DETERMINING THE FEASIBILITY OF UTILIZING RECYCLED HOUSEHOLD WASTEWATER FROM AEROBIC TREATMENT SYSTEMS FOR CATTLE WATERING

By

LAREE CHRISTINE ODEN

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Dissertation Approved:

Dr. Brian J. Carter

Dissertation Adviser

Dr. Sergio Abit

Dr. Shiping Deng

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Name: LAREE CHRISTINE ODEN

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Abstract: Alternative sources of water for the purpose of non-human (direct) consumption are needed to mitigate the effects of drought and increasing water resource use and depletion within the United States. Emerging ideas that are already implemented in some regions for the reuse of wastewater include: watering of lawns and the irrigation of some crops. I present an idea that may help to conserve fresh, direct, human potable water through the reuse of wastewater from household aerobic sewage treatment systems. Through the process of these systems' treatment of the wastewater, the effluent (as per United States Environmental Protection Agency (U.S. EPA) and Oklahoma Department of Environmental Quality (Ok DEQ) Regulations) could be a potential source of water for watering cattle, or the irrigation of lawns and certain crops.

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INTRODUCTION

The demand for fresh water is increasing globally. According to Brown et al. (2013), fresh (non-saline) water usage is projected to increase approximately 3% annually overall, assuming no climate change. When considering the effects of climate change, the projected freshwater demand and use increases significantly and varies with the regions of focus. Some areas will see a decrease in projected freshwater use, while others will have a substantial increase. Brown et al. (2013) includes many sources of freshwater withdraw and considers technological advances in water-use efficiency in the past, present, and future. However, Brown et. al. (2013) does not address certain factors, such as the increasing demand for water-based hydraulic fracturing methods in the U.S. (Freyman, 2014). Brown et. al. (2013) and Freyman (2014) show the need for further consideration of environmental factors and human activity. In order to better mitigate the effects of increasing global water resource usage, more options and alternative methods should be made available to conserve and recycle water, especially in regions where water is scarce.

A method not previously considered is the use of household wastewater for the watering of livestock, such as cattle. According to Wright (2007), cattle are hardy species that are able to tolerate water at a much lower quality than humans. Wright (2007) quantified and characterized the basic water quality factors for safe cattle use. Beede (2006), Wright (2007), Parish (2009), and Morgan (2011) were produced as guides for cattle water quality and were used to determine if water samples from household aerobic wastewater treatment systems are feasible to be utilized by cattle owners to water cattle safely. Wastewater should be recycled according to standards that the reclaimed water meets. All water is recycled, and if water passes standards for a particular use, it should not be "wasted", but put toward that particular use whenever feasible. Previous examples of wastewater being recycled include the use of reclaimed water in the municipal drinking water system in Wichita Falls, Texas, where approximately 5 million gallons per day are treated, recycled, and blended into the municipal system. (Scientific American, 2014). Urine is also recycled upon the International Space Station, where the reclaimed water within the urine is converted to potable drinking water. (NASA, 2000). This study addresses the need to increase alternative sources of water in order to conserve fresh, potable water and provides an idea for the reclamation of a common source of wastewater. Lastly, ideas on the improvement and amendment of these systems are addressed, which could be a low-cost approach to improving the water quality from aerobic wastewater treatment systems even further.

CHAPTER II

REVIEW OF LITERATURE

Wastewater Reuse – current methods & lack of studies for cattle use

According to the United States Environmental Protection Agency (U.S. EPA, 2012), all water on Earth is recycled, and there are five main categories of water regarding human use, either direct or indirect:

1. *Potable Water*: water that is fit for direct human consumption, such as tap water.
2. *Potable Reused Water*: water that has been reclaimed, or recycled, and meets standards for direct human consumption, of which, there are two types:
    a. *Direct Potable Reused Water*: reclaimed water placed (with or without retention in an engineered storage buffer) directly into a drinking water treatment plant, either collocated or remote from the advanced wastewater treatment system.
    b. *Indirect Potable Reused Water*: Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes drinking water treatment.
3. *Non-potable Reused Water*: water that has been reclaimed for uses other than direct human consumption and does not meet drinking water quality standards for humans.

4. *Reclaimed Water*: water that has been recycled through various methods of filtration and sterilization and meets the standards for its particular reuse.
5. *De facto Reused Water*: A situation where reuse of treated wastewater is, in fact, practiced but is not officially recognized (e.g., a drinking water supply intake located downstream from a wastewater treatment plant discharge point).

Recycled wastewater, or reclaimed water, is used through various methods around the world, but as of now, is limited. Concerns for wastewater reuse include: pathogen content (methods of sterilization), cost and feasibility (including implementation of infrastructure required for recycling wastewater), equipment failure, and human acceptance on a psychological level (U.S. EPA, 1981). Current methods of wastewater reuse include: human consumption in some regions with a high demand for potable water, such as in Wichita Falls, Texas, where in the summer of 2014, the operation of a wastewater recycling system began, which blends approximately 5 million gallons of recycled wastewater per day into their municipal water system. With systems such as these, the infrastructure is complex and regulations are stringent and carefully followed. Groundwater recharging for the purpose of supplying potable drinking water is also used in some areas, such as with the Bear Canyon Recharge Project in Albuquerque, New Mexico, where treated industrial wastewater (approximately 5.6 million gallons/day) is pumped in an in-stream system engineered to allow for the downward flow of wastewater into the vadose zone, where the water is filtered before it joins the water table, becoming an additional source of water for the surrounding communities. (New Mexico Water Conservation Alliance, 2008)

Cattle Water Quality

According to Wright (2007), cattle can tolerate constituents in water at much higher levels, and at much lower overall quality, than humans. For example, the human drinking water standard for total suspended solids (TSS) is <500ppm, while cattle can tolerate 5,000-7,000ppm. The human standard for fecal coliform presence in water is <1 MPN (most probable number of colony forming units) per 100 mL, while the optimal *dairy* cattle level is <10 MPN per 100 mL (Beede, 2006), while tolerance in cattle is attained at levels up to 1,000,000 MPN/ 100 mL for Total Coliform. There are studies such as (Morgan, 2011) that address the main water quality variables for cattle, which include: odor, taste, pH, total dissolved solids (TDS), total dissolved oxygen, hardness, heavy metals, toxic minerals, organophosphates, hydrocarbons, nitrates, sodium, sulfates, iron, and bacteria. Morgan (2011) summarized the most common water quality analyses for cattle water and they include: TDS, sodium, sulfates, nitrates, nitrites, and blue-green algae, along with Total Coliform. According to (Wright, 2007), water quality is integral for the health and performance of beef cattle. Fecal contamination, blue-green algae, nitrates, water hardness & salinity, and sulfate are some of the most important water quality parameters (Wright, 2007; Morgan, 2011), yet these studies vary in the number of constituents tested. Dairy cattle water quality is extensively addressed in (Beede, 2006), and the water quality parameters determined to be the most significant include: TDS, hardness, nitrates, sulfates, pesticides, organoleptic properties (odor), and microorganisms. University extension factsheets such as (Parish, 2009) detail water quality for cattle and mention water quality parameters similar to the above studies, namely: pH, TDS, salinity, nitrates, sulfates, blue-green algae, and microorganisms.

Irrigation (lawn and/or crop watering) and Eutrophication

Studies such as Corwin and Perry (2013) determine the feasibility of using reclaimed household wastewater for the purpose of watering lawns and potentially, watering certain types of crops. According to Corwin and Perry (2013), the most important parameters of water quality for irrigation of lawns and crops by wastewater means are microbial presence (levels), salinity, and sodium absorption ratio (SAR).

Nitrogen and phosphorous content in the effluent from aerobic wastewater treatment systems (or any type of sewage system) can have an effect on the environment, to include the potential to contribute to nutrient loading of the local watershed, leading to eutrophication, according to Conley et. al. (2009). Eutrophication caused by the anthropogenic addition of nitrogen and phosphorous contributes to the degradation of the ecology of streams (and other bodies of water) and to drinking water supplies (such as lakes). Prevention of additions of nitrogen and phosphorous is imperative, whenever possible (Conley et. al. 2009). Capturing and reusing wastewater may help mitigate the effects of nutrient loading by capturing the water before it is freely released into the environment. If the water is to be reclaimed and reused, nitrogen and phosphorous removal can be a potential mitigation to the problem of nutrient loading. The possibility exists that there are ways to increase the water quality of the effluent wastewater output from these systems, and reuse of the water could be attained by treating the water further to attain standards for its particular proposed reuse.

Aerobic Wastewater Treatment System Types

Aerobic wastewater treatment systems are more effective at clarifying water than standard, or conventional, sewage systems and are used in regions where soil is poorly drained or where there is a high water table which prevents the use of conventional household sewage systems. (Abit, S., Jones, J., 2014) They are effective at reducing odors, organics, and solids within the water (up to 98%). The final treated water from these systems is supposed to be a high quality effluent that is commonly used for lawn irrigation and is approved by the United States Environmental Protection Agency for direct discharge into streams. University extension factsheets such as (Abit, 2014) are available regarding the operation of household aerobic wastewater systems. The focus in this study is on the operation of the Clearstream™ and NuWater™ Aerobic Wastewater

Treatment System types. These systems use a 3 stage process (Figure 1), consisting of wastewater entry into a “sludge” tank, followed by an aeration chamber with an air diffuser meant to oxygenate the wastewater to allow aerobic microorganisms to break down organic matter within the waste. Aeration supplies oxygen to the water, is an integral part of the system, and creates aerobic conditions in the wastewater, facilitating the growth and support of aerobic (beneficial) bacteria, while suppressing anaerobic (potentially harmful or pathogenic bacteria). The wastewater then enters into a holding “pump” tank, where it is disinfected with one of two different chlorinators. For the Clearstream™ system, a liquid chlorinator “doses” the wastewater directly into the holding “pump” tank, typically with standard 8% household bleach (sodium hypochlorite), for the purpose of killing microbes. For the NuWater™ system type, the wastewater passes over calcium hypochlorite (17%) tablets upon leaving the clarification chamber, prior to entering the holding “pump”, tank. After that, there is typically piping leading to a sprayer for irrigation, or some other means of dispersal for the end-product wastewater. Modifications to these systems are proposed, which could consist of simple piping to divert the water to either an alternative sprayer (for irrigation purposes) or for diversion into an additional holding tank(s) where the water can be made available to cattle. Homeowners should have a good understanding of the basic operation and maintenance requirements for their wastewater treatment system. University extension factsheets such as *Keep Your Septic System in Working Order* (Abit, 2014) are an excellent guide for homeowners to prevent costly repairs and health and environmental issues from an improperly maintained or malfunctioning unit.

