not as important to turf managers.

Residual Sodium Carbonate (RSC)= -3.27 ((CO_3+HCO_3) – (Ca+Mg)): This is within the desired range for RSC (<1.25). This value indicates that there is not a Na hazard. Ca and Mg will not be precipitated as carbonates from irrigation water, but will remain active to prevent Na accumulation on CEC sites.

Alkalinity= 174.33 ppm as $CaCO_3$: This is above the desired range (<150 ppm) for irrigation water quality. Most irrigation waters range between 20 to 300 mg/l or ppm of $CaCO_3$ equivalent (Duncan, et al, 2009).

Total Soluble Salts (TSS)=749.24 in ppm: This is within the desired range (256-832 ppm) for irrigation water quality.

Bicarbonate (HCO_3)=191.13 ppm: This is above the desired range (<120 ppm), but within the usual range (<610 ppm) for irrigation water. Although HCO_3 >500 ppm (8.2 meq/l) can cause unsightly, but not harmful, deposits on foliage of plants, HCO_3 or CO_3 levels that result in turfgrass nutritional problems are not specific. Instead, the imbalance of HCO_3 and CO_3 with Na, Ca, and Mg is the most important consideration.

Calcium (Ca)= 75 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

Boron (B)= 0.2 ppm: This is within the desired range (<0.5 ppm) for irrigation water quality.

Sodium (Na)= 103 ppm: This is slightly above the standard for moderate to high Na content (>100 ppm) in irrigation water quality.

Sulfate (SO_4)= 202.8 ppm: This is above the desired range for SO_4 (100-200 ppm) for irrigation water quality. Irrigation water at 200 ppm SO_4 would supply 4.2 lbs S per 1000 ft^2 per acre-foot of reclaimed water (Duncan, Carrow, Huck, 2009). The best management practice to reducing high levels is by leaching. Another method is by application of lime to the soil at low rates, which can help "scrub" SO_4 from the system. As SO_4 in the irrigation water reacts with Ca from the lime, gypsum ($CaCO_3$) is created. In this form, S is much less soluble and is protected from beginning reduced (more stable). Application of 10 lb $CaCO_3$ per 1000 ft^2 provides about 3.8 lb Ca that can react with 9.1 lb SO_4, which is equivalent to 3 lb S per 1000 ft$^{.}$ Thus for every 3 lb elemental S (or the equivalent rate of 9.1 lb SO_4) added with irrigation water, 3.8 lb Ca will remove the S through the process of gypsum formation.

Chloride (Cl)= 122.83 ppm: This is above the desired range (<100 ppm) for irrigation water quality. Chloride salts are quite soluble, so they can be leached from well-drained soils with good subsurface drainage.

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Quail Creek Soil and Water Preliminary Analysis Report:

Soil:

Greens:

pH= 8.2-8.4: This is slightly above the normal pH range (5.5-6.5) for bentgrass greens. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)= 93.5 lbs/A or 46.75 ppm: This is within the medium sufficiency level range for P (26-54 ppm, Mehlich III).

Potassium (K)= 253.67 lbs/A or 126.84 ppm: This is within the medium sufficiency level range for K (75-176 ppm, Mehlich III).

Calcium (Ca)=3494.5 lbs/A or 1747.25 ppm: This is above the medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Soil Sulfur (SO_4-S)= 159.5 lbs/A or 79.75 ppm: This is above the medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$). The major concern is that SO_4 can be reduced to forms of S under anaerobic conditions and contribute to black layer formation. SO_4 ions is readily leachable, another method of reduction is application of lime to soil at low rates, which can help “scrub” SO_4 from the system.

Iron (Fe)= 9.3165 ppm: This is within the medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA).

Magnesium (Mg)= 275 lbs/A or 137.5 ppm: This is within the medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Zinc (Zn)= 3.9575 ppm: This is within the medium sufficiency level range for Zn (>2.0, DTPA).

Boron (B)= 2.038 ppm: This is slightly above the suggested medium sufficiency level range (0.1-2.0 ppm).

Nitrate (NO_3-N)= 12.33 lbs/A 6.17 ppm: Supplemental N will need to be applied. Creeping bentgrass greens require about 4 to 6 lbs N/1000 ft^2 or 175 to 262 lbs N/acre annually.

Sodium (Na)= 593.83 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to promote leaching to displace Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 16.683%: This is above the percentage of significant concern for sodic conditions (15%), which indicates sodic soil conditions.

Electrical Conductivity (EC)= 4782.5 umhos/cm or 4.7925 mmhos/cm or dS/m: In conjunction with the ESP, this value indicates saline-sodic soil conditions. This can cause osmotic stress. The presence of excessive salts in soils causes plants to prematurely suffer drought stress even though substantial water may be present in the soil. Osmotic potential is a direct result of the combined concentrations of dissolved Na, Ca, K, and Mg cations, and Cl, HCO_3, SO_4, and CO_3 anions which are common constituents in salty water. The only effective way to reduce salts in soil is to remove them. This can be done either by leaching the salts out of the root zone or by plant uptake and removal. Adding organic matter and installing drain tiles can improve soil drainage. However, gypsum is needed to reclaim sodic soils by replacing Na with Ca on soil particles.

Fairways:

pH= 7.6-8.1: This is above the normal range (6.0-7.0) for bermudagrass fairways, and significant turfgrass growth problems would not be expected. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)= 205.5 lbs/A or 102.75 ppm: This is above the suggested medium sufficiency level range for P (26-54 ppm, Mehlich III). No additional P fertilizer is required at this time, but levels can be monitored over time. Over- or misapplication of P can be a concern for urban runoff into surface waters.

Potassium (K)= 956.167 lbs/A or 478.08 ppm: This is above the suggested medium sufficiency level range for K (75-176 ppm, Mehlich III). Supplemental K may be above the adequate level indicated by soil test results. This approach is used to enhance heat, cold, drought, and wear tolerance on fairways. As a general rule, the K requirement is approximately 75-100% of the nitrogen rate being applied; assuming the K soil test is in the high range.

Calcium (Ca)= 9716.83 lbs/A or 4858.42 ppm: This is above the suggested medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Magnesium (Mg)= 886.33 lbs/A or 443.17 ppm: This is above the suggested medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Soil Sulfur (SO_4-S)=102 lbs/A or 51 ppm: This is above the suggested medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$). The primary problem of high SO_4 additions onto turfgrass sites occurs when anaerobic conditions (upper surface layering from compaction or salt deposition layering in the soil profile that seals in a particular zone) develop, which transforms SO_4 into reduced S. Reduced S can react with reduced forms of Fe and Mn to create FeS and MnS compounds in the soil that are contributors to black layer, and this condition results in additional anaerobic conditions, leading to the sealing of soil pores. Remediation involves cultivation for better aeration, limiting S additions, and leaching SO_4 as a preventative measure (Carrow & Duncan, 2012).

Iron (Fe)= 35.65 ppm: This is above the suggested medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA).

Zinc (Zn)= 6.57 ppm: This is within the medium sufficiency level range for Zn (>2.0 ppm, DTPA).

Boron (B)= 3.63 ppm: This is above the medium sufficiency level range for B (0.1-2.0 ppm).

Nitrate (NO_3-N)= 24.17 lbs/A or 12.09 ppm: Supplemental N may be required. Bermudagrass fairways require 4-5 lbs/1000 ft^2 or 175-218 lbs/acre per year.

Sodium (Na)=460.5 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to move the displaced Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 11.81%: This is below the percentage for significant concern for sodic conditions (15%).

Electrical Conductivity (EC)=3798.5 umhos/cm or 3.7985 mmhos/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

Irrigation Water:

pH=8.19-8.2: This is within the normal range (6.5-8.4) for irrigation water.

Electrical Conductivity (EC)=716.33 umhos/cm or 0.7163 mmhos/cm or dS/m: This is within the desired range for EC for irrigation water (0.40-1.20 dS/m).

Sodium Adsorption Ratio (SAR)= 7.2: This is above the preferred range or limit (<6.0), but within the usual range (<15) for irrigation water.

Hardness= 70.33 ppm: This is within the desired range for Hardness (<150 ppm) in irrigation water.

Residual Sodium Carbonate (RSC)= 2.92 ((CO_3+HCO_3) – (Ca+Mg)): This is above the desired range for RSC (<1.25). This value indicates that all or most of the Ca and Mg removed as carbonate precipitates, leaving Na to accumulate. When Na is present along with a high (positive) RSC, sodium carbonate forms at the same time Na displaces Ca and Mg from soil CEC sites; and the soil becomes increasingly sodic. In order to mitigate sodic soils, sufficient Ca must be added to displace Na in the sodium carbonate and on the CEC sites.

Alkalinity= 215.67 ppm as $CaCO_3$: This is above the desired range (<150 ppm) for irrigation water quality. Most irrigation waters range between 20 to 300 mg/l or ppm of $CaCO_3$ equivalent (Duncan, Carrow, and Huck, 2009).

Total Soluble Salts (TSS)=567.6 in ppm: This is within the desired range (256-832 ppm) for irrigation water quality.

Bicarbonate (HCO_3)= 263.3 ppm: This is above the desired range (<120 ppm), but within the usual range (<610 ppm) for irrigation water. Although HCO_3 >500 ppm (8.2 meq/l) can cause unsightly, but not harmful, deposits on foliage of plants, HCO_3 or CO_3 levels that result in turfgrass nutritional problems are not specific. Instead, the imbalance of HCO_3 and CO_3 with Na, Ca, and Mg is the most important consideration.

Calcium (Ca)=16 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

Boron (B)= 0.8 ppm: This is within the desired range (<0.5 ppm) for irrigation water quality.

Sodium (Na)= 138.67 ppm: This is slightly above the standard for moderate to high Na content (>100 ppm) in irrigation water quality.

Soil Sulfur (SO_4-S)=103.37 ppm: This is above the desired range for SO_4 (100-200 ppm) for irrigation water quality. Irrigation water at 200 ppm SO_4 would supply 4.2 lbs S per 1000 ft^2 per acre-foot of reclaimed water (Duncan, Carrow, Huck, 2009). The best management practice to reducing high levels is by leaching. Another method is by application of lime to the soil at low rates, which can help "scrub" SO_4 from the system. As SO_4 in the irrigation water reacts with Ca from the lime, gypsum ($CaCO_3$) is created. In this form, S is much less soluble and is protected from beginning reduced (more stable). Application of 10 lb $CaCO_3$ per 1000 ft^2 provides about 3.8 lb Ca that can react with 9.1 lb SO_4, which is equivalent to 3 lb S per 1000 ft$^{.}$ Thus for every 3 lb elemental S (or the equivalent rate of 9.1 lb SO_4) added with irrigation water, 3.8 lb Ca will remove the S through the process of gypsum formation.

Chloride (Cl) = 35.8 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

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Jimmie Austin OU Soil and Water Preliminary Analysis Report

Soil:

Greens:

pH=7.2-8.3: This is slightly above the normal range (especially greens 12, 15, & 18), and could result in some reduced availability of nutrients as pH increases. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)=98.67 lbs/A or 49.34 ppm: This is within the medium sufficiency level range for P (26-54 ppm, Mehlich III).

Potassium (K)= 111.83 lbs/A or 55.92 ppm: This is within the medium sufficiency level range for K (75-176 ppm, Mehlich III).

Calcium (Ca)=1394.67 lbs/A or 697.34 ppm: This is within the medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Soil Sulfur (SO_4-S)= 33.21 lbs/A or 16.61 ppm: This is within medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$).

Iron (Fe)= 13.73 ppm: This is within the medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA). Fe toxicity can occur in very acidic soils, but that is not a concern at this time since the current soil pH is 7.2-8.3.

Magnesium (Mg)= 173.67 lbs/A or 86.84 ppm: This is within the medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Zinc (Zn)= 5.73 ppm: This is within the medium sufficiency level range for Zn (>2.0, DTPA).

Boron (B)= 0.57 ppm: This is within the suggested medium sufficiency level range (0.1-2.0 ppm).

Nitrate (NO_3-N)= 8.67 lbs/A or 4.34 ppm: Supplemental N will need to be applied. Creeping bentgrass greens require about 4 to 6 lbs N/1000 ft^2 or 175 to 262 lbs N/acre annually.

Sodium (Na)= 88.83 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to promote leaching to displace Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)=4.32%: This is below the percentage of significant concern for sodic conditions (15%).

Electrical Conductivity (EC)= 918 umhos/cm or 0.918 mmhos/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

Fairways:

pH= 7-7.5: This falls within the normal range, and significant turfgrass growth problems would not be expected.

Phosphorus (P)= 242.17 lbs/A or 121.09 ppm: This is above the suggested medium sufficiency level range for P (26-54 ppm, Mehlich III). No additional P fertilizer is required at this time, but levels can be monitored over time. Over- or misapplication of P can be a concern for urban runoff into surface waters.

Potassium (K)= 586 lbs/A or 293 ppm: This is above the suggested medium sufficiency level range for K (75-176 ppm, Mehlich III). Supplemental K may be above the adequate level indicated by soil test results. This approach is used to enhance heat, cold, drought, and wear tolerance on fairways. As a general rule, the K requirement is approximately 75-100% of the nitrogen rate being applied; assuming the K soil test is in the high range (Beard, 2002).