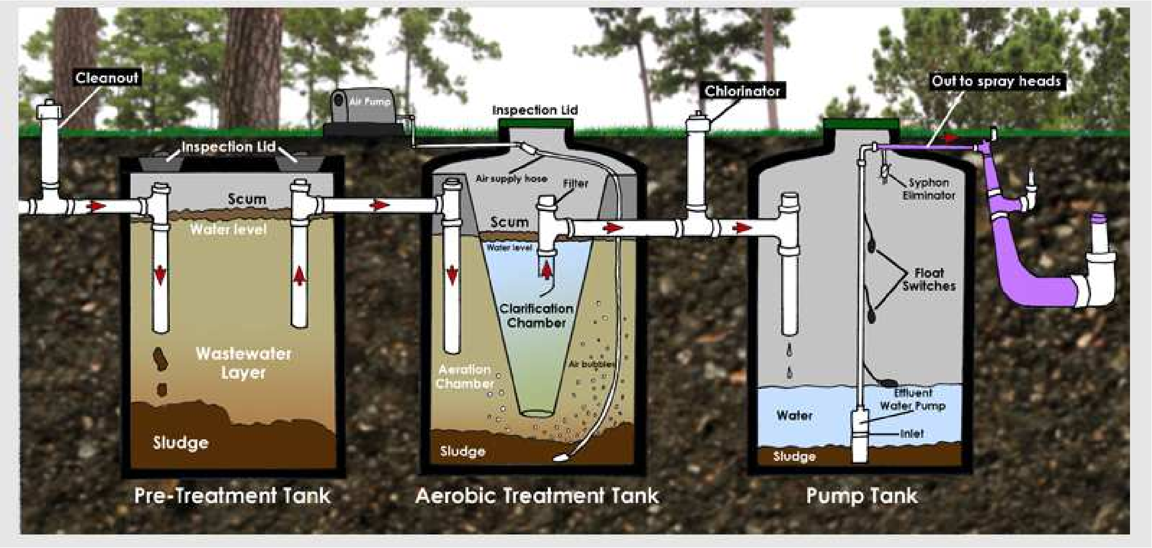


Figure 1. Diagram showing the basic operation of multi-stage aerobic treatment system. Obtained from www.septicpumpingtexas.com

Aerobic wastewater treatment systems need to be in proper working order to prevent environmental and health issues due to the release of improperly treated wastewater being discharged into the environment during a malfunction. Concerns of these systems, if functioning improperly, include: bacteria, protozoans, viruses, and a high nutrient load which could contribute to eutrophication of bodies of water. Household aerobic wastewater treatment standards vary from state to state, yet for Oklahoma, the regulations match those from the U.S. EPA (federal standards). As stated on page 14 of Oklahoma Law: Title 252. Department of Environmental Quality, Chapter 641, Individual and Small Public on-site Sewage Treatment Systems (2012), the main concerns are as follows: there needs to be a concentration of continual Free Residual Chlorine, which is chlorine composed of dissolved hypochlorite ions, hypochlorous acid and chlorine gas (within the final holding “pump” tank where disinfection takes place) of at least 0.2 mg L^{-1} (mg/L), and a live Fecal Coliform level of <200 colonies/100ml. These are the 2 requirements of these systems for disinfection purposes, in order to disperse the treated, final-product wastewater. According to the United States Centers for Disease Control (2014), in the Chlorine Residual Testing Factsheet, the presence of Free Residual Chlorine in drinking water is inversely correlated with the absence of disease-causing organisms, and thus is a measure of the potability of water regarding microbial activity.

Wastewater Treatment Methods of Disinfection for Aerobic Systems – chlorination: a cost effective method

Disinfection methods of wastewater from aerobic wastewater treatment systems include: ozonation, ultraviolet (UV) radiation, and chlorination, in the form of chlorine, chlorine gas, hypochlorite (bleach), chloramines (hypochlorites mixed with ammonia 4:5 to 1), and chlorine dioxides. The most common and cost efficient method of disinfection used within household aerobic treatment systems is hypochlorite (using standard bleach). According to the U.S. EPA in Wastewater Technology Factsheet, Disinfection for Small Systems (2003), common disinfection methods were comparatively studied (Table 1).

Table 1.

	Disinfection Type					
	Ozonation	UV Light	Chlorine Dioxide	Chloramines	Chlorine Gas	Hypochlorites
Effectiveness	30K times faster than chlorine, kills all pathogenic organisms	Effective, when used/maintained correctly	Very effective, kills pathogens including viruses	Effective at killing bacteria, some protozoans, but inffective on viruses	Very effective, kills pathogens & viruses	Depending on concentration, very effective
Advantages	No harmful residual	Significantly reduces protozoan & bacterial count	Oxidizes metals & organic matter to CO2 & H2O	Low cost, more stable than chlorine	High concentration of chlorine results in high effectiveness	Very low cost, easy to handle, not highly toxic
Disadvantages	High cost, high electricity consumption, corrosive	High cost, must obtain full exposure of UV light to treat water	Very costly, very technical maintenance, corrosive & dangerous around activated carbon	Weaker than chlorine	High cost, difficult to handle & maintain, corrosive, toxic, irritant	Concentration can vary, hypochlorites can break down before they reach pathogens

A basic comparison of the common disinfection methods used for wastewater disinfection

According to the U.S. EPA (2003), a cost-benefit analysis needs to be made on a case-by-case basis for each individual system, yet for most small systems, hypochlorite (using standard bleach or calcium hypochlorite tablets, depending on the system type) is the most cost-effective. (U.S. EPA, 2003)

Free Residual Chlorine (FRC) is the chlorine available in water after oxidation of organic matter and removal of nitrates in the water has taken place. FRC is the available chlorine that is able to inactivate pathogens within the water. Water with a chlorine demand (any water that is not pure: containing nutrients or organics), upon addition of chlorine, consists of Total Chlorine, which is composed of Combined Chlorine, and Free Residual Chlorine. Figure 2 shows a description of the reaction process of chlorination in water. When chlorine is added, a series of reactions within the water begin to take place. First, some of the chlorine is taken up by the chlorine demand in the water, which is the chlorine that is taken up by the presence of metals and organic material. This chlorine that is taken up by the chlorine demand is not available for inactivation of pathogens. After the chlorine demand is taken up, the remaining chlorine concentration is Total Chlorine and consists of 2 parts: Combined Chlorine and Free Residual Chlorine (FRC). Combined Chlorine is the chlorine that reacts with organic and inorganic forms of nitrogen in the water to produce chloramines. This chlorine is also not available for inactivation of pathogens. Free Residual Chlorine is the concentration of chlorine that remains in the water after all previous reactions have taken place, and this is the chlorine that is available for disinfection and inactivation of pathogens within the water. If FRC is present in water and at a sufficient level, it indicates that sufficient chlorine was added to the system and the water is protected from bacteria and pathogens within the water, preventing health concerns. The presence of sufficient FRC also indicates that the water will be protected from being contaminated during storage. According to the Washington State Department of Health: Chlorine Contact Time for Small Systems (2011), chlorine contact time (the amount of time it takes for chlorine to disinfect water) is dependent on the FRC concentration, and for a FRC concentration of 0.2 mg/L (as required for these systems under normal operation) the contact time for chlorination is 30 minutes.

A simple summary reaction for chlorination in water is as follows:

$$NaClO + H_2O \rightarrow Na^+ + Cl^- + \underline{2\ HO\bullet}$$

Sodium hypochlorite reacts with water to form sodium and chlorine ions and hydroxyl radicals. Hydroxyl radicals are molecules that have one unpaired electron on the oxygen atom, and are intermediate stages in many chemical reactions. These hydroxyl radicals are unstable, can oxidize organic compounds or self-react to form water and oxygen, as shown in the simplified equation:

$$2\,HO\bullet \rightleftharpoons H_2O_2 \rightarrow H_2O + O_2$$

Hydroxyl radicals are highly chemically reactive, are unstable, and are responsible for inactivation of pathogens within the water, along with hypochlorous acid and hypochlorite ions, by way of the breakdown of proteins.

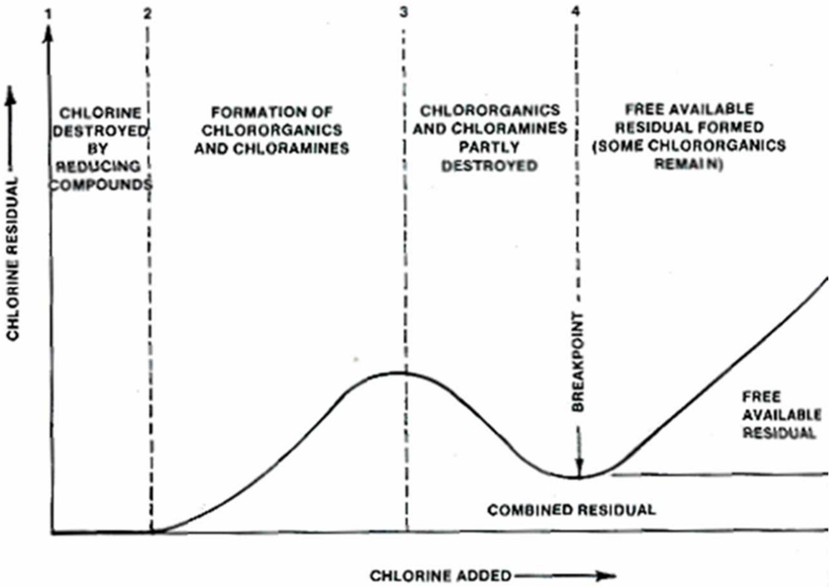


Figure 2. Chlorine Residual (FRC) versus chlorine added in a system. From www.water.me.vccs.edu, April 2015.

Microbial Analysis: Total Coliform and *E. coli*

Important microbial analyses within water, including wastewater, are tests for the presence of Total Coliform and *Escherichia coli* (*E. coli*). The reasoning behind the use of these simple analyses is the fact that Coliform (more specifically, *E. coli*) are an indicator of the potential presence of pathogenic forms of microbes. The presence of *E. coli* is not necessarily a cause for alarm, but its presence indicates that there is a potential for health hazards associated with the sub-groups of pathogenic *E. coli*. Figure 3 shows the groups of bacteria within the Coliform species:

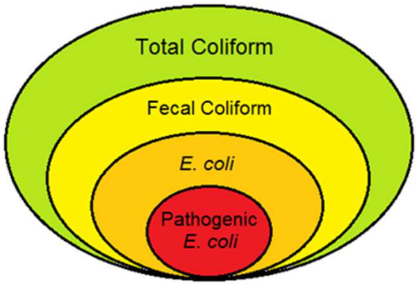


Figure 3. Pictorial summary of the groups and sub-groups of Coliform bacteria. Idea from U.S. EPA, Web (2013)

For the purpose of this study, it is known that the water is composed of wastewater from human households, so the presence of coliform, specifically; *E. coli* is definitely expected with the initial discharge of wastewater into the aerobic treatment system. However, what is important is the need for effective operation of the system, including proper and adequate chlorination, in order to inactivate the expected presence of fecal coliform. Total Coliform and *E. coli* analysis is performed by using the Colilert IDEXX Quanti-Tray® Method, and according to Rompre et. al., (2002), this method is relatively simple (as opposed to using a conventional count plate method) and approved by the U.S. EPA for drinking water and wastewater microbial analysis. Units for the results of this analysis are MPN/ 100 mL of water (most probable number of colony forming units per 100 mL of water). For very high suspected microbial counts, dilutions can be performed using sterile reagent water to make a better estimate for the calculation of Total Coliform and *E. coli* quantification.

Colorimetry Interference—turbidity & manganese

Determining the Free Residual Chlorine Concentration of a sample of wastewater can be challenging in the presence of high turbidity. Colorimeters work by way of a certain wavelength of light passing through a sample of water, which is usually reacted with a reagent (depending on the sample analysis). The transmitted light is then received and read by a calibrated unit, and a resulting output is given in units which are dependent on the analysis being performed. According to Harp (2002), interference by turbidity in wastewaters is a common problem that needs to be accounted for, by the filtration of the sample of wastewater with a standard 45 micron filter, typical for removing for suspended solids from water. Harp (2002) states that the volatility and instability of chlorine make the analysis of chlorine concentration difficult in highly turbid water. This is because filtering the sample is not appropriate due to potential loss of chlorine during filtering, which can be caused by the natural volatility of chlorine or from reactions with the filtering media. Additionally, the salt of N, N-Diethyl-p-Phenylenediamine (DPD) reagent used for measuring Free Residual Chlorine is sensitive to turbidity and the interference is significant.

Harp (2002) also describes potential interference with colorimetry by manganese in the water being analyzed. Soluble manganese in water samples is oxidized in the presence of Free Residual Chlorine:

$$Mn^{2+} + HOCl + 3OH^{-} \rightarrow MnO_2 + \ Cl^{-} + 2H_2O$$

These manganese oxides then react with the DPD reagent, specifically, the iodine formed in the reaction of DPD with chlorine that develops the “red” color which is used for sample analysis to determine FRC concentration. The presence of manganese oxide causes a significant increase in the red color intensity, giving a falsely high reading of FRC.

CHAPTER III

METHODOLOGY

Based on previous research concerning constituents regarding cattle water quality regarding lawn and crop irrigation and known water quality issues associated with human wastewater: Beede (2006, 2009), Parish (2009), Wright (2007), and Morgan (2011), the testing parameters were as follows:

Total Coliform: most probable number (MPN), *E. coli* MPN, pH, EC (electroconductivity) in µS/cm, SAR (sodium absorption ratio), salinity, K^+, Ca^{+2}, Mg^{+2}, Zn^{+2}, Cu^+, Mn^{+2}, Fe^{+3}, total phosphorous, $NO_3{}^- - N$, $Cl^-, SO_4{}^{-2}, HCO_3{}^-$, B^{+3}, TSS (total suspended solids), hardness and alkalinity, and Free Residual Chlorine.

A total of 5 samples were taken on dates: 4/8, 4/23, 5/5, 5/19, and 6/9 of 2015. Water samples were analyzed by: the Oklahoma State University Soil, Water, and Forage Analytical Laboratory (SWFAL), and in the Soil Microbiology laboratory at Oklahoma State University. Sodium Absorption Ratio and salinity, hardness, pH, TDS, nitrates, sulfates and all other water quality constituents were analyzed in the OSU SWFAL. Methods for each of the analyses completed in SWFAL include: EC, Na^+, Ca^{+2}, Mg^{+2}, $K^+, SO_4{}^{-2}$, B^{+3}, P^{+3}, Fe^{+3}, Cu^+, Zn, and Mn:

Standard Methods for the Examination of Water and Wastewater (2005) Method 3120 B. Cl^- and $NO_3{}^- - N$: American Public Health Association: Standard Methods (2005), Methods 4500 Cl-G and 4500 NO3-I. HCO_3 and pH: Standard Methods (2005), Alkalinity Method 2320 B. Acid digestion was also performed by SWAFL to get total phosphorous results for the last set of samples using University of Wisconsin extension, *Recommended Methods for Manure Analysis* (2003).

Four of the five sets of samples (omitting sample date 4/5/2015, due to error) were analyzed for Total Coliform and *E. coli* in the Soil Microbiology laboratory, according to the IDEXX™ Quantitray Colilert Method (IDEXX company, Westbrook, Maine). Free Residual Chlorine tests were completed with a Free Residual Chlorine test kit: Hach™ Pocket Calorimeter II™, Chlorine.

Water Sampling and Analysis

Water samples from household aerobic treatment systems were taken from the third (3rd) stage holding "pump" tank (Figure 1) on each individual system. When sampling, care should be taken to ensure that components are in working order (to the best knowledge of the homeowner), especially the chlorinator (sanitizing unit) and that there is ample disinfectant, such as sodium hypochlorite (bleach), in each reservoir/holding "pump" tank chamber. Samples were taken from two different aerobic system types, with 5 households for the liquid chlorinator aerobic system type (systems 1-5), and with 3 households for the tablet (calcium hypochlorite) aerobic system type (systems 6-8). Five sampling events (two weeks apart) occurred on 8 systems, on the same day for each of the sampling events, for a total of forty (40) samples. A statistical mean comparison using the Z-test, $\alpha = 0.05$ was then calculated, and results of the water quality testing parameters were individually analyzed for any values falling outside of the recommended water quality parameters, and to determine if the values for water quality testing parameters were significantly different from the threshold needed for this wastewater source to be used for the purposes of livestock watering (specifically cattle).

Samples were collected in sterile bottles, while donning personal protective equipment, to include a laboratory coat (or an overcoat that is easily removed). Sample bottles were washed once sampling was complete to prevent pathogen contamination. Three samples were drawn from the holding “pump” tank unit from each site for each sampling event. Sample bottles that went to SWAFL and the Soil Microbiology laboratory were closed tightly and placed inside a container (sealed bucket) with an approximate 1:12.5 chlorine bleach: water solution (8%) for at least 10 minutes for disinfection of the outside of the bottles, then removed with a clean pair of gloves, rinsed well in deionized water, and dried with a clean towel away from the site (outside the vehicle used to travel to sampling sites). Samples that were tested for Free Residual Chlorine (on site) occurred immediately (or as soon as possible) using the Hach™ Pocket Colorimeter II™, Chlorine (Free and Total) portable test kit. According to the U.S. EPA in Health Risks of Humans to Wastewater (1981), great care should be taken to prevent the individual taking samples from coming into contact with the wastewater and that the wastewater does not touch any surfaces that others may come into contact with, since there is a risk of contamination with many different species of bacteria, viruses, and other pathogens. This would be especially true if the individual unknowingly takes samples from a site where the treatment system is not functioning properly, such as with the chlorinator/disinfecting stage of the system failing or where the aerator is malfunctioning, due to the importance of the aerator for proper system function. (Abit, 2014)

Free Residual Chlorine

Wastewater samples were analyzed for FRC using the Hach™ Pocket Colorimeter II™, Chlorine (Free and Total) portable test kit. Approximately 10 mL of the water is placed in a pre-made glass vial and used as a comparative “blank” for the colorimeter to zero out. The outside of the glass vial was cleaned with a cloth to remove any water, residue, or finger prints. After zeroing the meter, a small packet of reagent for reading FRC as Cl_2 mg/L was gently mixed into the sample. Within one minute, the sample was read on the meter, and reported as FRC mg/L.

The mode of action for the Free Residual analysis using this method is by way of a reagent, specifically, salt of N, N-Diethyl-p-Phenylenediamine (DPD), where a red solution is formed from the oxidation of Iodine in the DPD, and Total Chlorine in the sample, which consists of the Free Residual Chlorine and Combined Chlorine. The resulting color of the solution is then analyzed by the colorimeter to give a reading for the concentration of FRC in the sample. FRC is read within one minute, and Total Chlorine can be read after a timed 3 minute reaction. The color intensity (red) of the reaction is proportional to the chlorine concentration in the sample, which also correlates with a higher propensity to inactivate microbes.

Turbidity Affecting Free Residual Chlorine—a short experiment

As mentioned in Harp (2002), chlorine concentration analysis by colorimetry is affected by turbidity in the water being analyzed. A short experiment was performed using varying weights (0, 0.2, 0.5, 0.8, and 1.0 g) of calcium carbonate suspended in deionized water with a constant chlorine concentration of 0.2 mg/L, to reaffirm Harp (2002). Calcium carbonate is slightly soluble in water and hypochlorous acid (formed from the reaction of water and sodium hypochlorite), yet the solutions analyzed in this experiment were used to form a turbid sample. The Hach™ Pocket Colorimeter was used, as in the FRC concentration analysis method. Ten mL samples of deionized water with a constant chlorine concentration of 0.2 mg/L were mixed with each weight of calcium carbonate and FRC concentrations were analyzed as per the Hach™ DPD method mentioned in the previous section: Free Residual Chlorine.

Microbial Analysis

Microbial analysis was performed using the Colilert IDEXX Quanti-Tray® Method. Samples from the wastewater treatment systems were captured as described above and taken to a laboratory (Soil Microbiology Laboratory at OSU). The analysis was performed according to the Colilert IDEXX Quanti-Tray® Method 06-02320-07. Briefly, a 100 mL water sample was poured into a prepackaged plastic bottle where a substrate/reagent mixture was added to the sample, gently mixed well until dissolved, and then poured into a Quanti-Tray®, which is a plastic, multi-well vessel with a foil-lined seal. After pouring the sample into the tray, air bubbles were removed by gently tapping the tray with fingers to release any bubbles from individual wells. The tray was then placed into a rubber insert that seats the tray while it is placed into the Quanti-Tray® sealer, which seals each well individually. After sealing, it was ensured that each well had sample water within it and the tray(s) were placed in an incubator set at 35 degree Celsius for approximately 24 hours. After incubation, the tray(s) were removed and observed for chromogenesis and fluorogenesis simultaneously, for an indication of the presence of Total Coliform and *E. coli*, respectfully. The color of each well in each tray was compared to a color indicator; a dark yellow color indicates the presence of Coliform bacteria (Figure 5). This analysis is for the quantification of Total Coliform, where the trays are viewed in ambient, white light. Each of the positive wells was counted, large and small, and an algorithm chart was used to determine the MPN of Total Coliform (Figure 4). For *E. coli* quantification, fluorogenesis was observed in wells that are positive (Figure 6). The trays for this analysis were viewed under a 365 nm wavelength UV light, where positive wells “fluoresce”. Similarly, the large and small wells that indicate a positive result were counted and the same algorithm chart was used to quantify the MPN of *E. coli*. Total Coliform is quantified by a reaction that produces a color indication (chromogenic), which is compared to a standard to give a positive or negative result in each individual “well”, while the presence of *E. coli* is determined by a reaction that produces fluorescence (fluorogenic) under a 365 nm UV light. Reactions in the water sample during analysis through the breakdown of substances by specific enzymes are responsible for the chromogenic (β-D-galactosidase) for Total Coliform, or for *E. coli*: fluorogenic (β-D-glucuronidase) result(s). The numbers of wells that indicate a positive result for either the Total Coliform or *E. coli* analysis are counted and an algorithm chart, similar to the example in Figure 4 is then used to indicate the quantity of each group of microbes.