Calcium (Ca)= 2753.67 lbs/A or 1376.84 ppm: This is above the suggested medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Magnesium (Mg)= 570.83 lbs/A or 285.42 ppm: This is above the suggested medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Soil Sulfur (SO_4-S)=47.05 lbs/A or 23.53 ppm: This is slightly above the suggested medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$). The primary problem of high SO_4 additions onto turfgrass sites occurs when anaerobic conditions (upper surface layering from compaction or salt deposition layering in the soil profile that seals in a particular zone) develop, which transforms SO_4 into reduced S. Reduced S can react with reduced forms of Fe and Mn to create FeS and MnS compounds in the soil that are contributors to black layer, and this condition results in additional anaerobic conditions, leading to the sealing of soil pores. Remediation involves cultivation for better aeration, limiting S additions, and leaching SO_4 as a preventative measure (Carrow & Duncan, 2012).

Iron (Fe)= 55.83 ppm: This is above the suggested medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA).

Zinc (Zn)= 3.32 ppm: This is within the medium sufficiency level range for Zn (>2.0 ppm, DTPA).

Boron (B)= 1.33 ppm: This is within the medium sufficiency level range for B (0.1-2.0 ppm).

Nitrate (NO_3-N)= 15.67 lbs/A or 7.84 ppm: Supplemental N may be required. Bermudagrass fairways require 4-5 lbs/1000 ft^2 or 175-218 lbs/acre per year.

Sodium (Na)=199.33 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to move the displaced Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 8.2 %: This is below the percentage for significant concern for sodic conditions (15%).

Electrical Conductivity (EC)=759 umhos/cm or 0.759 mmhos/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

Irrigation Water:

Reclaimed Water:

pH=7.1-7.16: This is within the normal range (6.5-8.4) for irrigation water.

Electrical Conductivity (EC)=665 umhos/cm or 0.665 mmhos/cm or dS/m: This is within the desired range for EC for irrigation water (0.40-1.20 dS/m).

Sodium Adsorption Ratio (SAR)= 3.47: This is within the preferred range or limit (<6.0) for irrigation water quality.

Hardness= 124.67 ppm: This is within the desired range for Hardness (<150 ppm) for irrigation water.

Residual Sodium Carbonate (RSC)= -0.70 ((CO_3+HCO_3) – (Ca+Mg)): This is within the desired range for RSC (<1.25). This value indicates that there is not a Na hazard. Ca and Mg will not be precipitated as carbonates from irrigation water, but will remain active to prevent Na accumulation on CEC sites.

Alkalinity= 91 ppm as $CaCO_3$: this is within the desired range (<150 ppm) for irrigation water quality.

Total Soluble Salts (TSS)=443.45 in ppm: This is within the desired range (256-832 ppm) for irrigation water quality.

Bicarbonate (HCO_3)=110.9 ppm: This is within the desired range (<120 ppm) for irrigation water quality.

Calcium (Ca)=26.67 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

Boron (B)= 0.4 ppm: This is within the desired range (<0.5 ppm) for irrigation water quality.

Sodium (Na)=89.67 ppm: This is below the standard for moderate to high Na content (>100 ppm) in irrigation water quality.

Sulfate (SO_4)=55.47 ppm: This is below the desired range for SO_4 (100-200 ppm) for irrigation water quality.

Chloride (Cl)= 96.07 ppm: This is within the desired range (<100 ppm) for irrigation water quality. Chloride salts are quite soluble, so they can be leached from well-drained soils with good subsurface drainage.

Groundwater:

pH: 7.849-7.935: This is within the desired range for pH (6.5-8.5) for irrigation water. A high pH can be a warning that you need to evaluate the water for other chemical constituents. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. To bring the pH down, you can mix sulfuric acid with the irrigation water. By lowering the pH to slightly below 7 (about 6.5), there is little danger of excessively lowering the soil pH to a degree that could harm the turf. One disadvantage to note with this method is that irrigation systems are not completely uniform in distribution, which results in some areas receiving greater acidification than others.

Electrical Conductivity (EC)=663 umhos/cm or 0.663 mmhos/cm or dS/m: This is within the desired range for EC for irrigation water (0.40-1.20 dS/m).

Sodium Adsorption Ratio (SAR)=0.9: This is below the preferred range or limit (<6.0) for irrigation water quality.

Hardness= 300 ppm: This water is considered “hard” (150-300 mg/l or ppm of $CaCO_3$). Hard water can lead to scaling in pipes, but is usually not as important to turf managers.

Residual Sodium Carbonate (RSC)= -0.39 ((CO_3+HCO_3) – (Ca+Mg)): This is within the desired range for RSC (<1.25). This value indicates that there is not a Na hazard. Ca and Mg will not be precipitated as carbonates from irrigation water, but will remain active to prevent Na accumulation on CEC sites.

Alkalinity= 280.5 ppm as $CaCO_3$: This is above the desired range (<150 ppm) of alkalinity for irrigation water. Alkalinity is typically not as important to turf managers compared to RSC.

Total Soluble Salts (TSS)=551.07 ppm: This is within the desired range (256-832 ppm) for irrigation water quality.

Bicarbonate (HCO_3)=341.9 ppm: This is above the desired range of (<120 ppm), but within the usual range (<610) for irrigation water.

Calcium (Ca)=80 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

Boron (B)=0.2 ppm: This is within the desired range (<0.5 ppm) for irrigation water quality.

Sodium (Na)=36.5 ppm: This is below the standard for moderate to high Na content (>100 ppm) in irrigation water quality.

Sulfate (SO_4)=32.75 ppm: This is below the desired range for SO_4 (100-200 ppm) for irrigation water quality.

Chloride (Cl)=32.95 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

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Gaillardia Soil and Water Analysis Report

Soil:

Greens:

pH= 7.3-7.6: this is within the normal range, and significant turfgrass growth problems would not be expected. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)= 71. 83 lbs/A or 35.92 ppm: this is within the suggested medium sufficiency level range (26-54 ppm for Mehlich III).

Potassium (K)= 113.17 lbs/A or 56.59 ppm: this is within the suggested medium sufficiency level range (75-176 ppm, Mehlich III)..

Calcium (Ca)= 1418.5 lbs/A or 709.25 ppm: this is within the suggested medium sufficiency level range (500-750 ppm for Mehlich III).

Soil Sulfur (SO_4-S)=85.83 lbs/A or 42.92 ppm: this is higher than the suggested medium sufficiency level range (10-20 ppm). The major concern is that SO_4 can be reduced to forms of S under anaerobic conditions and contribute to black layer formation. SO_4 ions is readily leachable, another method of reduction is application of lime to soil at low rates, which can help “scrub” SO_4 from the system.

Iron (Fe)= 18.04 ppm: this is higher than the suggested medium sufficiency level range (10.0-15.0 ppm). Fe toxicity can occur in very acidic soils, but that is not a concern at this time since the current soil pH is 7.3-7.6.

Zinc (Zn)= 8.95 ppm: this is within the suggested medium sufficiency level range for Zn (>2.0 ppm).

Boron (B)= 0.79 ppm: this is within the suggested medium sufficiency level range. (0.1-2.0 ppm).

Nitrate (NO_3-N)= 10.83 lbs/A 5.42 ppm: Supplemental N will need to be applied. Creeping bentgrass greens require about 4 to 6 lbs N/1000 ft^2 or 175 to 262 lbs N/acre annually.

Sodium (Na)= 223 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to promote leaching to displace Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 7.68: this is below the percentage for significant concern for sodic conditions (15%).

Electrical Conductivity (EC)= 2097.5 µmhos/cm or 2.0975 mmho/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

<u>Fairways:</u>

pH=7.3-7.5: this falls within the normal range, and significant turfgrass growth problems would not be expected.

Phosphorus (P)= 193.5 lbs/A or 96.75 ppm: this is above the suggested medium sufficiency level range for P (26-54 ppm). No additional P fertilizer is required at this time, but levels can be monitored over time. Over- or misapplication of P can be a concern for urban runoff into surface waters.

Potassium (K)= 878 lbs/A or 439 ppm: this is above the suggested medium sufficiency level range for K (75-176 ppm).

Calcium (Ca)= 8668 lbs/A or 4334 ppm: this is above the suggested medium sufficiency level range for Ca (500-750 ppm).

Soil Sulfur (SO_4-S)= 222.17 or 111.9 ppm: this is higher than the suggested medium sufficiency level range for SO_4 (10-20 ppm). The major concern is that SO_4 can be reduced to forms of S under anaerobic conditions and contribute to black layer formation. SO_4 ions is readily leachable, another method of reduction is application of lime to soil at low rates, which can help "scrub" SO_4 from the system.

Iron (Fe)= 38.17 ppm: this is significantly higher than the suggested medium level range for Fe (10.0-15.0 ppm). Fe toxicity can occur in very acidic soils, but that is not a concern at this time since the current soil pH is 7.3-7.5.

Zinc (Zn)= 8.2 ppm: this is within the suggested medium level range for Zn (>2.0 ppm).

Boron (B)= 2.55: this is slightly above the suggested medium sufficiency level range for B (0.1-2.0 ppm). The major symptom of boron toxicity in turfgrass is necrosis at leaf tips. Mowing regularly removes accumulated Boron. Irrigation water high in Boron may require applying additional water for leaching Boron out of soil.

Nitrate (NO_3-N)=24 lbs/A or 12 ppm: Supplemental N may be required. Bermudagrass fairways require 4-5 lbs/1000 ft^2 or 175-218 lbs/acre per year.

Sodium (Na)= 468 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to move the displaced Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 7.71: this is below the percentage for significant concern for sodic conditions (15%).

Electrical Conductivity (EC)=5567 µmhos/cm or 5.567 mmho/cm or dS/m: In conjunction with the ESP, this soil would be considered saline (>4000µmhos/cm). The only effective way to reduce salts in the soil is to remove them. Applying the sufficient volume of water to allow net downward movement of salts would be the best management practice.

Irrigation Water:

pH= 9.24: this is above the desired range for pH (6.5-8.5). A high pH can be a warning that you need to evaluate the water for other chemical constituents. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. To bring the pH down, you can mix sulfuric acid with the irrigation water. By lowering the pH to slightly below 7 (about 6.5), there is little danger of excessively lowering the soil pH to a degree that could harm the turf. One disadvantage to note with this method is that irrigation systems are not completely uniform in distribution, which results in some areas receiving greater acidification than others.

Electrical Conductivity (EC)= 1280.33 µmhos/cm or 1.28 mmho/cm or dS/m: this is slightly above the desired range (0.7-1.20 dS/m) but within the usual range (<3.0 dS/m). Irrigation water with EC above 3.0 dS/m can cause deleterious accumulation of salts in the soil.

Sodium Adsorption Ratio (SAR)=3.7: this is within the desired level (<6.0) for irrigation water quality.

Hardness= 277.67 ppm: this water is considered “hard” (150-300 mg/l or ppm of $CaCO_3$). Hard water can lead to scaling in pipes, but is usually not as important to turf managers.

Residual Sodium Carbonate (RSC)= -3.72 ((CO_3+HCO_3) – (Ca+Mg)): this value indicates that there is not a Na hazard (<1.25). Ca and Mg will not be precipitated as carbonates from irrigation water, but will remain active to prevent Na accumulation on CEC sites.

Alkalinity=95 ppm as $CaCO_3$: this is within the desire range for irrigation water quality.

Total Soluble Salts (TSS)= 845.02 ppm: this is slightly above the desired range (256-832 ppm), but within the usual range (<2000 ppm) for irrigation water quality.

Bicarbonate (HCO_3)= 53.83 ppm: this is within the desired range (<90 ppm) for irrigation water quality.

Calcium (Ca)= 61 ppm: this is within the desired range (<100 ppm) for irrigation water quality.

Boron (B)= 0.4 ppm: this is within the desired range (<0.5 ppm) for irrigation water quality.

Sodium (Na)=142.33 ppm: this is considered in the moderate to high content range (>100 ppm) for irrigation water quality, although there is no single Na concentration value in irrigation water that indicates a problem in all situations. A close evaluation of excess Na and its potential to accumulate in the soil profile relative to Ca and Mg concentrations is a valuable consideration.

Sulfate (SO_4)= 206.03 ppm: this is slightly above the desired range (100-200 ppm). Irrigation water at 200 ppm SO_4 would supply 4.2 lbs S per 1000 ft^2 per acre-foot of reclaimed water (Duncan, Carrow, Huck, 2009). The best management practice to reducing high levels is by leaching.

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Lincoln Park Soil and Water Preliminary Analysis Report

Soil:

Greens:

pH= 6.6-6.8: This is within and slightly above the normal pH range (5.5-6.5) for bentgrass putting greens.

Phosphorus (P)=73.33 lbs/A or 36.67 ppm: This is within the medium sufficiency level range for P (26-54 ppm, Mehlich III).

Potassium (K)= 132.67 lbs/A or 66.34 ppm: This is slightly below the medium sufficiency level range for K (75-176 ppm, Mehlich III). As a general rule, potassium (K_2O) requirement is approximately 75-100% of the nitrogen rate applied, although higher levels of potassium are sometimes desirable. Spring and late summer-early autumn are times when potassium applications are commonly made. Lights amounts of potassium also can be applied at 20- to 30-day intervals during heat, drought, and wear stress periods. Potassium sulfate (48 to 53% K_2O), potassium chloride (60 to 62% K_2O), and potassium nitrate (44% K_2O) are the water-soluble potassium carriers most commonly used.

Calcium (Ca)=1444.17 lbs/A or 722.09 ppm: This is within the medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Soil Sulfur (SO_4-S)= 23.79 lbs/A or 11.9 ppm: This is within medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$).