# Large Wells Positive	# Small Wells Positive			
0	0	1	2	3
1	<1	1.0	2.0	3
2	1.0	2.0	3.0	4.0
3	2.0	3.0	4.1	5.1
4	3.1	4.1	5.1	6.1

Figure 4. Example of the algorithm chart used for quantification of microbes in water samples tested, using the IDEXX Quanti-Tray® Method. 3 large wells and 2 small wells with a positive indication result in 4.1 MPN/ 100mL. (Rompre et. al., 2002)

Figure 5. Example of chromogenic result for the presence of Coliform bacteria in a sample of the wastewater. Note the color difference in the sample on the left, which showed a chromogenic indication (dark yellow in color) compared to the right, where the result was negative for each of the wells.

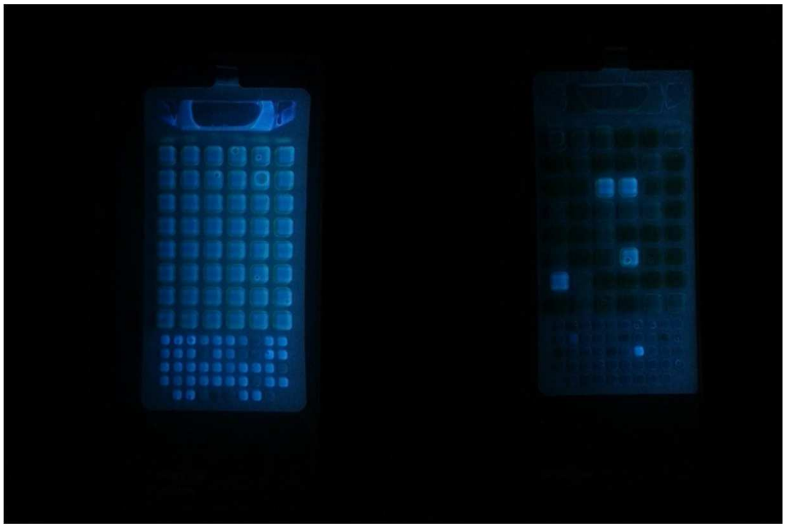


Figure 6. Example of fluorogenic result for the presence of *E. coli* bacteria in a sample of the wastewater. Note the difference in the sample on the left, which showed a high rate of fluorogenic indication (fluorescence) compared to the right, where the result was positive for a few of the wells.

CHAPTER IV

FINDINGS

Constituent Testing

Descriptive statistics for each of the water quality testing parameters: constituent testing (pH, EC Na, K, Ca, Mg, $NO_3 - N$, Cl, SO_4, HCO_3, B, TSS, Hardness, Alkalinity, Zn, Cu, Mn, and Fe), Free Residual Chlorine concentration, and microbial analysis: Total Coliform and *E. coli*, follows in Table 2.

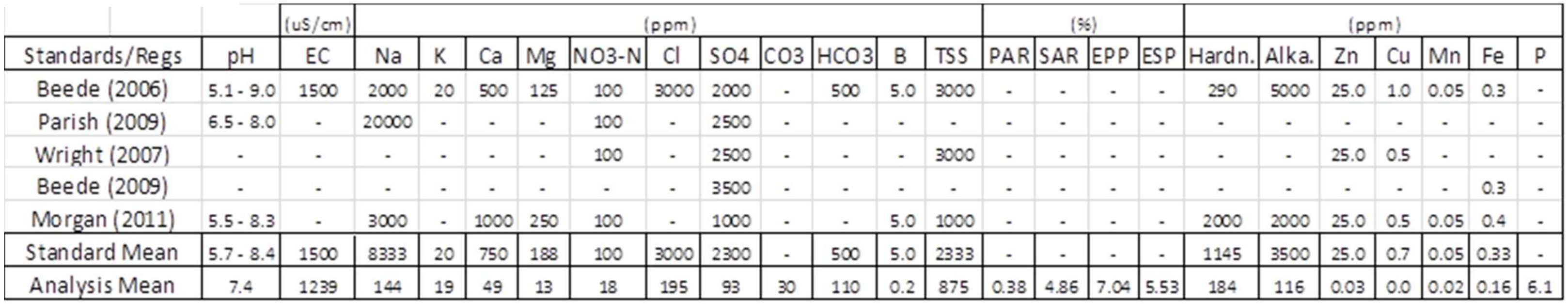
Table 2.

	Analysis	N	Mean	SD	Mode	Min	Max	Skew
MPN/100mL	Total Coli	32	219284.2	326466.7	1011200	0.0	1011200.0	1.7
	E. coli	32	7563.2	20448.7	0	0.0	100725.0	3.8
	FRC	32	0.7	1.1	0.2	0.1	5.7	3.6
	pH	32	6.1	0.7	-	4.6	8.6	5.7
uS/cm	EC	32	1192.5	384.1	-	388.0	1777.0	-0.6
ppm	Na	32	139.9	46.7	170	39.3	237.1	-0.4
	K	32	18.3	5.6	25	7.7	27.7	-0.4
	Ca	32	48.3	12.1	50	26.1	73.0	0.1
	Mg	32	13.0	2.5	14	6.3	16.0	-0.9
	NO3-N	32	15.1	14.9	0	0.0	54.2	0.9
	Cl	32	188.3	67.3	215.4	42.4	290.9	-0.8
	SO4	32	89.9	29.2	103.7	24.9	132.2	-0.9
	HCO3	32	101.0	115.4	-	0.0	388.1	1.2
	B	32	0.2	0.1	0.1	0.1	0.5	1.3
	TSS	24	852.9	188.7	-	522.1	1122.7	-0.6
	Hardness	24	181.3	33.5	190	120.0	242.0	-0.1
	Alkalinity	31	114.0	90.5	27	17.0	355.0	1.2
	Zn	32	0.0	0.0	0.01	0.0	0.1	1.5
	Cu	32	0.0	0.0	0	0.0	0.0	2.5
	Mn	32	0.0	0.0	0.01	0.0	0.0	0.6
	Fe	32	0.2	0.2	0.12	0.0	1.0	2.7

Descriptive statistics of water quality parameters tested across all sites and sample dates.

Analysis of constituents in the OSU SWAFL showed all water quality perimeters to be within known ranges for cattle water quality found in the literature, except for a few occasions of potassium, iron, and electroconductivity (EC) slightly exceeding recommended standards. However, these levels are not known to be problematic according to Beede (2007), Parish (2009), Wright (2007), and Morgan (2011) and the means for these constituents are within the acceptable ranges (Table 3). Statistical analysis (Z-test, $\alpha = 0.05$) resulted in each of the constituents tested to be within tolerance of the standard for cattle when compared to the water quality parameter standards. The water quality of the final effluent from aerobic wastewater treatment systems appears to be within standard for each of the recommended constituents to be tested. Due to the result of the constituent analysis, when compared to recommendations by previous studies, the water quality from these systems in this category is of sufficient quality for use by cattle. Full water constituent analysis results are located in the appendix.

Table 3.



		(uS/cm)	(ppm)											(%)				(ppm)						
Standards/Regs	pH	EC	Na	K	Ca	Mg	NO3-N	Cl	SO4	CO3	HCO3	B	TSS	PAR	SAR	EPP	ESP	Hardn.	Alka.	Zn	Cu	Mn	Fe	P
Beede (2006)	5.1 - 9.0	1500	2000	20	500	125	100	3000	2000	-	500	5.0	3000	-	-	-	-	290	5000	25.0	1.0	0.05	0.3	-
Parish (2009)	6.5 - 8.0	-	20000	-	-	-	100	-	2500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wright (2007)	-	-	-	-	-	-	100	-	2500	-	-	-	3000	-	-	-	-	-	-	25.0	0.5	-	-	-
Beede (2009)	-	-	-	-	-	-	-	-	3500	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-
Morgan (2011)	5.5 - 8.3	-	3000	-	1000	250	100	-	1000	-	-	5.0	1000	-	-	-	-	2000	2000	25.0	0.5	0.05	0.4	-
Standard Mean	5.7 - 8.4	1500	8333	20	750	188	100	3000	2300	-	500	5.0	2333	-	-	-	-	1145	3500	25.0	0.7	0.05	0.33	-
Analysis Mean	7.4	1239	144	19	49	13	18	195	93	30	110	0.2	875	0.38	4.86	7.04	5.53	184	116	0.03	0.0	0.02	0.16	6.1

Mean water constituent analysis results compared to known standards

Phosphorous

A sample of effluent from each system during the last sampling event (total of 8 samples) was tested for total phosphorous (organic and inorganic forms) through a high temperature, acid digestion method by SWAFL at OSU (Table 4) and compared to previous samples (undigested: total of 40 samples) in order to determine if there was an overlooked source of phosphorous in the effluent:

Table 4.

System	P-Digested (ppm)	P-Undigested (ppm)
1	13	9
2	2	2
3	5	4
4	2	3
5	6	7
6	1	2
7	3	4
8	4	4

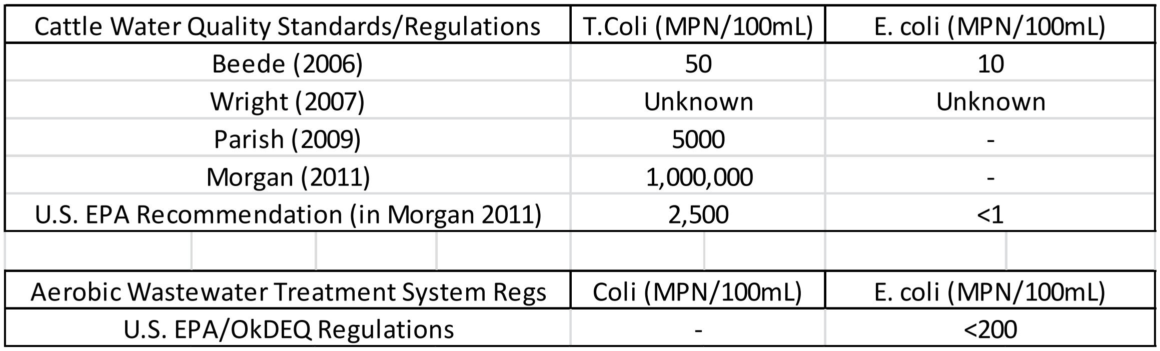
Digested and Undigested (soluble) phosphorous results for each system

Mean digested phosphorous (of 8 samples) was 5 ppm. The mean after omitting system 1, which had a much higher result, likely from system 1's aerator and chlorinator malfunctioning, was 3 ppm. Using the visual representation of digested to undigested phosphorous in the final effluent; there is not much difference between the digested and undigested phosphorous in the final effluent. However, phosphorous at these levels are potentially problematic for nearby bodies of water. High phosphorous levels in these systems can be explained by detergent use, feces, soil washed from clothing, and organic waste (such as food waste expelled by garbage disposal). Phosphorous TMDL (Total Maximum Daily Load) levels for Oklahoma depend on the specific body of water. The maximum TMDL for scenic rivers is 0.37 ppm, and watershed streams commonly have concentrations of 0.5 – 1 ppm, at which is concerning for potential eutrophication (Dunne and Leopold, 1978). Additionally, municipal wastewater treatment plants are efficient at decreasing the phosphorous levels in wastewater to less than 1 ppm using methods such as phosphate precipitation or microbial bioremediation. Removal of phosphorous from aerobic wastewater treatment systems appears to be a necessity, if environmental issues due to phosphorous loading and eutrophication are to be avoided.

Microbial Analysis Results

Microbial analysis results are concerning for *E. coli*, specifically. Total Coliform was statistically within tolerance (Z-test, α= 0.05) for the standard for cattle water quality, Morgan (2011). For these systems, EPA regulations for the normal operation of Aerobic Wastewater Treatment systems do not include Total Coliform. The field of cattle water quality is new and evolving; with very few studies to determine the safe level of *E. coli* in drinking water. According to Wright (2007), it can be difficult to determine the actual microbial counts of water that cattle consume, especially in ponds where defecation by cattle occurs and disturbance of the sediment in the bottom of the pond takes place while cattle are drinking. Examples of a few recommended guidelines are shown below, with Beede (2006) as a stringent recommendation for dairy cattle and calves (Figure 5).

Table 5.



Cattle Water Quality Standards/Regulations	T.Coli (MPN/100mL)	E. coli (MPN/100mL)
Beede (2006)	50	10
Wright (2007)	Unknown	Unknown
Parish (2009)	5000	-
Morgan (2011)	1,000,000	-
U.S. EPA Recommendation (in Morgan 2011)	2,500	<1

Aerobic Wastewater Treatment System Regs	Coli (MPN/100mL)	E. coli (MPN/100mL)
U.S. EPA/OkDEQ Regulations	-	<200

Water Quality Standards for Cattle and Normal Aerobic Wastewater Treatment System Operation

For the purpose of this study, a Total Coliform threshold of 1,000,000 MPN/100mL and an *E. coli* threshold of 10 MPN/100mL were used. Results of the mean MPN for both Total Coliform and E. coli are shown below (Table 6), with pass/fail conditions shown for each analysis.

Table 6.

Sample Date	System Number	1	2	3	4	5	6	7	8
4/23/2015	Total Coli	328,200	238,200	104,345	12,400	1,011,200	0	0	49,695
	Cattle Water	✓	✓	✓	✓	X	✓	✓	✓
	E. coli	22,860	34	4	73	100,725	0	0	1,995
	Cattle Water	X	✓	✓	✓	X	✓	✓	X
	EPA Reg	X	✓	✓	✓	X	✓	✓	X
5/5/2015	Total Coli	913,900	1,011,200	77,835	37,110	1,011,200	865	83,885	239,545
	Cattle Water	✓	X	✓	✓	X	✓	✓	✓
	E. coli	59,085	38	33	4,995	10,225	37	1,234	8,567
	Cattle Water	X	✓	✓	X	X	✓	X	X
	EPA Reg	X	✓	✓	X	X	✓	X	X
5/19/2015	Total Coli	83,095	14,705	524,700	67,400	25,495	37,335	35	101,695
	Cattle Water	✓	✓	✓	✓	✓	✓	✓	✓
	E. coli	226	345	5005	152	36	190	0	6285
	Cattle Water	X	X	X	X	X	X	✓	X
	EPA Reg	X	X	X	✓	✓	✓	✓	X
6/2/2015	Total Coli	556,160	31,675	150,000	76,625	105	228,200	140	150
	Cattle Water	✓	✓	✓	✓	✓	✓	✓	✓
	E. coli	843	1	18,974	60	0	1	0	0
	Cattle Water	X	✓	X	X	✓	✓	✓	✓
	EPA Reg	X	✓	X	✓	✓	✓	✓	✓

Pass/fail status for Total Coliform and *E. coli* MPN by date and system number

The standard for *E. coli* for both cattle water quality and EPA regulations for these systems (10 MPN/100 mL and 200 MPN/100 mL, respectively) were exceeded often (Figure 7), and were shown to be statistically significantly different from the standards with a left-tailed Z-test p-value of 0.02, α = 0.05. However, it is important to note that the systems sampled from were relatively old (approximately 5 years) and were not being serviced regularly. During sampling, problems in the operation of some of the systems (specifically numbers 1, 5, and 8) were discovered. However, the servicer that accompanied and assisted during sampling was quick to inform the homeowner(s) and implement the needed repair/service(s). The mean results of the *E. coli* analysis are shown to be high in systems 1, 5, and 8, which were found to be malfunctioning (chlorinator and aerator were initially inoperative on systems 1, 5, and 8).

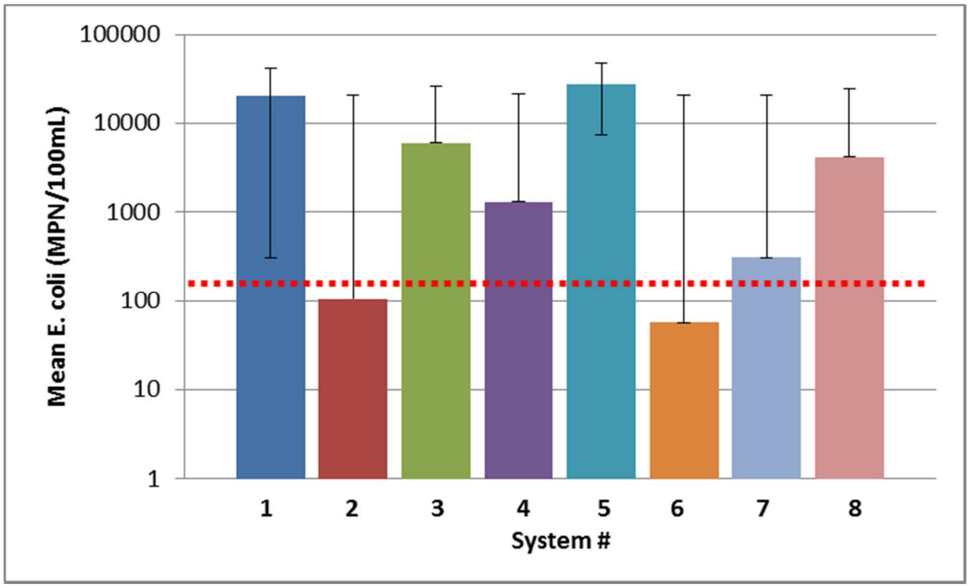


Figure 7. Mean *E. coli* MPN for each ATU system. Dotted red line indicates EPA standard for the normal operation of these systems: 200 MPN/100 mL. Error bars indicate +/- 1 standard deviation.

The systems that were not known to be malfunctioning had relatively low *E. coli* MPN results. *E. coli* to Total Coliform ratio was calculated to give an approximation of the percentage of Total Coliform that is *E. coli*. The mean *E. coli*: Total Coliform ratio was found to be 0.03 or 3%. Full results of the analyses, including FRC concentration in mg L^{-1} (mg/L), Total Coliform and *E. coli* (both in MPN/100 mL) results are located in the appendix.

Free Residual Chlorine Concentration and Possible Interference

Through statistical analysis (Z-test, α=0.05), FRC readings were found to meet the standard for these systems, according to the U.S. EPA and Oklahoma DEQ regulations (Figure 9). However, turbidity in the wastewater was shown to affect the FRC readings. A short experiment in the laboratory using calcium carbonate (to increase turbidity in the water) mixed with deionized water with a constant concentration of chlorine (0.2 mg/L) was used to determine if turbidity affected the FRC concentration reading. An increase in turbidity was directly proportional to an increase in FRC concentration up until a certain concentration, after which, the correlation drops to an undefined value (Figure 8). Erroneous FRC readings are the result of the water becoming so turbid that the colorimeter reading becomes invalid, meaning the light is not able to correctly pass through the water sample, causing a false positive (higher than actual) FRC concentration.

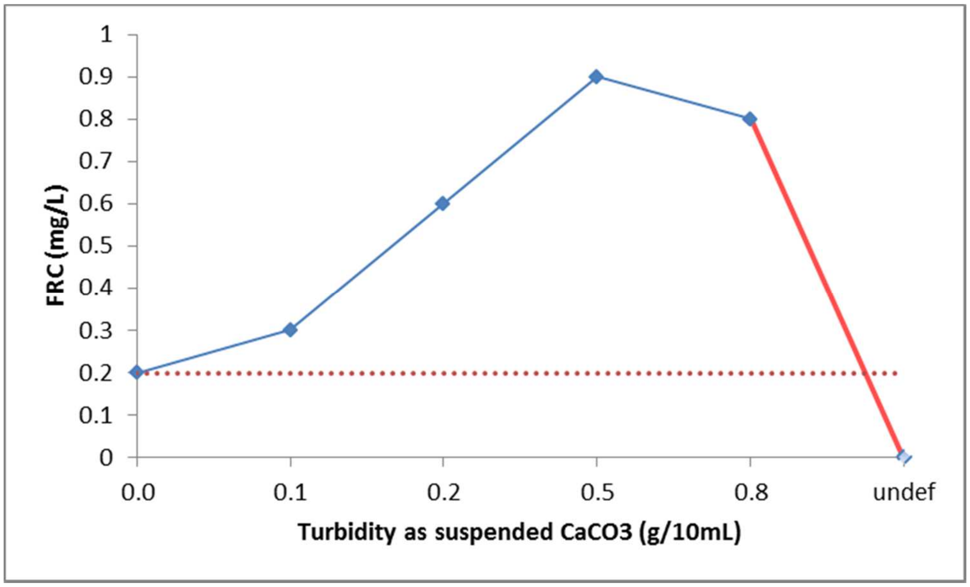


Figure 8. Free Residual Chlorine concentration versus turbidity as suspended CaCO3 in g/10 mL sample of deionized water with a constant chlorine concentration of 0.2 mg/L, shown as dotted line.

Turbidity affecting the Free Residual Chlorine concentration analysis is a problem for anyone performing field work testing for FRC on aerobic wastewater treatment systems. Some of the samples that had a high reading for FRC concentration also had a very high reading in microbial MPN counts, which is counterintuitive and should not be, since the FRC is the chlorine that is available to inactivate microbes and pathogens in the water. Figure 9 shows high FRC concentration in system numbers 1, 5 and 8 (systems that were known to be malfunctioning during sampling and had high *E. coli* MPN values). System number 7 is a tablet form (17%

calcium hypochlorite) unit. The tablet reservoir on unit 7 was found to be empty on the first day of sampling, it was refilled, and 2 tablets were also placed in the holding "pump" tank by the servicer. This could explain the high FRC concentration values for unit 7. Systems 2, 4, and 6 were not known to be malfunctioning and were averaging values near the standard requirement (0.25-0.35 mg/L FRC) for these systems for Free Residual Chlorine concentration of 0.2 mg/L.