Iron (Fe)= 41.2 ppm: This is above the medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA). Fe toxicity can occur in very acidic soils.

Magnesium (Mg)= 173.67 lbs/A or 86.84 ppm: This is within the medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Zinc (Zn)= 49.43 ppm: This is within the medium sufficiency level range for Zn (>2.0, DTPA).

Boron (B)= 0.17 ppm: This is within the suggested medium sufficiency level range (0.1-2.0 ppm).

Nitrate (NO_3-N)= 9.83 lbs/A 4.92 ppm: Supplemental N will need to be applied. Creeping bentgrass greens require about 4 to 6 lbs N/1000 ft^2/year or 175-262 lbs./A annually.

Sodium (Na)= 22.5 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to promote leaching to displace Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= <DL (less than detectable limit): This is below the percentage of significant concern for sodic conditions (15%).

Electrical Conductivity (EC)= 744.5 umhos/cm or 0.745 mmhos/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

Fairways:

pH=6.8-7.5 : This is within and slightly above the normal range (6.0-7.0) for bermudagrass fairways, and significant turfgrass growth problems would not be expected. At pH of 8, deficiencies in nutrients in P, Fe, Mn, B, Cu, and Zn can occur. Reducing pH through acidifying fertilizers can help reduce soil pH over a longer period. However, use of acidifying fertilizers such as elemental S can result in layering problems in golf greens. We do not generally suggest the addition of sulfur to greens. The soil pH tends to follow the pH of the irrigation water used on putting greens.

Phosphorus (P)= 122 lbs/A or 61 ppm: This is above the suggested medium sufficiency level range for P (26-54 ppm, Mehlich III). No additional P fertilizer is required at this time, but levels can be monitored over time. Over- or misapplication of P can be a concern for urban runoff into surface waters.

Potassium (K)= 509.17 lbs/A or 254.59 ppm: This is above the suggested medium sufficiency level range for K (75-176 ppm, Mehlich III). Supplemental K may be above the adequate level indicated by soil test results. This approach is used to enhance heat, cold, drought, and wear tolerance on fairways. As a general rule, the K requirement is approximately 75-100% of the nitrogen rate being applied; assuming the K soil test is in the high range.

Calcium (Ca)= 3331.17 lbs/A or 1665.59 ppm: This is above the suggested medium sufficiency level range for Ca (500-750 ppm, Mehlich III).

Magnesium (Mg)= 709 lbs/A or 354.50 ppm: This is above the suggested medium sufficiency level range for Mg (70-140 ppm, Mehlich III).

Soil Sulfur (SO_4-S)=16.52 lbs/A or 8.26 ppm: This is within the suggested medium sufficiency level range for SO_4 (10-20 ppm, $Ca(H_2PO_4)_2$).

Iron (Fe)= 62.27 ppm: This is above the suggested medium sufficiency level range for Fe (10.0-15.0 ppm, DTPA).

Zinc (Zn)= 7.18 ppm: This is within the medium sufficiency level range for Zn (>2.0 ppm, DTPA).

Boron (B)= 0.29 ppm: This is within the medium sufficiency level range for B (0.1-2.0 ppm).

Nitrate (NO_3-N)= 13.83 lbs/A or 6.92 ppm: Supplemental N may be required. Bermudagrass fairways require 4-5 lbs/1000 ft^2 or 175-218 lbs/acre per year.

Sodium (Na)=54.5 ppm: Sodium can be removed from soil exchange sites through addition of gypsum ($CaSO_4$) (Ca will replaced Na on soil exchange sites, Na will combine with SO_4 and become soluble) and irrigating to move the displaced Na through the soil profile.

Exchangeable Sodium Percentage (ESP%)= 1.05 or <DL (less than detectable limit)%: This is below the percentage for significant concern for sodic conditions (15%).

Electrical Conductivity (EC)=1152 umhos/cm or 1.52 mmhos/cm or dS/m: In conjunction with the ESP, this value falls within the normal soil range for EC.

Irrigation Water:

pH=7.44-7.55: This is within the normal range (6.5-8.4) for irrigation water.

Electrical Conductivity (EC)=161.7 umhos/cm or 0.1617 mmhos/cm or dS/m: This is within the desired range for EC for irrigation water (0.40-1.20 dS/m).

Sodium Adsorption Ratio (SAR)= 0.47: This is within the preferred range or limit (<6.0) for irrigation water quality.

Hardness= 58.33 ppm: This is within the desired range for Hardness (<150 ppm) in irrigation water.

Residual Sodium Carbonate (RSC)= -0.38 ((CO_3+HCO_3) – (Ca+Mg)): This is within the desired range for RSC (<1.25). This value indicates that there is not a Na hazard. Ca and Mg will not be precipitated as carbonates from irrigation water, but will remain active to prevent Na accumulation on CEC sites.

Alkalinity= 41 ppm as $CaCO_3$: This is within the desired range (<150 ppm) for irrigation water quality.

Total Soluble Salts (TSS)=109.31 in ppm: This is below the desired range (256-832 ppm) for irrigation water quality.

Bicarbonate (HCO_3)=49.77 ppm: This is within the desired range (<120 ppm) for irrigation water quality.

Calcium (Ca)=17.33 ppm: This is within the desired range (<100 ppm) for irrigation water quality.

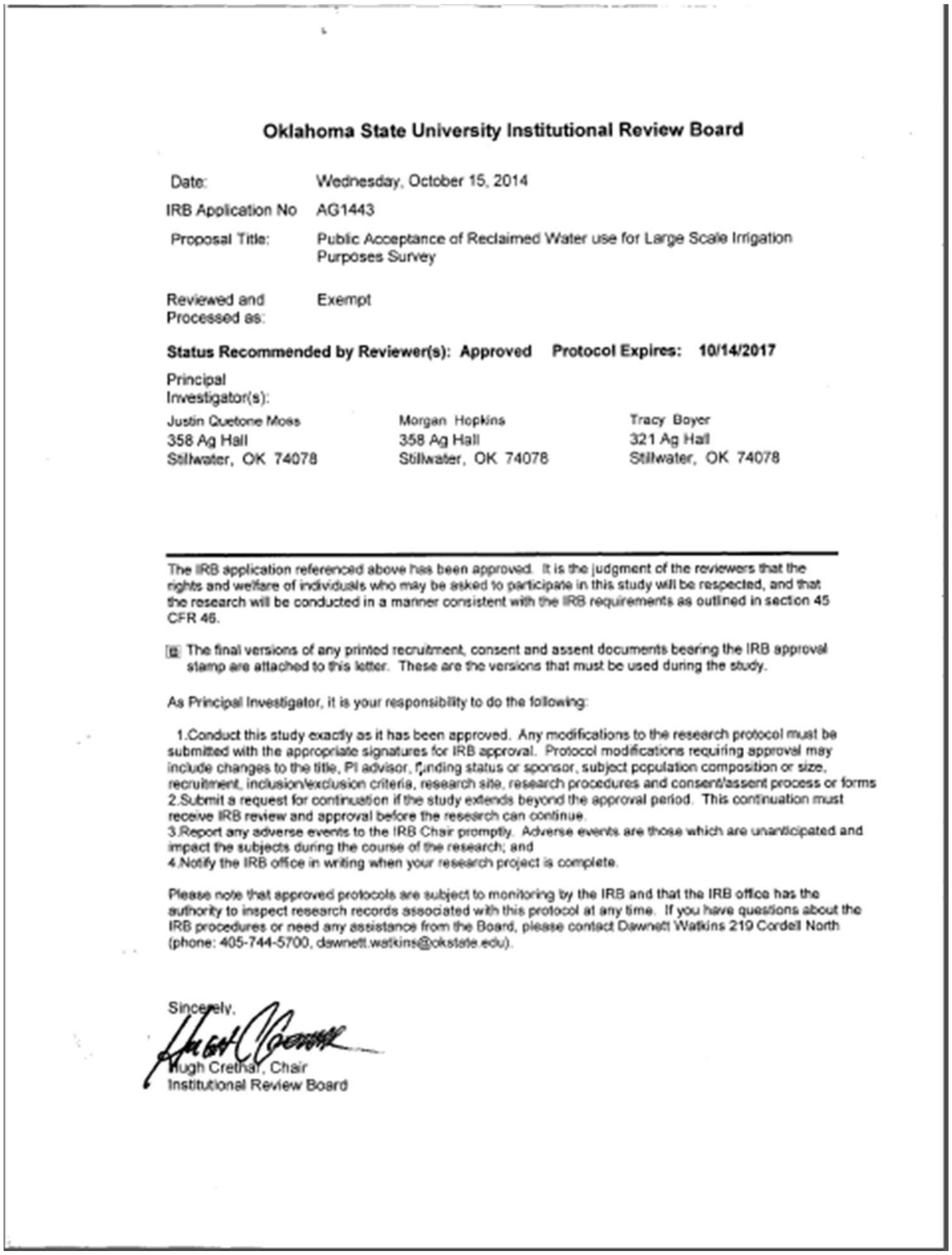
Boron (B)= <DL (less than detectable limit): This is within the desired range (<0.5 ppm) for irrigation water quality.

Sodium (Na)= 8 ppm: This is below the standard for moderate to high Na content (>100 ppm) in irrigation water quality.

Sulfate (SO_4)=12.53 ppm: This is below the desired range for SO_4 (100-200 ppm) for irrigation water quality.

Chloride (Cl)= 14.4 ppm: This is within the desired range (<100 ppm) for irrigation water quality. Chloride salts are quite soluble, so they can be leached from well-drained soils with good subsurface drainage.

APPENDIX B: PUBLIC ACCEPTANCE AND WILLINGNESS TO PAY FOR RECLAIMED WATER USE IN OKLAHOMA



Oklahoma State University Institutional Review Board

Date: Wednesday, October 15, 2014

IRB Application No AG1443

Proposal Title: Public Acceptance of Reclaimed Water use for Large Scale Irrigation Purposes Survey

Reviewed and Processed as: Exempt

Status Recommended by Reviewer(s): Approved Protocol Expires: 10/14/2017

Principal Investigator(s):

Justin Quetone Moss
358 Ag Hall
Stillwater, OK 74078

Morgan Hopkins
358 Ag Hall
Stillwater, OK 74078

Tracy Boyer
321 Ag Hall
Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

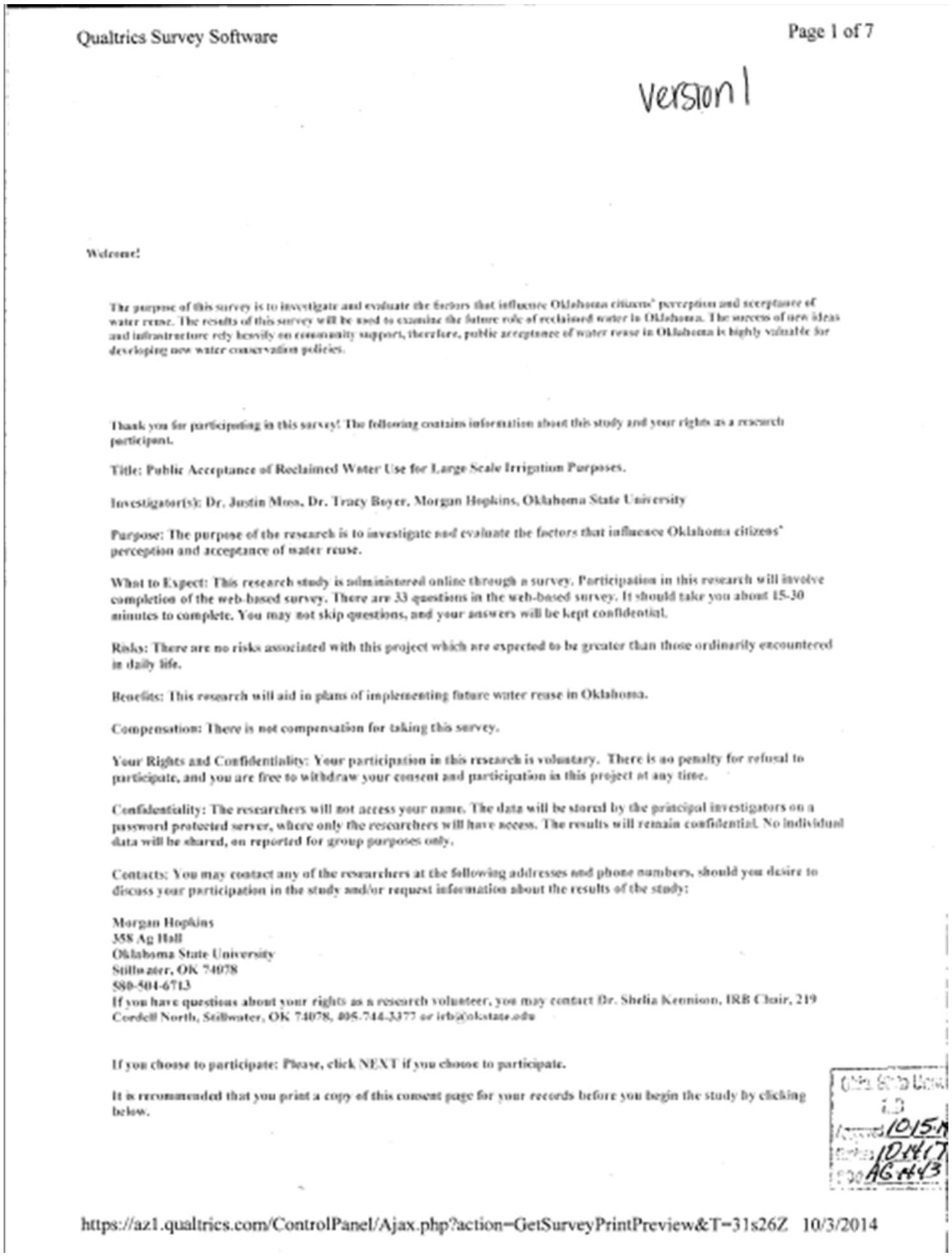
As Principal Investigator, it is your responsibility to do the following:

1.Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2.Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3.Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4.Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Cordell North (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Hugh Crethar, Chair
Institutional Review Board



Qualtrics Survey Software

Page 1 of 7

version 1

Welcome!

The purpose of this survey is to investigate and evaluate the factors that influence Oklahoma citizens' perception and acceptance of water reuse. The results of this survey will be used to examine the future role of reclaimed water in Oklahoma. The success of new ideas and infrastructure rely heavily on community support, therefore, public acceptance of water reuse in Oklahoma is highly valuable for developing new water conservation policies.

Thank you for participating in this survey! The following contains information about this study and your rights as a research participant.

Title: Public Acceptance of Reclaimed Water Use for Large Scale Irrigation Purposes.

Investigator(s): Dr. Justin Moss, Dr. Tracy Boyer, Morgan Hopkins, Oklahoma State University

Purpose: The purpose of the research is to investigate and evaluate the factors that influence Oklahoma citizens' perception and acceptance of water reuse.

What to Expect: This research study is administered online through a survey. Participation in this research will involve completion of the web-based survey. There are 33 questions in the web-based survey. It should take you about 15-30 minutes to complete. You may not skip questions, and your answers will be kept confidential.

Risks: There are no risks associated with this project which are expected to be greater than those ordinarily encountered in daily life.

Benefits: This research will aid in plans of implementing future water reuse in Oklahoma.

Compensation: There is not compensation for taking this survey.

Your Rights and Confidentiality: Your participation in this research is voluntary. There is no penalty for refusal to participate, and you are free to withdraw your consent and participation in this project at any time.

Confidentiality: The researchers will not access your name. The data will be stored by the principal investigators on a password protected server, where only the researchers will have access. The results will remain confidential. No individual data will be shared, on reported for group purposes only.

Contacts: You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study:

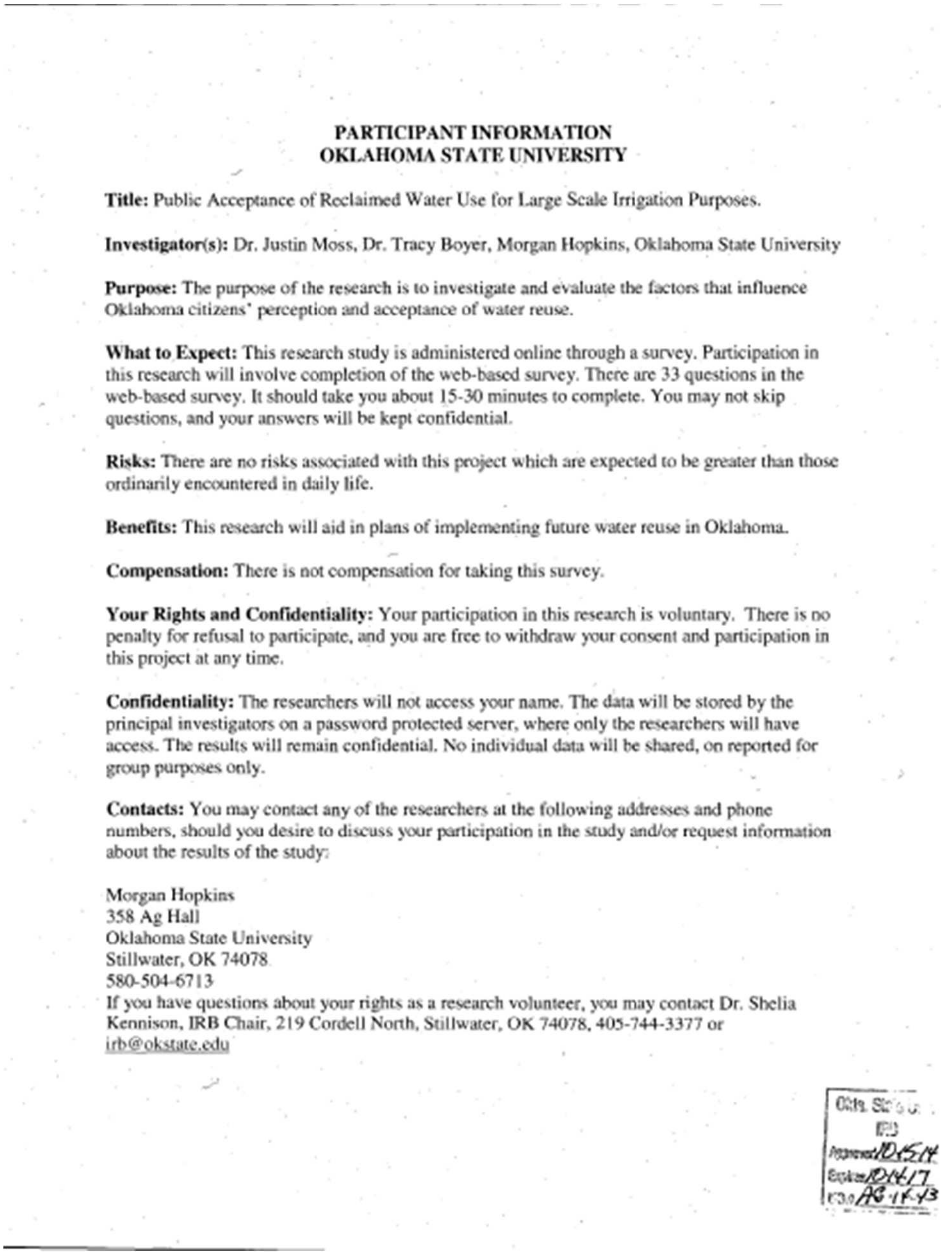
Morgan Hopkins
358 Ag Hall
Oklahoma State University
Stillwater, OK 74078
580-504-6713
If you have questions about your rights as a research volunteer, you may contact Dr. Shelia Kennison, IRB Chair, 219 Cordell North, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

If you choose to participate: Please, click NEXT if you choose to participate.

It is recommended that you print a copy of this consent page for your records before you begin the study by clicking below.

Okla. State Univ
IRB
Approved 10/15/1
Expires 10/14/1
IRB# AG-14-3

https://az1.qualtrics.com/ControlPanel/Ajax.php?action=GetSurveyPrintPreview&T=31s26Z 10/3/2014



PARTICIPANT INFORMATION
OKLAHOMA STATE UNIVERSITY

Title: Public Acceptance of Reclaimed Water Use for Large Scale Irrigation Purposes.

Investigator(s): Dr. Justin Moss, Dr. Tracy Boyer, Morgan Hopkins, Oklahoma State University

Purpose: The purpose of the research is to investigate and evaluate the factors that influence Oklahoma citizens' perception and acceptance of water reuse.

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Benefits: This research will aid in plans of implementing future water reuse in Oklahoma.

Compensation: There is not compensation for taking this survey.

Your Rights and Confidentiality: Your participation in this research is voluntary. There is no penalty for refusal to participate, and you are free to withdraw your consent and participation in this project at any time.

Confidentiality: The researchers will not access your name. The data will be stored by the principal investigators on a password protected server, where only the researchers will have access. The results will remain confidential. No individual data will be shared, on reported for group purposes only.

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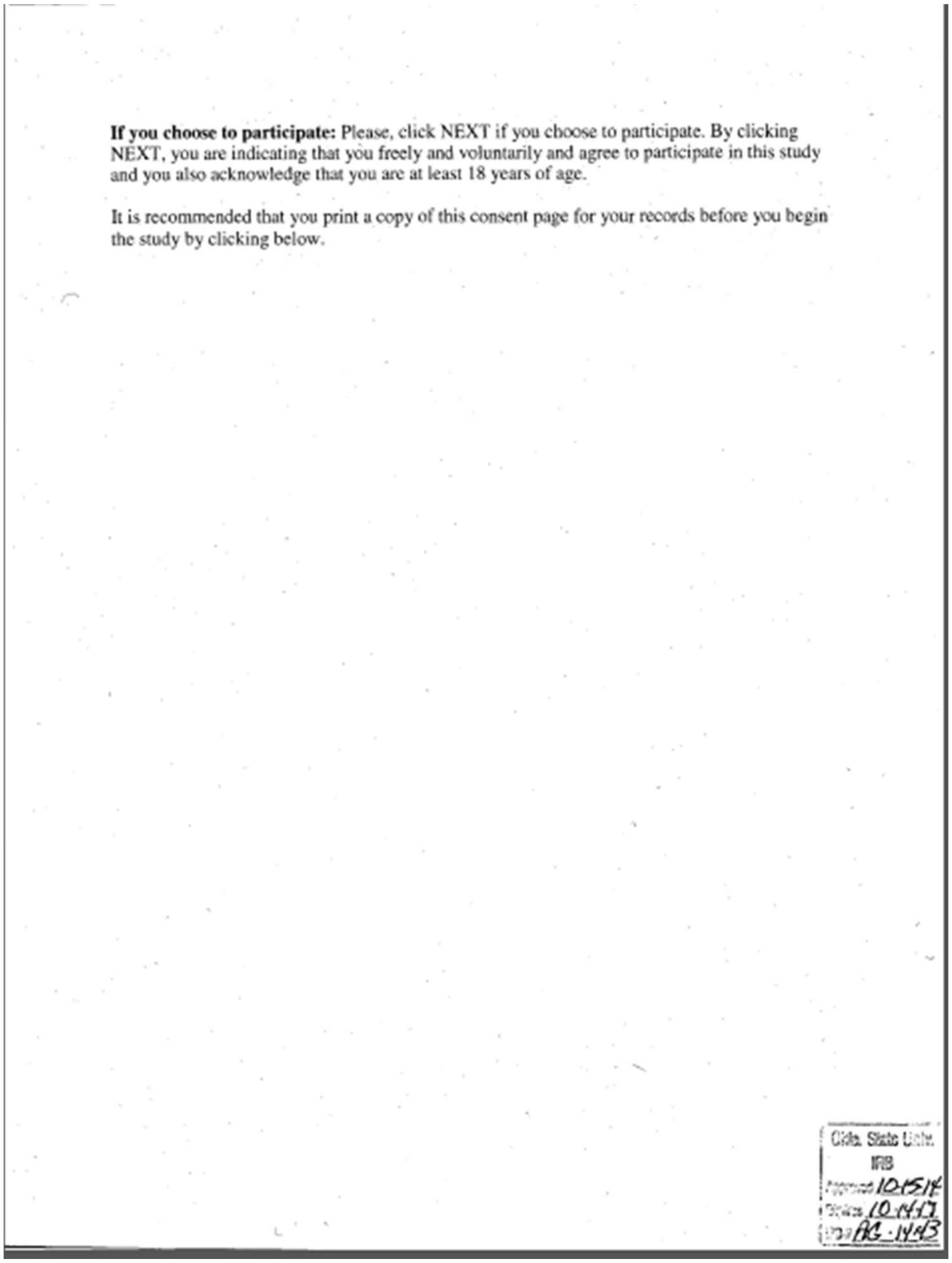
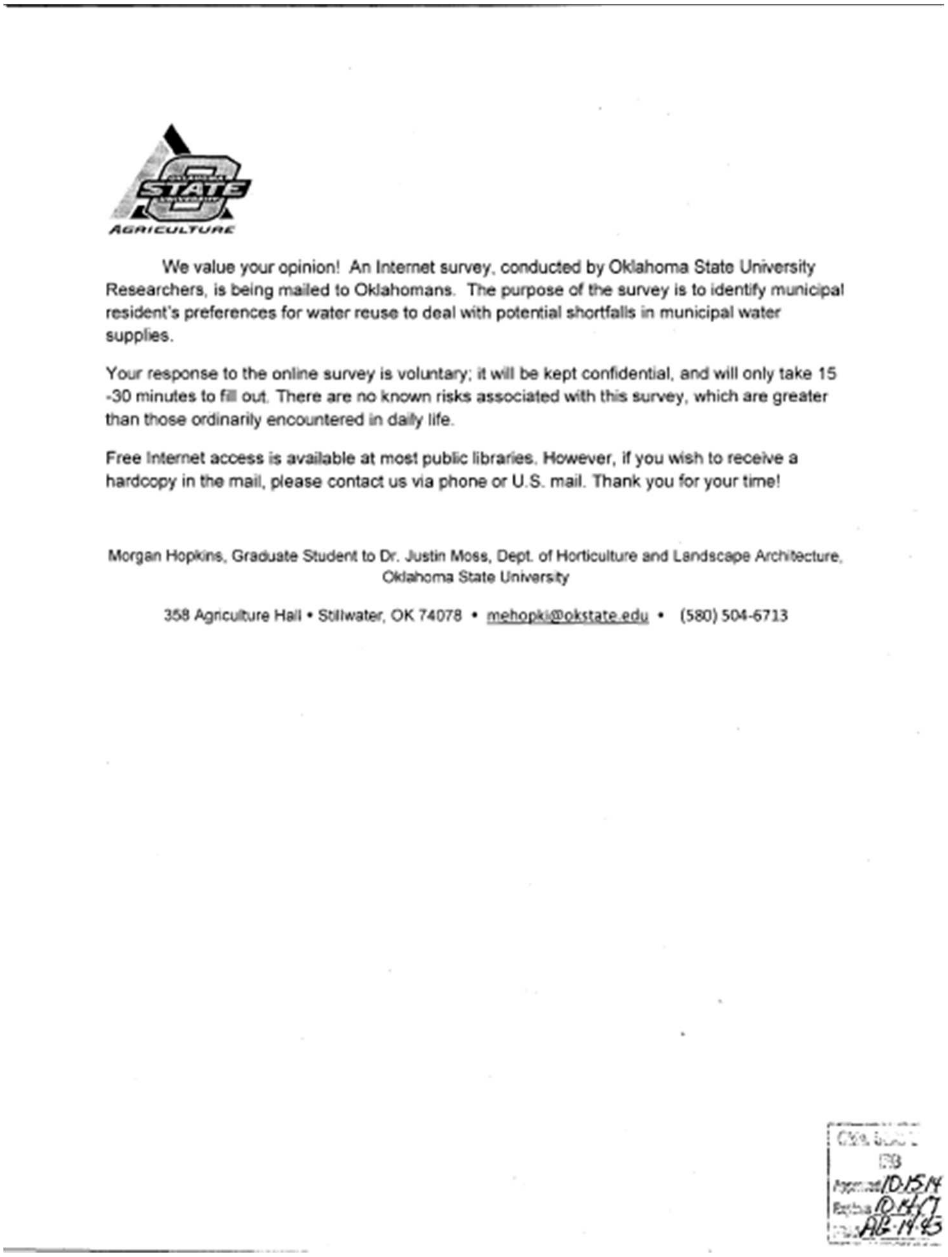
Okla. State U.
IRB
Approved 10-15-14
Expires 10-14-17
IRB# AG-14-43