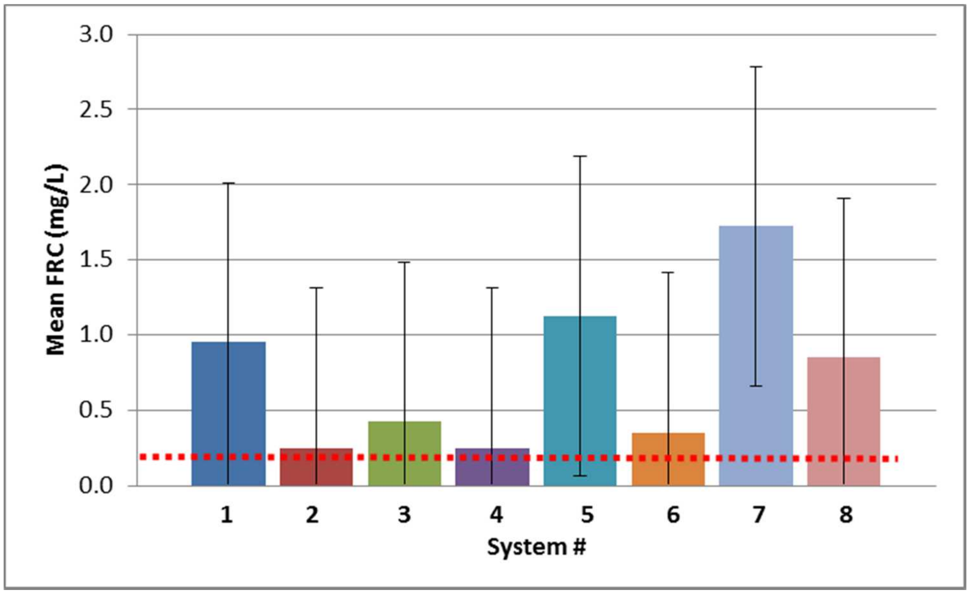


Figure 9. Mean FRC concentration for each system. Dotted red line indicates 0.2 mg/L standard. Error bars indicate +/- 1 standard deviation.

The FRC concentration and MPN counts of the samples should be inversely proportional. That is, as FRC increases, MPNs should decrease (as available chlorine to inactivate pathogens (FRC) increases, microbial counts (MPNs) should decrease). This did not always occur, and additionally, it was found that with the samples having very high apparent turbidity (systems 1, 5, and 8), the reverse was true. That is, as apparent turbidity increased (by way of visual inspection), FRC concentration increased. However, the microbial MPN counts of these samples were high. The explanation for this occurrence appears to be that turbidity affects the operation of the colorimeter. Colorimeters work through the passage of a certain wavelength of light (420 nm) through a sample, and if this passage of light is interrupted, inhibited, or affected by suspended solids in the water, the resulting output is affected (Harp, 2002). This is a very important consequence when considering wastewater treatment systems, since malfunctioning systems will sometimes have effluents that are high in turbidity, due to failure of the breakdown of organics in the wastewater. Additionally, there is a potential for microbial mass to create additional turbidity in the water, which is likely to happen during wastewater treatment system malfunction. The only known potential solution to this problem is to filter each of the samples before testing for FRC concentration. It is believed that each sample should be filtered, due to unknown conditions of the wastewater. In systems where it is known that there is a malfunction in the treatment process, it is imperative that the samples be filtered to remove the suspended solids to get a true reading of FRC, and then the method for determining FRC concentration should be performed immediately after filtration to avoid loss of FRC concentration by way of chlorine breakdown. However, chlorine breakdown can occur during filtration (Harp 2002). Additionally, in systems where it is unknown whether the treatment process is functioning properly, the samples should be filtered, due to the fact that there may be interference from turbidity, and one would not know whether or not the FRC concentration readings are accurate. However, in systems where it is known that each of the treatment steps in the system are functioning properly as they should be, it may prove to be unnecessary to filter the samples prior to testing for FRC. One observation was that the smell of effluent water from the holding “pump” tanks of the systems was very indicative of the function of the systems. One does not need to hold the water sample near them to smell it, but when removing the holding “pump” tank lid, a very pungent smell will oftentimes emit from the unit. This is not the only recommended suggestion to determine whether the sample should be filtered, but certainly if the smell is apparent, the sample should be filtered, due to the fact that the final effluent from these systems should have very little odor if the systems are functioning as they should be. A correlation analysis (r value -1 - +1) was performed and is affected by what is believed to be due to the interference from turbidity. A weak correlation was found for FRC versus *E. coli*. of 0.11, and for FRC versus Total Coliform (0.03).

Through a personal communication with Hach™ over the phone (June 9th, 2015), it was also learned that manganese and hexavalent chromium can interfere with the FRC concentration reading from the colorimeter. Water samples that are suspected to contain either of these elements should have an additional analysis done, by way of elimination of chlorine in the water samples. According to Hach™, elimination of chlorine in samples can be done if there is suspicion of manganese or hexavalent chromium interference in the water. This is accomplished through the addition of either a potassium iodide or sodium arsenite reagent, which reacts with all the chlorine in the water. If, after elimination of chlorine, there is a chlorine concentration reading on the colorimeter, one can deduce that there is interference in the system. Otherwise, the concentration of chlorine in the sample after elimination of chlorine by way of these two chemicals will result in a reading of zero for chlorine concentration. It is important to note that samples treated with sodium arsenite for countering the influence of manganese and hexavalent chromium will be hazardous wastes and should be disposed of properly, according to U.S. RCRA (Resource Conservation and Recovery Act (1976) for arsenic (D004). Manganese was present in this study's samples, yet at low levels (mean = 0.02 ppm, max = 0.04 ppm).

System Maintenance

There was an expectation that the aerobic wastewater treatment systems tested would meet the Oklahoma DEQ regulations regarding output of the effluent from these systems, as they normally should be in working order and functioning properly. A functioning aerobic wastewater treatment system that meets Oklahoma DEQ standards should provide water that meets the regulations regarding dispersal on lawns and should meet the recommendations found in my literature review for water quality for the purpose of watering cattle. Using these known regulations, recommendations, and analyses for water quality parameters, the wastewater should be for lawn watering, and possibly, for cattle watering, if *E. coli* is suppressed to a sufficient level. However, systems do not always function properly, homeowners do not always maintain their equipment, and variability will likely occur as a result of these and other factors. It is imperative to stress the need of system maintenance and regular inspections, to include regular Free Residual Chlorine tests (every 6 months, as recommended by the Oklahoma DEQ), and possibly, more often, if the wastewater is being used for a high-risk purpose, such as watering crops that are in direct contact with humans, or when watering cattle. This would help ensure that chlorine levels are maintained to a sufficient concentration, and as a result, will be effective at eliminating the risks of pathogen contamination to humans or cattle.

It was determined that the chlorinators of the systems tested in this study were not functioning properly at all times. This made correlations of data difficult and variable. Turbidity was high in many samples taken from systems that seemed to be malfunctioning. It was difficult to determine which systems were functioning properly because access to each stage of the treatment process was not always possible. However, the chlorination reservoir was fairly easy to see when taking samples, and many of them appeared to be empty when samples were taken. It was requested to the servicing and maintenance technician accompanying during the field sampling dates that the chlorination reservoirs and tablet chlorinators be filled.

It is possible that systems that have been in inoperative condition (or not completely functioning as they should) will need to have the system water "shocked" with a high FRC concentration to decrease the microbial counts in the water to a level sufficiently low to suppress the anaerobic bacteria count. The basis behind this suggestion is that there may be an overgrowth in anaerobic bacteria in the holding "pump" tank and simply refilling the chlorination reservoir, where the standard dosing of the water in the holding "pump" tank may not be sufficient to kill enough microbes in the wastewater. If the system has been malfunctioning for some time, the holding “pump” tank may need to be disinfected to a sufficient level to return the system to proper chlorination, as the chlorination unit functions on the assumption that the system has continually been functioning as it should. A malfunctioning wastewater treatment system can have microbial levels that far exceed what is expected to be present during proper function of the system.

Water Quantity and Cost – Calculations for potential water quantity produced and cost savings

Calculations for potential wastewater produced for reuse are based on known (or easily discovered) volumes of water that flow into the household for use. Since most of this water entering a household will be flushed into the treatment system, a clear approximation can be made for each household’s quantity of water that can potentially be used for alternative purposes. These quantities will vary based on household size & composition, water usage by individuals, including daily habits, and the amount of time that the individuals spend at home.

A conservative example for the calculation of water quantity produced is as follows: According to the United States Geological Survey website (www.water.usgs.gov/qa-home-percapita), a typical two-person household averages about 150 gallons of water use per day, which is equivalent to approximately 4500 gallons per month. According to Rasby and Walz (2011), cattle typically drink about 12 gallons per cow, per day, depending on climate. Approximately 13 cattle could be supported with the water from this theoretical 2 person household. For cost analysis, the price of water in Stillwater, Oklahoma was $9.91/1000 gallons (at the time of the study) for the rural water district that the systems in this study were located. The savings for this example equate to $44.60/month, or $535.14/year (per 13 cattle). This is significant enough for many homeowners with cattle to consider implementing, especially if they already have an aerobic wastewater treatment system installed on their property. Obviously, larger households with more people using more water will result in more wastewater to be treated and, in effect, to be available for reuse. It also follows that this would equate to more savings, or a greater ability to supply larger amounts of recycled wastewater for alternative purposes.

CHAPTER V

CONCLUSION

Current Research

The water quality from properly functioning aerobic wastewater treatment systems is sufficient enough that the effluent could be a potential source of reclaimed water for reuse. It is already widely used for lawn irrigation and when the units are functioning properly, the effluent is a high quality source of non-potable water that could potentially be reused for many alternative purposes. For cattle watering, it is imperative that the systems are in working order, namely, the aerator (to suppress anaerobic microbes, especially *E. coli*) and the chlorinator (for proper disinfection). When these mechanisms are working as they should, samples of the water appeared colorless, transparent, and virtually odor free (especially systems 6 and 7 on the last sampling date, which are tablet (calcium hypochlorite) chlorinating systems). Data from this study suggested that proper functioning of the wastewater treatment system is important to ensure that the water quality of the effluent is sufficient enough to meet standards for discharge into streams, and also for any proposed reuse. Water generated from a malfunctioning system should not be reused or discharged onto a lawn. Indicators of a malfunctioning system include turbid or odorous water. The data from this study suggests that highly turbid water will not produce an accurate FRC reading.

It would help if government regulations or subsidies were in place to promote the use the effluent water for alternative uses, if the water passes specific standards for the intended uses. This could save money, would be beneficial to the environment, and could lessen the strain on fresh, potable water resources.

Future Research Needs

Additional research should be completed for further treatment, specifically, filtration and phosphorous removal. This could be attained by the use of a designed activated charcoal and sand filtration unit. Additional research for further discoveries similar to this study is suggested. This could be used to ensure that the systems are in working order and functioning at optimal. Not only would this be beneficial for insight on the systems as they stand (for their current use), but this could give an ideal scenario where the best possible water quality for these systems can be discovered. Future research may also show that this water can be used for many other purposes, if the water quality is sufficient.

Results of the study showed that phosphorous is potentially concerning when effluent is discharged from malfunctioning systems. Because municipal wastewater is commonly treated to bring phosphorous levels to </= 1 ppm, it may prove to be beneficial to discover a way to remove phosphorous in this wastewater, regardless of whether the water is used for alternative purposes. Phosphorous inputs into the watershed where the treatment systems are located could contribute to local eutrophication, as they stand. For the purpose of cattle watering, if the unit is properly functioning and microbes are sufficiently suppressed, a covered stock tank that feeds into troughs to reduce algae/cyanobacteria growth could be easily designed. In this case, it is suggested that the stock tank be cleaned at least once a year if uncovered to reduce biomass in the tank, due to nutrient load of the water. However, if nitrogen and phosphorous removal is implemented, this may not be necessary.