If you choose to participate: Please, click NEXT if you choose to participate. By clicking NEXT, you are indicating that you freely and voluntarily and agree to participate in this study and you also acknowledge that you are at least 18 years of age.

It is recommended that you print a copy of this consent page for your records before you begin the study by clicking below.



AGRICULTURE

We value your opinion! An Internet survey, conducted by Oklahoma State University Researchers, is being mailed to Oklahomans. The purpose of the survey is to identify municipal resident's preferences for water reuse to deal with potential shortfalls in municipal water supplies.

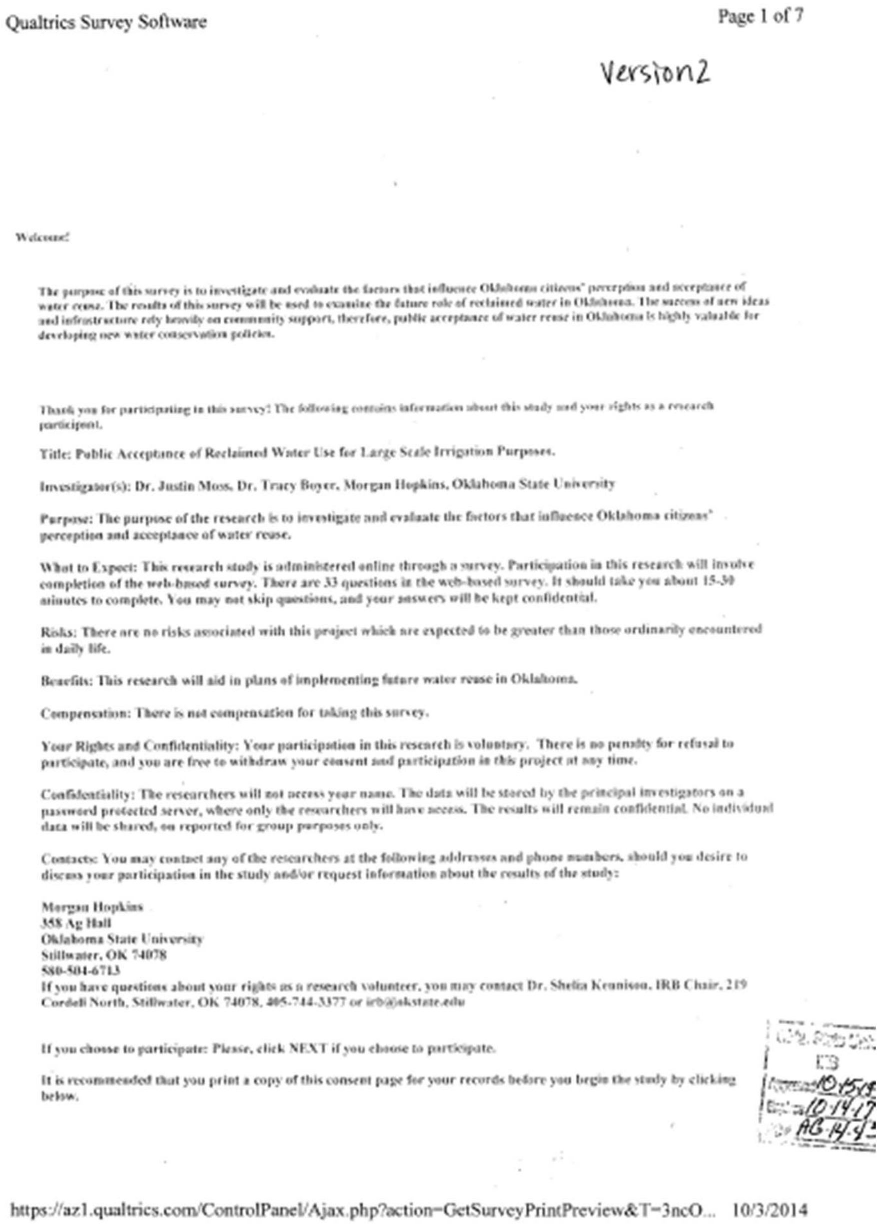
Your response to the online survey is voluntary; it will be kept confidential, and will only take 15 -30 minutes to fill out. There are no known risks associated with this survey, which are greater than those ordinarily encountered in daily life.

Free Internet access is available at most public libraries. However, if you wish to receive a hardcopy in the mail, please contact us via phone or U.S. mail. Thank you for your time!

Morgan Hopkins, Graduate Student to Dr. Justin Moss, Dept. of Horticulture and Landscape Architecture, Oklahoma State University

358 Agriculture Hall • Stillwater, OK 74078 • mehopki@okstate.edu • (580) 504-6713

Okla. State U.
IRB
Approved 10-15-14
Expires 10-14-17
IRB# AG-14-45



Version2

Welcome!

The purpose of this survey is to investigate and evaluate the factors that influence Oklahoma citizens' perception and acceptance of water reuse. The results of this survey will be used to examine the future role of reclaimed water in Oklahoma. The success of new ideas and infrastructure rely heavily on community support, therefore, public acceptance of water reuse in Oklahoma is highly valuable for developing new water conservation policies.

Thank you for participating in this survey! The following contains information about this study and your rights as a research participant.

Title: Public Acceptance of Reclaimed Water Use for Large Scale Irrigation Purposes.

Investigator(s): Dr. Justin Moss, Dr. Tracy Boyer, Morgan Hopkins, Oklahoma State University

Purpose: The purpose of the research is to investigate and evaluate the factors that influence Oklahoma citizens' perception and acceptance of water reuse.

What to Expect: This research study is administered online through a survey. Participation in this research will involve completion of the web-based survey. There are 33 questions in the web-based survey. It should take you about 15-30 minutes to complete. You may not skip questions, and your answers will be kept confidential.

Risks: There are no risks associated with this project which are expected to be greater than those ordinarily encountered in daily life.

Benefits: This research will aid in plans of implementing future water reuse in Oklahoma.

Compensation: There is not compensation for taking this survey.

Your Rights and Confidentiality: Your participation in this research is voluntary. There is no penalty for refusal to participate, and you are free to withdraw your consent and participation in this project at any time.

Confidentiality: The researchers will not access your name. The data will be stored by the principal investigators on a password protected server, where only the researchers will have access. The results will remain confidential. No individual data will be shared, or reported for group purposes only.

Contacts: You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study:

Morgan Hopkins
358 Ag Hall
Oklahoma State University
Stillwater, OK 74078
580-504-6713
If you have questions about your rights as a research volunteer, you may contact Dr. Shelia Kennison, IRB Chair, 219 Cordell North, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

If you choose to participate: Please, click NEXT if you choose to participate.

It is recommended that you print a copy of this consent page for your records before you begin the study by clicking below.

Public Acceptance of Reclaimed Water Use in Oklahoma Survey

Results Report

Prepared by

Morgan Hopkins, Graduate Research Assistant

Department of Horticulture and Landscape Architecture

Oklahoma State University

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Section 1

Questions 20, 26, 27, 29, 30, 31, 32

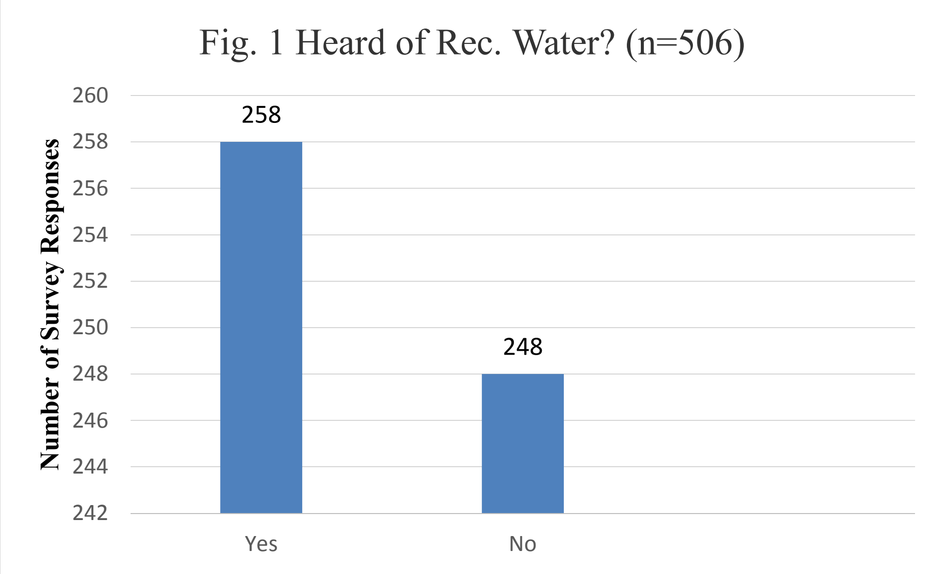
Table 1: Basic Demographics

	Mean	Standard Deviation		Mean	Standard Deviation
Education (n=486)			Household Income (n=481)		
• Less than High School Degree	6.79%		• Under $20,000	23.7%	42.57%
• High School Degree	22.84%		• $21,000-40,000	29.94%	45.85%
• Some College	38.68%		• 41,000-60,000	19.54%	39.69%
• B.S. degree or higher	31.69%		• 61,000-80,000	10.4%	30.55%
			• 81,000-100,000	5.82%	23.44%
			• $100,000+	10.6%	30.82%
Age in years (n=488)	41.91	16.07	Gender (n=487)	0.45	---
Household Size (n=478)	3	4.65	Home Ownership (n=494)	43.53%	0.5
Employment Status (n=481)			---	---	---
• Unemployed	9.98%	30%			
• Self-Employed	3.95%	19.5%			
• Employed	49.69%	50.05%			
• Homemaker	10.19%	30.28%			
• Student	4.37%	20.45%			
• Retired	13.31%	34%			
• Unable to work	7.07%	25.66%			
• Prefer not to specify	1.46%	11.99%			

- Out of 494 survey respondents, 44% are home owners.
- Out of 478 survey respondents, the average household size is 3.
- Average age of the survey respondent is 42 years with a standard deviation of 4.65 years.
- Looking at education, out of 486 survey responses, it has been reported that almost 32% have a B.S. degree or higher, 38.68% have some college credit, 22.84% have a high school degree, and 6.79% have less education than a high school degree.
- Looking at employment, out of 481 survey responses it has been reported that almost 10% of respondents are unemployed, 3.95% are self-employed, 49.69% are employed, 10.19% are homemakers, 4.37% are students, 13.31% are retired, 7.07% are unable to work, and 1.46% preferred no to specify their employment status.
- Income data reveals that, out of 481 survey responses, 23.7% of respondents have an annual income of less than $20,000. The remaining respondent's income data is as