Further DEQ and possibly EPA regulations could be used for maintaining these systems more effectively, specifically, the aerator and the chlorinating unit and may be beneficial not only for the environment, but for health concerns due to pathogens being discharged. This could help to prevent costly repairs and further problems, due to a malfunctioning unit, which would save the homeowner money.

It is important that homeowners are aware of the basic function of their aerobic wastewater treatment system. Homeowners should retain a copy of extension factsheets (available online) to better understand their system and to help keep them in proper working order. It may be beneficial for homeowners to enter into service contracts beyond the 2 year regulation that is already required. These systems still need to be maintained as they are being used. It is important to keep them in working order, and as they age, it is only logical that there will be potential problems with their function, in time. Service contracts and regular inspections throughout the life of the treatment systems will help ensure proper function of the units and decreases in environmental and health risks.

Additional uses of the effluent water should be investigated. If the water is able to meet standards for particular categories of use, it should not be “wasted”. Aerobic wastewater treatment systems are an effective method of clarifying and treating wastewater. This water is a high quality effluent when the unit is functioning as it should be. The water should be reused, whenever possible, toward uses where the water quality meets the standards for reuse. In areas where these systems are common, it may prove to be a relatively easy and inexpensive way to conserve freshwater resources, which is beneficial to all.

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APPENDICES

Appendix Table 1.

System	Mean *E. coli* MPN	Mean Total Coli MPN	*E. coli*/Total	%
1	20,754	470,339	0.03	3.5
2	15,047	447,839	0.02	1.7
3	285	472,164	0.00	0.1
4	315	455,066	0.01	0.6
5	104	323,945	0.01	0.6
6	97	290,481	0.01	0.6
7	96	57,140	0.01	0.6
8	1,261	184,639	0.00	0.3

E. coli to Total Coliform ratio across all sites and sampling dates. N = 40

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Appendix Table 2.

		Sample Event				
System	Analysis	1	2	3	4	5
1	FRC	1.4	1.8	1	0.8	0.2
	Tot. Coli	52	328,200	913,900	83,095	556,160
	E. coli	0	22,860	59,085	226	843
	E. coli /T. Coli	0	0.070	0.065	0.003	0.002
2	FRC	1.9	0.2	0.3	0.3	0.2
	Tot. Coli	0	238,200	1,011,200	14,705	31,675
	E. coli	0	34	38	345	1
	E. coli /T. Coli	-	0.000	0.000	0.023	0.000
3	FRC	2	0.2	0.5	0.8	0.2
	Tot. Coli	0	104,345	77,835	524,700	150,000
	E. coli	0	4	33	5,005	18,974
	E. coli /T. Coli	-	4 X 10^ -5	4 X 10^ -4	1E-02	1 X 10^ -1
4	FRC	0.4	0.2	0.3	0.4	0.1
	Tot. Coli	591	12,400	37,110	67,400	76,625
	E. coli	52	73	4,995	152	60
	E. coli /T. Coli	0.088	0.006	0.135	0.002	0.001
5	FRC	4	1.6	2.5	0.3	0.1
	Tot. Coli	10,112	1,011,200	1,011,200	25,495	105
	E. coli	6,294	100,725	10,225	36	0
	E. coli /T. Coli	0.622	0.100	0.010	0.001	0
6	FRC	2.2	0.6	0.2	0.5	0.1
	Tot. Coli	1,723	0	865	37,335	228,200
	E. coli	0	0	37	190	1
	E. coli /T. Coli	0	-	0.043	0.005	0.000
7	FRC	0.9	5.7	0.5	0.5	0.2
	Tot. Coli	145	0	83,885	35	140
	E. coli	0	0	1,234	0	0
	E. coli /T. Coli	0	-	0.015	0.009	0
8	FRC	3.1	0.9	1.3	1	0.2
	Tot. Coli	160	49,695	239,545	101,695	150
	E. coli	0	1,995	8,567	6,285	0
	E. coli /T. Coli	0	0.040	0.036	0.062	0

FRC mg L^{-1}, Total Coliform and *E. coli* (MPN/100 mL) analysis

Appendix Table 3.

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	939	4/8/2015	4/9/2015	8.7	1575	161	25	48	16	1.3	226.1	115.7	37.8	232.6	0.1	1039.5	0.47	5.1	7.9	5.9	185	254	0.01	< DL	0.02	0.12	10.36
2	938	4/8/2015	4/9/2015	6.3	1456	155	22	57	16	46.6	220.2	106.2		12.6	0.3	960.96	0.39	4.7	7.2	5.3	206	10	0.11	< DL	0.05	0.06	7.72
3	940	4/8/2015	4/9/2015	6.4	1574	168	24	64	16	56.9	223.1	109.3		15.8	0.2	1038.84	0.41	4.9	7.3	5.5	226	13	0.06	< DL	0.04	0.03	9.56
4	934	4/8/2015	4/9/2015	6.8	1223	149	18	48	14	23.8	213.7	104.4		34.5	0.1	807.18	0.35	4.9	6.7	5.6	178	28	< DL	< DL	0.02	0.03	4.96
5	935	4/8/2015	4/9/2015	8.7	1551	158	19	49	15	0.2	222.4	84.9	42.3	283.5	0.4	1023.66	0.36	5.1	6.9	5.8	183	303	0.02	< DL	0.01	0.11	5.74
6	937	4/8/2015	4/9/2015	7.8	1307	175	20	50	14	8.3	209.6	119.1		170.3	0.1	862.62	0.38	5.6	7	6.5	184	140	0.03	< DL	0.01	0.05	6.78
7	933	4/8/2015	4/9/2015	7.2	1398	167	20	49	15	28.4	219.5	111.5		91.4	0.2	922.68	0.38	5.4	7	6.2	183	75	0.02	< DL	0.02	0.04	6.73
8	936	4/8/2015	4/9/2015	7.8	1332	162	24	49	15	0.3	221.2	108.8		219	0.2	879.12	0.45	5.2	7.7	6	184	180	0.01	< DL	0.02	0.08	6.13

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	941	4/23/2015	4/24/2015	8.1	1602	166	26	50	16	0.3	240.2	89.4		388.1	0.1	1057.32	0.48	5.3	8	6.1	190	318	0.01	< DL	0.04	0.12	10.99
2	942	4/23/2015	4/24/2015	6.5	1519	163	23	61	16	30.3	237.7	108.6		21.3	0.3	1002.54	0.4	4.8	7.2	5.5	220	17	0.1	< DL	0.04	0.09	8.43
3	943	4/23/2015	4/24/2015	6.8	1635	170	24	65	16	45.3	233.8	111.1		39.4	0.2	1079.1	0.41	4.9	7.3	5.6	227	32	0.05	< DL	0.04	0.08	10.65
4	944	4/23/2015	4/24/2015	6.8	1197	148	18	47	14	22.9	215.4	103.7		32.4	0.1	790.02	0.35	4.9	6.8	5.6	175	27	0.01	0.01	0.02	0.04	5.15
5	945	4/23/2015	4/24/2015	8.1	1468	156	19	55	14	< DL	237	89.8		317.8	0.5	968.88	0.35	4.9	6.8	5.6	195	261	0.02	< DL	0.03	0.13	3.84
6	946	4/23/2015	4/24/2015	7.5	1488	201	20	73	15	12.6	257.3	131.1		161.8	0.1	982.08	0.33	5.6	6.6	6.5	242	133	0.02	< DL	0.01	0.07	6.81
7	947	4/23/2015	4/24/2015	7.5	1480	170	20	63	15	16.9	257.9	111		132.3	0.4	976.8	0.34	5	6.7	5.7	221	108	0.03	< DL	0.01	0.06	7.6
8	948	4/23/2015	4/24/2015	7.6	1307	168	25	51	15	< DL	233.2	111.5		179.1	0.3	862.62	0.46	5.3	7.8	6.1	190	147	0.03	< DL	0.01	0.08	6.51

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	949	5/5/2015	5/6/2015	8.6	1701	177	25	53	16	< DL	234.8	105.8	24.8	382.7	0.1	1122.66	0.45	5.4	7.7	6.3	199	355	< DL	< DL	0.01	0.07	9.01
2	950	5/5/2015	5/6/2015	6.6	1398	152	22	50	14	40.2	229.3	99.4		32.7	0.3	922.68	0.41	4.8	7.4	5.5	185	27	0.08	< DL	0.03	0.06	6.78
3	951	5/5/2015	5/6/2015	4.6	1530	157	23	58	14	54.2	219.5	103.7			0.2	1009.8	0.41	4.8	7.4	5.4	203		0.04	< DL	0.04	0.05	9.54
4	952	5/5/2015	5/6/2015	7.3	1138	129	16	41	12	20	194.9	89.9		43.8	0.1	751.08	0.33	4.6	6.6	5.2	152	36	< DL	< DL	0.02	0.04	4.54
5	953	5/5/2015	5/6/2015	8.5	1566	176	22	65	15	0.1	244.2	117.1	16	298.8	0.4	1033.56	0.38	5.1	7	5.9	224	272	0.04	< DL	< DL	0.16	3.63
6	954	5/5/2015	5/6/2015	8.2	1286	172	18	50	12	13.8	215.4	111		179.8	0.1	848.76	0.35	5.6	6.8	6.5	177	147	0.01	< DL	< DL	0.09	6.03
7	955	5/5/2015	5/6/2015	6.7	1318	143	18	43	14	20.2	213.3	99		32.1	0.2	869.88	0.36	4.9	6.9	5.6	163	26	0.01	< DL	0.01	0.03	6.62
8	956	5/5/2015	5/6/2015	8.3	1370	167	25	44	14	0.1	233	107.7		200.2	0.2	904.2	0.49	5.6	8.1	6.5	169	164	0.02	< DL	< DL	0.08	6.5

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	957	5/19/2015	5/20/2015	7.5	1463	155	22	49	14	1.1	213.1	108.1		177.4	0.1	965.58	0.42	5	7.4	5.7	181	145	0.01	0.03	0.03	0.18	7.71
2	958	5/19/2015	5/20/2015	7.1	1025	115	16	46	13	29.3	157.2	73.6		55.7	0.2	676.5	0.32	3.9	6.5	4.2	167	46	0.05	0.02	0.03	0.1	5.43
3	959	5/19/2015	5/20/2015	7.0	791	86	15	34	9	24.3	117.5	58.7		38.3	0.1	522.06	0.35	3.4	6.8	3.6	120	31	0.03	0.03	0.03	0.83	3.99
4	960	5/19/2015	5/20/2015	7.1	836	103	13	36	10	14.3	146	72.7		45.2	0.1	551.76	0.29	3.9	6.2	4.3	132	37	< DL	< DL	< DL	0.16	3.94
5	961	5/19/2015	5/20/2015	7.4	1342	167	19	58	14	25.9	221.9	124		84.2	0.5	885.72	0.34	5.1	6.7	5.9	202	69	0.05	0.01	0.03	0.12	5.02
6	962	5/19/2015	5/20/2015	7.6	804	112	12	33	10	8.4	115.2	70.2		136.2	0.1	530.64	0.28	4.4	6.1	4.9	124	112	0.01	< DL	0.01	0.47	3.53
7	963	5/19/2015	5/20/2015	7.2	792	85	10	39	13	18.2	115.1	62		66.6	0.1	522.72	0.21	3	5.5	3.1	148	55	0.01	< DL	0.01	0.12	4.01
8	964	5/19/2015	5/20/2015	7.8	960	121	19	39	12	< DL	159.4	79.8		168.7	0.2	633.6	0.4	4.4	7.3	4.9	145	138	0.01	< DL	< DL	0.42	5.12