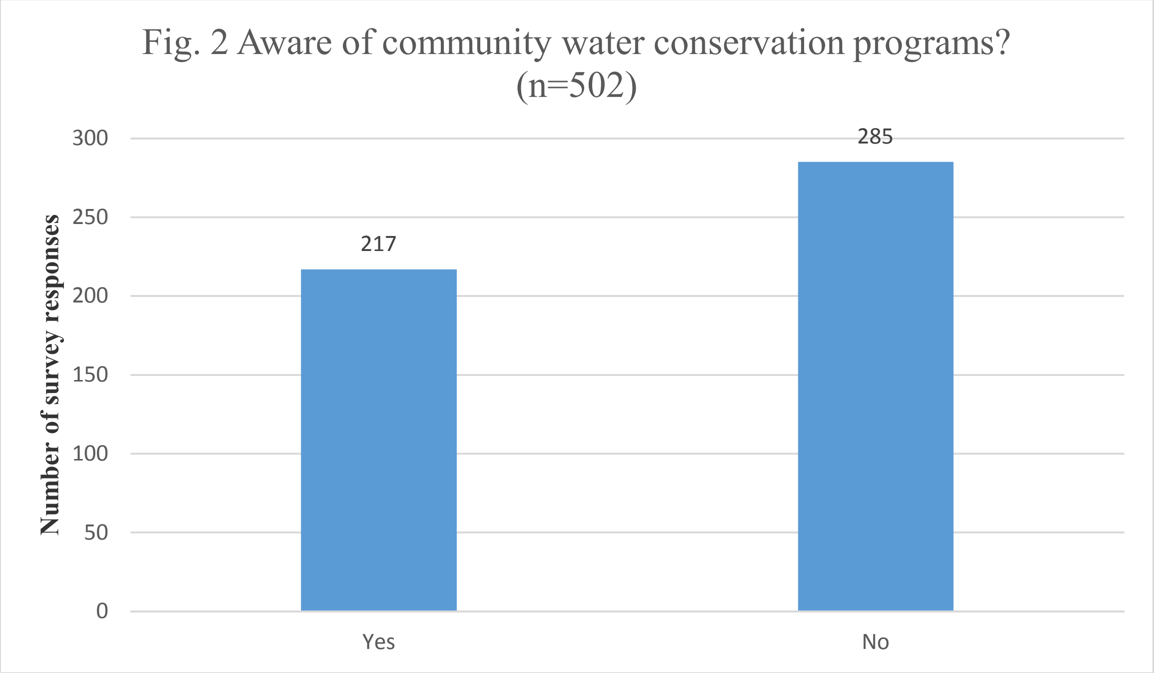
follows: 29.94% have an annual income between $21,000-40,000, 19.54% have an annual income between $41,000-60,000, 10.4% have an annual income between $61,000-80,000, 5.82% have an annual income between $81,000-100,000, and 10.6% have an annual income over $100,000. The average annual household income in Oklahoma is $43,777 (US Census Bureau, 2014). According to the survey responses, 53.64% have an annual income below the average income level in Oklahoma, indicating that only using a price approach for water conservation measures would place a burden on a significant number of households.

Question 1: Have you previously heard of reclaimed water, or water reuse systems?



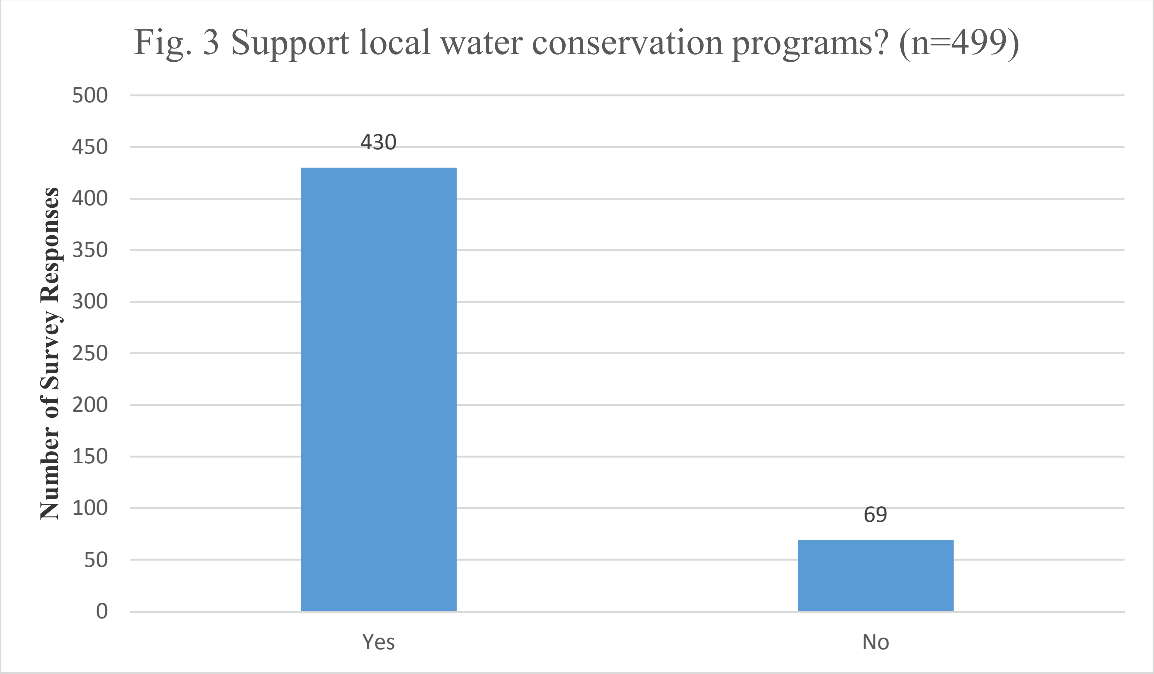
- Out of 506 survey responses, 51% of the respondents (n=258) had previously heard of reclaimed water or water reuse systems.

Question 3: Are you aware if your community has implemented any water conservation programs or policies?



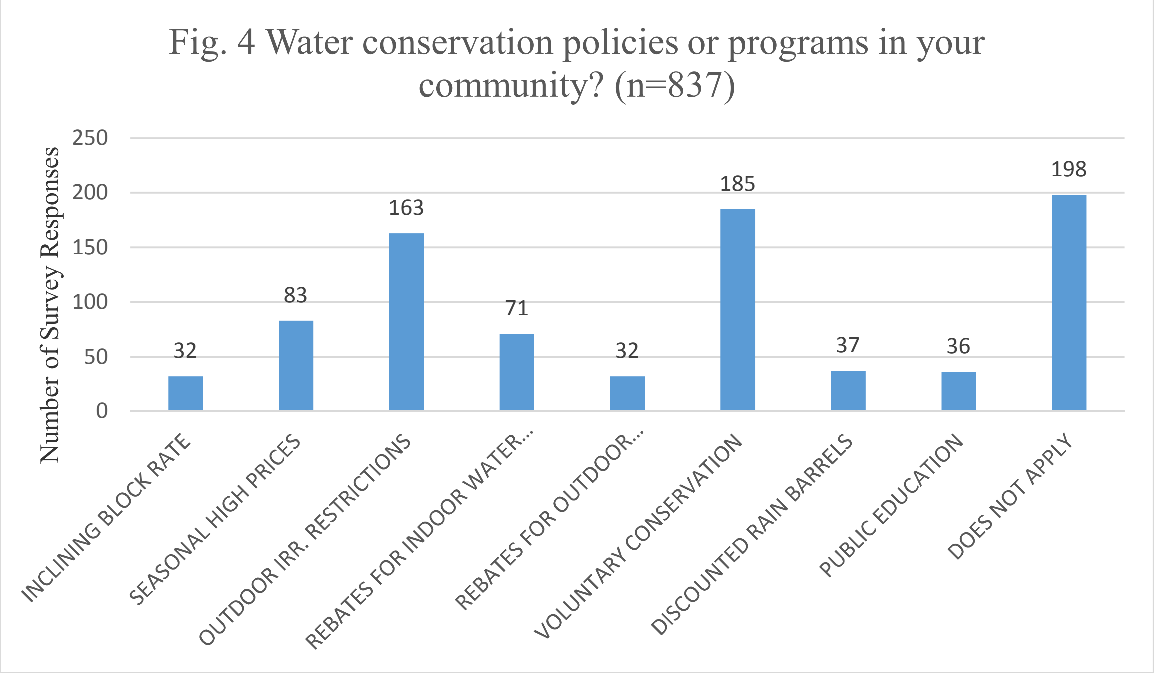
- Out of 502 survey responses, 57% (n=285) of respondents were not aware of water conservation programs or policies in their community.

Question 4: Do you support local water conservation programs or policies?



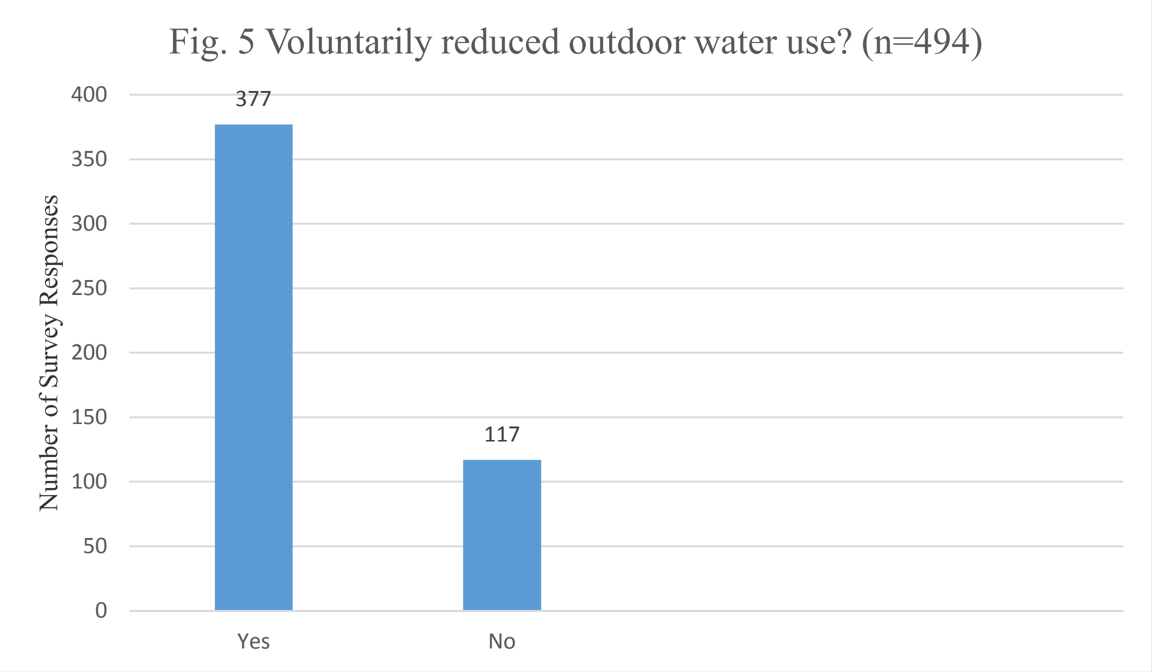
- ➢ Out of 499 survey responses, 86.17% of respondents support local water conservation programs and policies.

Question 5: Have you had any of the following policies or programs in your municipality or water district put in place to promote water conservation?



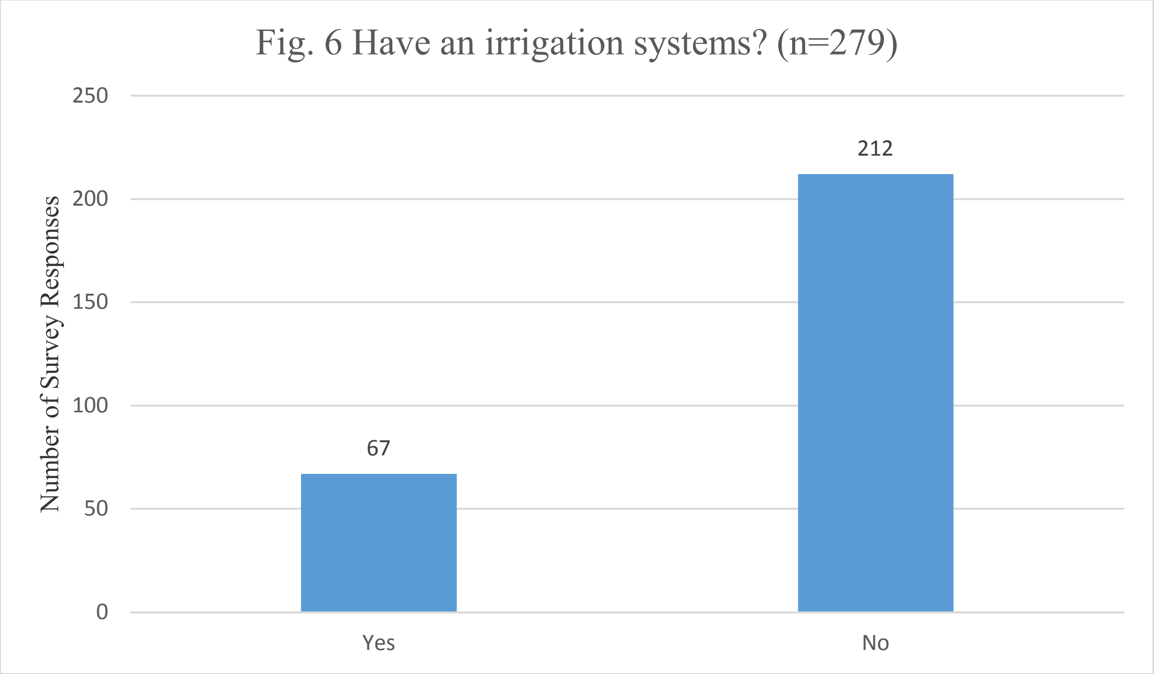
- Survey respondents were allowed to pick more than one option if necessary and according to the data, 837 survey responses were received.
- The largest percentage of survey responses (24%) said that none of the water conservation programs and policies applied to them and their community.

Question 6: Has your household voluntarily reduced your outdoor water use?



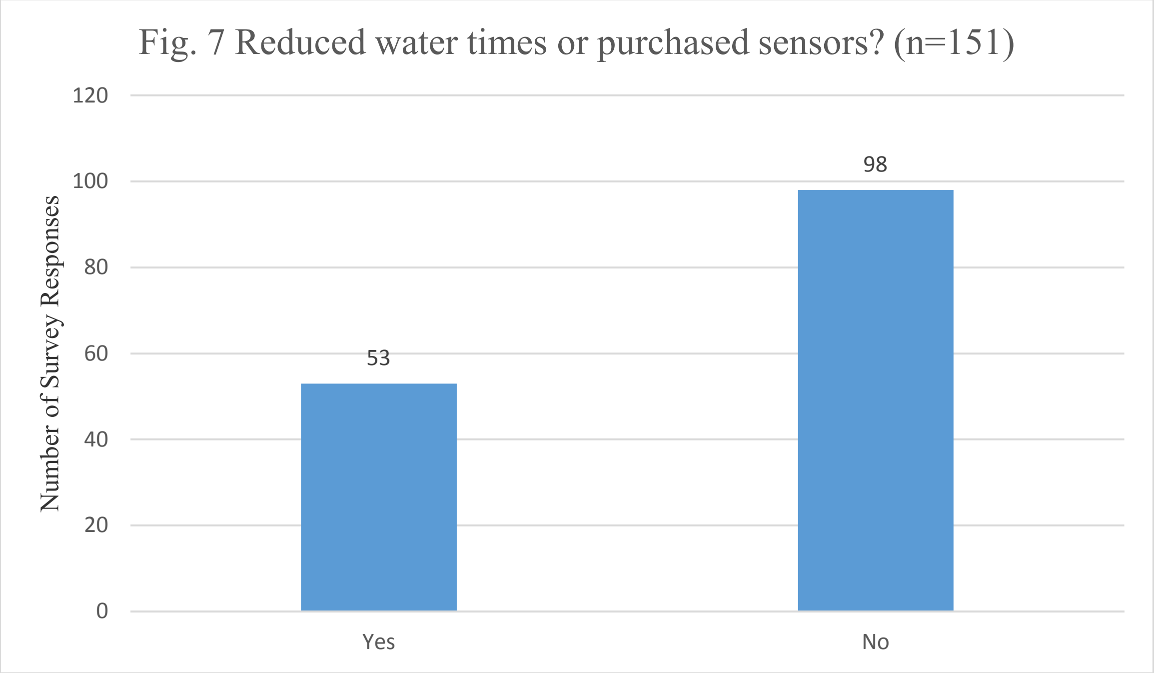
- Out of 494 survey responses, 76% of respondents say they have voluntarily reduced their outdoor water use.

Question 8: Do you have an irrigation system for your yard?



- Out of 279 survey responses, 76% of the respondents do not have an irrigation system for their yard. Based on these results, outdoor irrigation restrictions may not be effective for water conservation unless they include hand watering.

Question 9: Have you reduced your outdoor water times or purchased a rain/soil moisture sensor to reduce your outdoor water usage?



- Out of 151 survey responses, 65% (n=98) of respondents have not reduced their watering times or purchased a rain or soil moisture sensor.

Question 13: In your opinion, are the water supplies in your region of Oklahoma adequate to meet the needs of your community over the next 25 years?

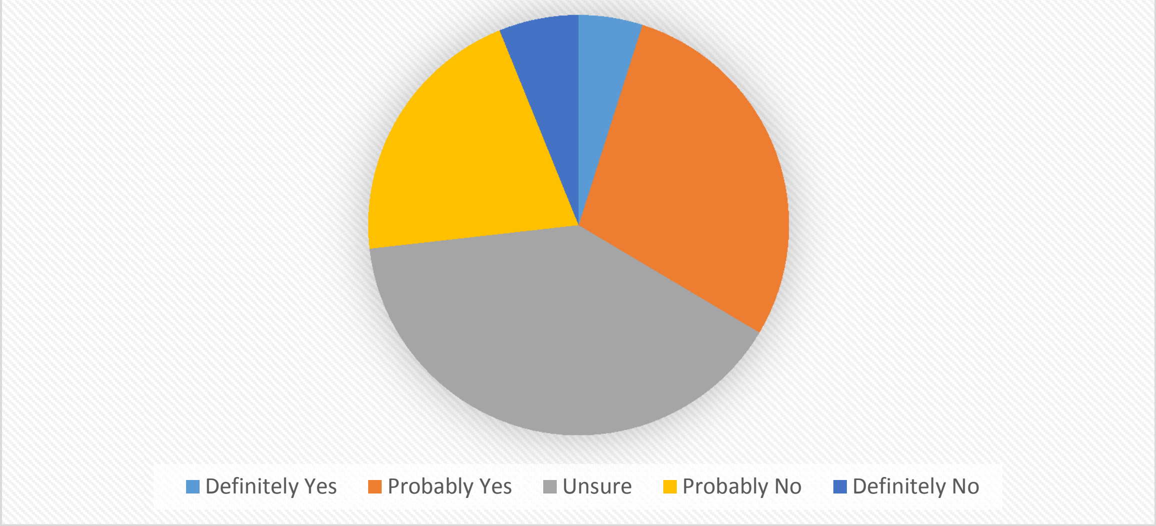
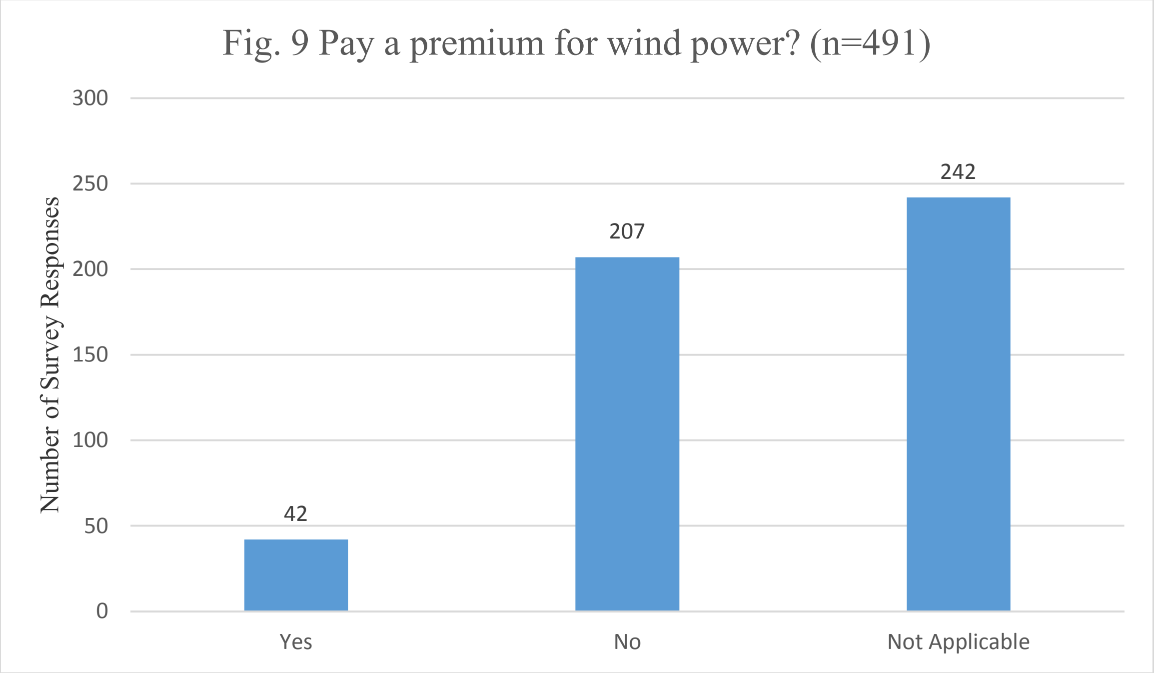


Fig. 8 Water supplies adequate for the next 25 years? (n=489)

- Out of 489 survey responses, 40% (n=194) of respondents were unsure if water supplies in their region of Oklahoma are adequate to meet the needs of their community over the next 25 years.
- The results showed that 29% (140) of respondents said probably yes and 5% (n=24) said definitely yes that the water supplies in their region of Oklahoma are adequate to meet the needs of their community over the next 25 years. The overall yes consensus response to this question was 34% (n=164) of the responses.
- The results showed that 21% (n=101) of respondents said probably no and 6% (n=30) said definitely no that the water supplies in their region of Oklahoma are adequate to meet the needs of their community over the next 25 years. The overall no consensus response to this question was 27% (n=131) of the responses.
- This question could be an indicator of how Oklahomans perceive water conservation.

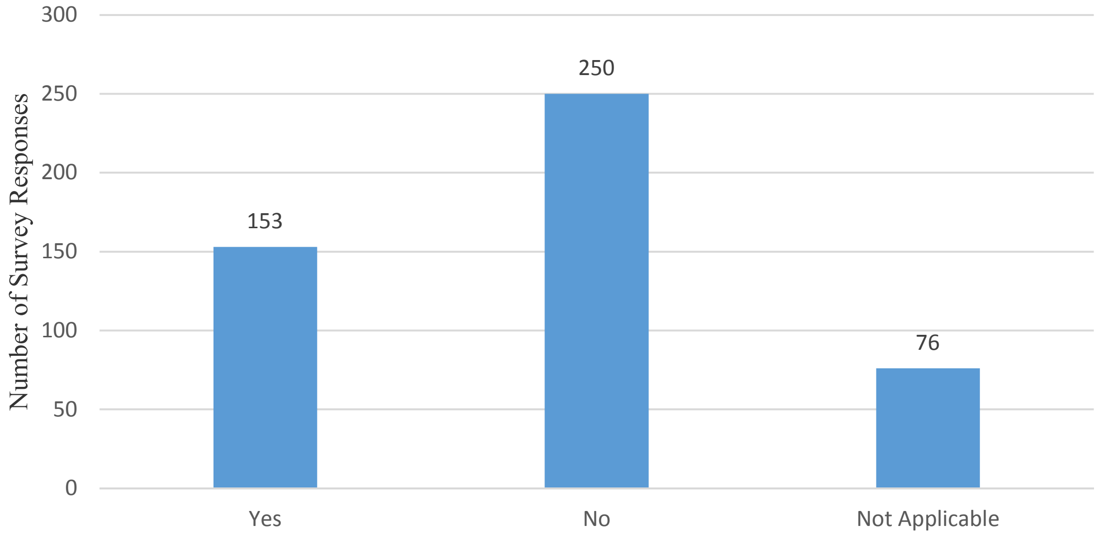
Question 14: If you use OG&E, do you currently pay a premium for wind power supplied on your electric bill?



- Out of 491 survey responses, 42% (n=207) of respondents said no, 9% (n=42) of respondents said yes, and 49% (n=242) of respondents said not applicable to whether they pay a premium for wind power supplied by your electric bill.

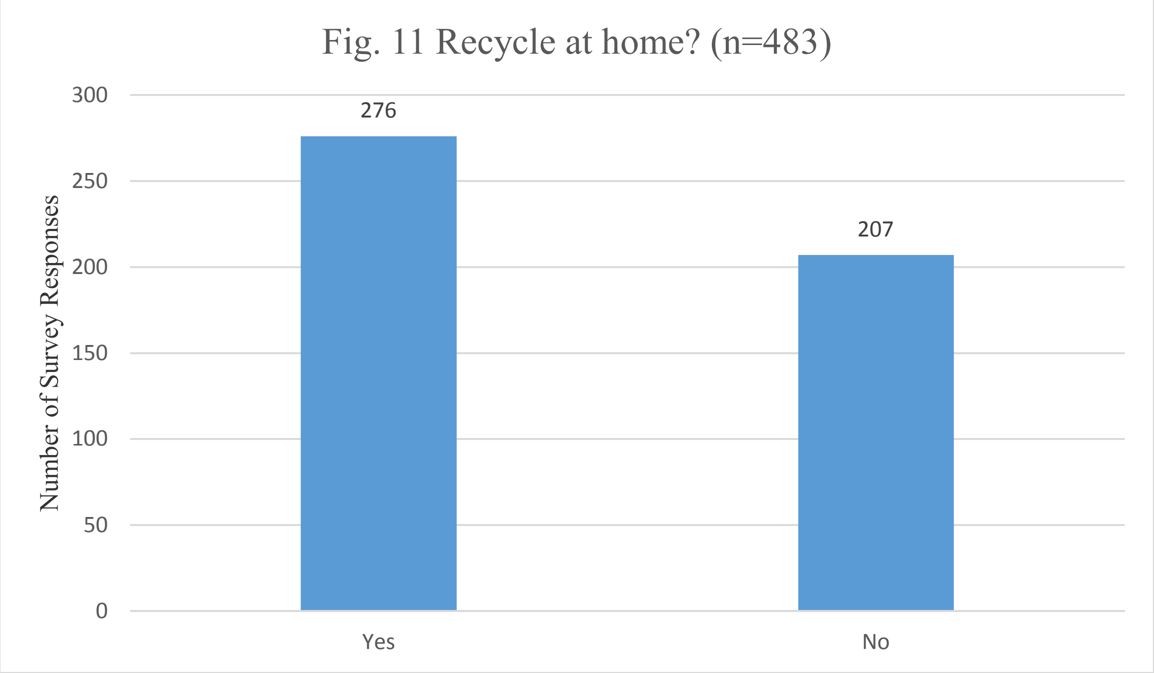
Question 15: Do you currently average your monthly heat or electricity bills (such as OG&E) over the year to avoid high seasonal bills, if your provider allows it?

Fig. 10 Average bills monthly to avoid seasonal highs? (n=479)



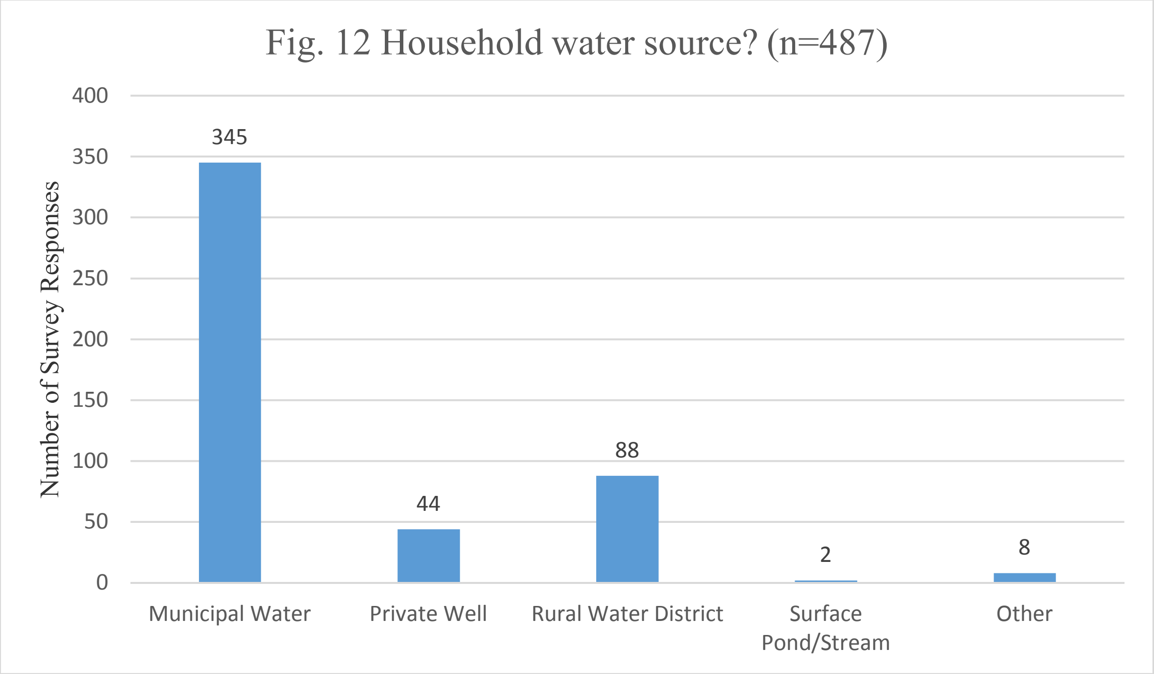
- Out of 479 survey responses, 52% (n=250) of respondents said no, 32% (n=153) of respondents said yes, and 16% (n=76) of respondents said not applicable when asked if they average monthly heat or electric bills over the year to avoid high seasonal bills, if allowed by their provider.

Question 18: At your home, do you recycle paper, plastic, aluminum, or glass through at a drop-off site or through curbside recycling?



- Out of 483 survey responses, 57% (n=276) of the respondents said yes and 43% (n=207) of the respondents said no to whether they recycle at their home via a drop-off site or through curbside recycling.

Question 19: What source do you get your household water from?



- Out of 487 survey responses, 71% (n=345) chose municipal water, municipality, 18% (n=88) chose rural water district, 9% (n=44) chose private well, 2% (n=8) chose other, and 0.4% (n=2) chose surface pond or stream when asked where the respondent get theirs household water from.
- The majority of respondents get their water from municipalities. This would suggest that if municipalities implemented water conservation programs, they would be reaching the majority of Oklahomans, according to this survey data.

Question 23: What is the approximate size of your yard?

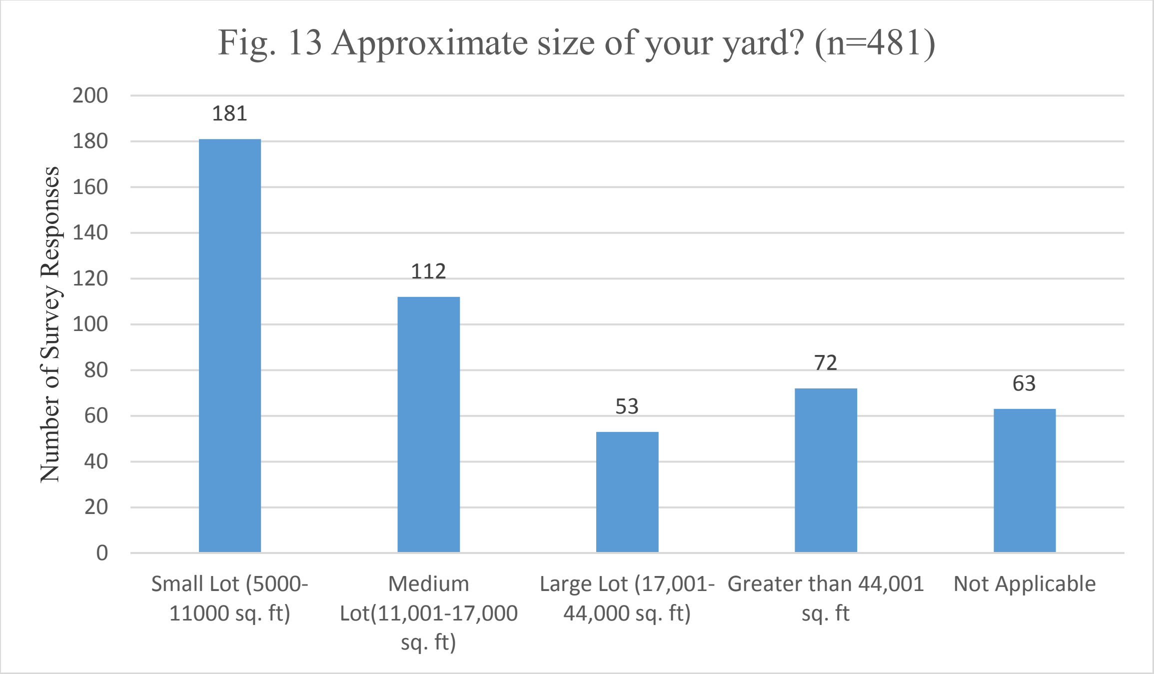
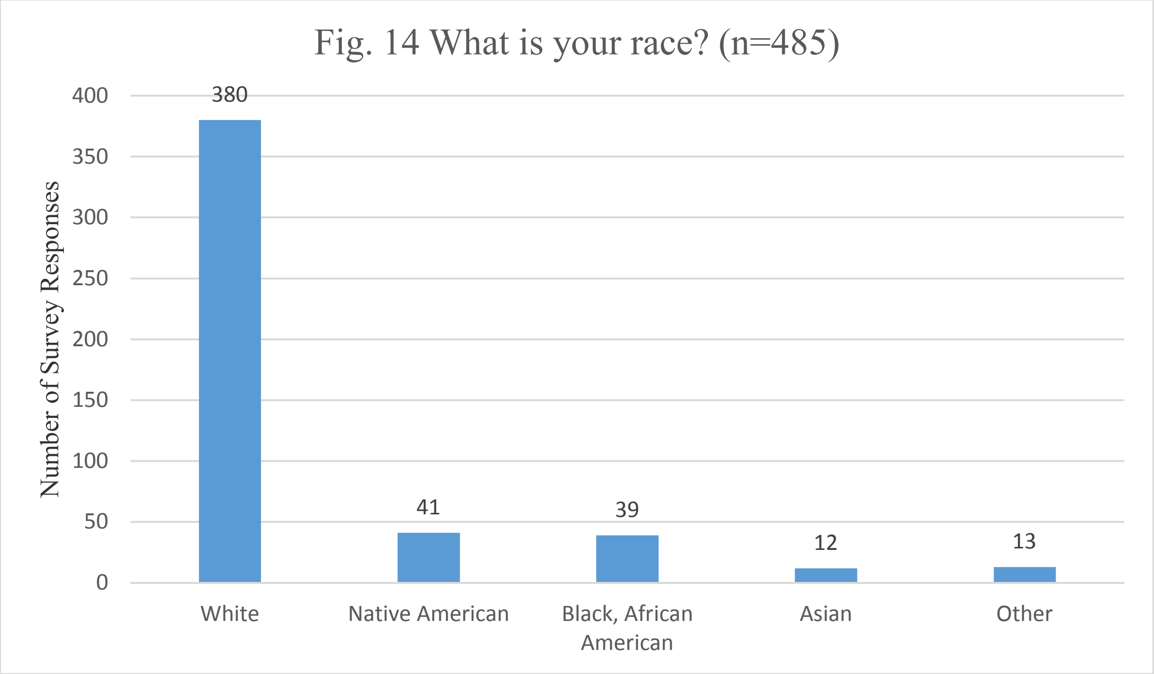


Fig. 13 Approximate size of your yard? (n=481)

- Out of 481 survey responses, 38% (n=181) have small lots, 23% (n=112) have medium lots, 15% (n=72) have lots greater than 44,001 square feet, 13% (n=63) chose not applicable, and 11% (n=53) have large lots when asked the approximate size of their yard.
- The majority of respondents (89%) have yards, and would be a target audience to educate about proper outdoor water conservation.

Question 28: What is your race?



- Out of 485 survey responses, 78% (n=380) identified as White, 9% (n=41) identified as Native American, 8% identified as Black or African American, 3% (n=13) identified as other, and 2% identified as Asian when asked about their race.

Question 11: An ultra-low flow toilet uses 1.6 gallons of water per flush. Would you install an ultra-low flow toilet if the rebate were (bid: $25; $50; $75; $100; $125; $150; $175)? (The sensor would be professionally installed and verified as installed).

Probit model results of Willingness to Accept (WTA) for a one time ultra-low flow toilet rebate in Oklahoma.

	Baseline Model			Model with Behavioral Variables		
Variable	Coefficients	Std. Error	Pr>ChiSq	Coefficient	Std. Error	Pr>ChiSq
Intercept	0.0549	0.4013	0.8913	-0.0391	0.5003	0.9378
BIDT	0.00145	0.00127	0.2561	0.00197	0.00133	0.1393
QUALITY	-0.0947	0.1285	0.4611	-0.0422	0.1344	0.7537
AGE	-0.00163	0.0046	0.7237	-0.00159	0.00484	0.7428
GENDER	-0.0561	0.1444	0.6979	-0.1087	0.152	0.4745
EMPLOYED	-0.0606	0.1501	0.6863	-0.0649	0.1552	0.6758
UNEMPLOY	0.0525	0.2359	0.8238	0.1197	0.2474	0.6286
HOME2	0.1507	0.195	0.4398	-0.0101	0.2056	0.9607
APT	0.1778	0.2398	0.4585	0.0747	0.2531	0.768
TWENTY	0.6484	0.1812	0.0003***	0.6422	0.1885	0.0007***
FORTY	0.6039	0.2082	0.0037**	0.5292	0.2145	0.0136**
SIXTY	0.3938	0.2462	0.1097	0.3061	0.2589	0.2372
EIGHTY	0.4161	0.3121	0.1825	0.2527	0.3205	0.4304
HUNDRED	0.4151	0.2651	0.1175	0.3126	0.2723	0.251
HS	-0.1102	0.1647	0.5034	-0.088	0.1737	0.6125
BS	-0.0782	0.1615	0.6284	-0.0674	0.168	0.6885
RENT	0.0107	0.163	0.9478	-0.0278	0.168	0.8685
REGPOL				0.3575	0.2114	0.0908*
RECUSE				0.4681	0.2223	0.0353**
DROUGHT				-0.0448	0.0675	0.5074
HAZARD				-0.0947	0.0708	0.181

*,**,*** represent the 90%, 95%, and 99% confidence levels respectively

Mean WTA for a one time ultra-low flow toilet rebate in Oklahoma.

Model	Mean WTP
Baseline	$253.12 (in 2014$)
Behavioral Variables	$463.36 (in 2014$)

VITA

Morgan Elizabeth Hopkins

Candidate for the Degree of

Master of Science

Thesis: ENVIRONMENTAL IMPLICATIONS OF RECLAIMED WATER IRRIGATION ON SOIL CHEMICAL PROPERTIES ON GOLF COURSES IN OKLAHOMA AND PUBLIC ACCEPTANCE OF RECLAIMED WATER USE IN OKLAHOMA

Major Field: Horticulture

Biographical:

Education:

Completed the requirements for the Master of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in July, 2015.

Completed the requirements for the Bachelor of Science in Business Administration at Oklahoma State University, Stillwater, Oklahoma in May, 2012.

Completed the requirements for the Bachelor of Science in Environmental Science at Oklahoma State University, Stillwater, Oklahoma in May, 2012.

Experience:

-Oklahoma State University Horticulture and LA, Graduate Research Assistant	Stillwater, OK
-The Fund for the Public Interest Citizen Outreach Director	Boulder, CO
-The Land Trust of North Alabama Environmental Education Intern	Huntsville, AL

Professional Memberships:
-American Society of Agronomy
-Crop Science Society of America
-Soil Science Society of America
-WateReuse Association