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	967	6/9/2015	6/10/2015	7.2	1777	237	28	59	15	6.3	290.9	109.3	0	4.364	0.1							218	0.02	0.00	0.01	0.13	9.08
2	968	6/9/2015	6/10/2015	7.5	527	62	8	32	9	5.0	60.0	25.5	0	2.359	0.1							118	0.01	0.00	0.01	0.23	2.23
3	969	6/9/2015	6/10/2015	6.8	1194	160	17	47	11	30.7	182.5	102.8	0	0.8109	0.1							41	0.01	0.00	0.00	0.14	4.32
4	970	6/9/2015	6/10/2015	7.4	388	39	8	26	6	5.5	44.0	29.6	0	1.13	0.1							57	0.00	0.00	0.01	0.18	2.67
5	971	6/9/2015	6/10/2015	7.0	1355	203	21	68	14	30.8	249.3	132.2	0	0.8839	0.5							44	0.07	0.01	0.01	0.08	6.54
6	972	6/9/2015	6/10/2015	7.7	435	51	9	27	8	3.7	42.4	24.9	0	2.061	0.1							103	0.01	0.00	0.00	1.03	1.80
7	973	6/9/2015	6/10/2015	7.6	736	80	9	42	13	3.1	98.8	56.0	0	2.69	0.1							135	0.01	0.00	0.00	0.13	3.58
8	974	6/9/2015	6/10/2015	7.7	731	84	15	42	10	0.7	115.1	58.4	0	2.294	0.1							115	0.02	0.00	0.00	0.45	4.28

Water Constituent Analysis results

Appendix Table 4.

Total & *E. coliform* Raw Data										
Date	Dilution	System Number	1	2	3	4	5	6	7	8
4/8/2015	Tot. Col 10%	Lg#	5	0	0	32	48	47	11	13
		Sm#	0	0	0	6	48	12	2	1
		MPN(exp)	5	0	0	59	1,011	172	15	16
		MPN(calc)	52	0	0	591	10,112	1,723	145	160
	E. coli 10%	Lg#	0	0	0	4	48	0	0	0
		Sm#	0	0	0	2	38	0	0	0
		MPN(exp)	0	0	0	5	629	0	0	0
		MPN(calc)	0	0	0	52	6,294	0	0	0

Total Coliform and *E. coli* results by date

Appendix Table 5.

Total Coliform Raw Data										
Date	Dilution	System Number	1	2	3	4	5	6	7	8
4/23/2015	0.1%	Lg#	48	48	45	5	48	0	0	30
		Sm#	24	17	18	1	48	0	0	6
		MPN(exp)	328	238	173	6	1011	0	0	54
		MPN(calc)	328,200	238,200	172,600	6,300	1,011,200	0	0	53,700
	1%	Lg#	48	48	48	47	48	0	0	48
		Sm#	48	48	26	14	48	0	0	31
		MPN(exp)	1011	1011	361	185	1011	0	0	457
		MPN(calc)	101,120	101,120	36,090	18,500	101,120	0	0	45,690
	100%	Lg#	48	48	48	48	48	0	0	48
		Sm#	48	48	48	48	48	0	0	48
		MPN(exp)	1,011	1,011	1,011	1,011	1,011	0	0	1,011
		MPN(calc)	1,011	1,011	1,011	1,011	1,011	0	0	1,011
5/5/2015	0.1%	Lg#	48	48	38	26	48	0	44	47
		Sm#	46	48	3	4	48	0	8	33
		MPN(exp)	914	1,011	73	41	1,011	0	119	388
		MPN(calc)	913,900	1,011,200	72,700	41,400	1,011,200	0	118,700	387,700
	1%	Lg#	48	48	48	48	48	14	47	48
		Sm#	48	48	44	24	48	1	39	46
		MPN(exp)	1,011	1,011	830	328	1,011	17	491	914
		MPN(calc)	101,120	101,120	82,970	32,820	101,120	1,730	49,070	91,390
	100%	Lg#	48	48	48	48	48	48	48	48
		Sm#	48	48	48	48	48	48	48	48
		MPN(exp)	1,011	1,011	1,011	1,011	1,011	1,011	1,011	1,011
		MPN(calc)	1,011	1,011	1,011	1,011	1,011	1,011	1,011	1,011
5/19/2015	0.1%	Lg#	45	7	48	45	24	29	0	47
		Sm#	13	8	34	5	1	7	0	13
		MPN(exp)	148	16	525	116	33	53	0	179
		MPN(calc)	148,300	16,100	524,700	116,200	33,100	52,800	0	178,500
	1%	Lg#	48	48	48	48	48	48	1	48
		Sm#	10	2	48	11	10	15	0	18
		MPN(exp)	178.9	133.1	1011.2	186	178.9	218.7	1	248.9
		MPN(calc)	17890	13310	101120	18600	17890	21870	100	24890
	100%	Lg#	48	48	48	48	48	48	3	48
		Sm#	48	48	48	48	48	48	1	48
		MPN(exp)	1,011	1,011	1,011	1,011	1,011	1,011	4.1	1,011
		MPN(calc)	1,011	1,011	1,011	1,011	1,011	1,011	4	1,011
6/2/2015	0.1%	Lg#	48	30	47	47	0	48	0	0
		Sm#	48	1	8	5	0	16	0	0
		MPN(exp)	1,011	46	150	135	0	228	0	0
		MPN(calc)	1,011,200	45,500	150,000	135,400	0	228,200	0	0
	1%	Lg#	48	47	48	48	2	48	3	2
		Sm#	48	13	48	13	0	48	1	2
		MPN(exp)	1,011	179	1,011	179	2	1,011	4.1	3
		MPN(calc)	101,120	17,850	101,120	17,850	200	101,120	410	300
	100%	Lg#	48	48	48	48	43	48	6	48
		Sm#	48	48	48	48	9	48	4	48
		MPN(exp)	1,011	1,011	1,011	1,011	115	1,011	11	1,011
		MPN(calc)	1,011	1,011	1,011	1,011	115	1,011	11	1,011

Total Coliform and *E. coli* results by date (continued)

Appendix Table 6.

E. coliform Raw Data										
Date	Dilution	System Number	1	2	3	4	5	6	7	8
4/23/2015	0.1%	Lg#	21	0	0	0	44	0	0	4
		Sm#	1	0	0	0	9	0	0	0
		MPN(exp)	28	0	0	0	122	0	0	4
		MPN(calc)	27,900	0	0	0	122,300	0	0	4,100
	1%	Lg#	46	1	0	0	48	0	0	13
		Sm#	16	0	0	0	43	0	0	3
		MPN(exp)	178	1	0	0	792	0	0	18
		MPN(calc)	17,820	100	0	0	79,150	0	0	1830
	100%	Lg#	48	0	10	48	48	0	0	15
		Sm#	48	2	0	15	48	0	0	29
		MPN(exp)	1,011	2	11	219	1,011	0	0	54
		MPN(calc)	1,011	2	11	219	1,011	0	0	54
5/5/2015	0.1%	Lg#	33	0	0	7	9	0	2	9
		Sm#	8	0	0	0	2	0	0	4
		MPN(exp)	66	0	0	8	12	0	2	14
		MPN(calc)	65,700	0	0	7,500	12,000	0	2,000	14,200
	1%	Lg#	48	0	1	20	36	1	6	32
		Sm#	34	1	0	0	12	0	1	30
		MPN(exp)	525	1	1	25	85	1	7.4	106
		MPN(calc)	52,470	100	100	2,490	8,450	100	740	10,630
	100%	Lg#	48	12	0	48	48	11	48	48
		Sm#	48	0	0	48	48	0	47	45
		MPN(exp)	1,011	14	0	1,011	1,011	12	961	870
		MPN(calc)	1,011	14	0	1,011	1,011	12	961	870
5/19/2015	0.1%	Lg#	0	1	4	0	0	0	0	5
		Sm#	0	0	0	0	0	0	0	1
		MPN(exp)	0	1	4	0	0	0	0	6
		MPN(calc)	0	1,000	4,100	0	0	0	0	6,300
	1%	Lg#	2	0	32	3	1	3	0	32
		Sm#	0	0	6	0	0	0	0	8
		MPN(exp)	2	0	59	3	1	3	0	63
		MPN(calc)	200	0	5,910	310	100	310	0	6,270
	100%	Lg#	48	19	48	46	6	48	1	48
		Sm#	32	8	48	10	1	20	0	48
		MPN(exp)	479	34	1,011	147	7	260	1	1,011
		MPN(calc)	479	34	1,011	147	7	260	1	1,011
6/2/2015	0.1%	Lg#	0	0	24	0	0	0	0	0
		Sm#	0	0	1	0	0	0	0	0
		MPN(exp)	0	0	33	0	0	0	0	0
		MPN(calc)	0	0	33,100	0	0	0	0	0
	1%	Lg#	15	0	48	1	0	0	0	0
		Sm#	1	0	17	0	0	0	0	0
		MPN(exp)	19	0	238	1	0	0	0	0
		MPN(calc)	1,870	0	23,820	100	0	0	0	0
	100%	Lg#	48	1	1	38	0	2	0	0
		Sm#	39	2	0	6	0	1	0	0
		MPN(exp)	659	3	1	79	0	3	0	0
		MPN(calc)	659	3	1	79	0	3	0	0

Total Coliform and *E. coli* results by date (continued)

Appendix Table 7.

Date	Sample #	1	2	3	4	5	6	7	8
4/8/2015	FRC (mg/L)	1.4	1.9	2.0	0.4	4.0	2.2	0.9	3.1
4/23/2015		1.8	0.2	0.2	0.2	1.6	0.6	5.7	0.9
5/5/2015		1.0	0.3	0.5	0.3	2.5	0.2	0.5	1.3
5/19/2015		0.8	0.3	0.8	0.4	0.3	0.5	0.5	1.0
6/2/2015		0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2

FRC concentration results by date

Appendix Table 8.

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	939	4/8/2015	4/9/2015	8.7	1575	161	25	48	16	1.3	226.1	115.7	37.8	232.6	0.1	1039.5	0.47	5.1	7.9	5.9	185	254	0.01	< DL	0.02	0.12	10.36
2	938	4/8/2015	4/9/2015	6.3	1456	155	22	57	16	46.6	220.2	106.2		12.6	0.3	960.96	0.39	4.7	7.2	5.3	206	10	0.11	< DL	0.05	0.06	7.72
3	940	4/8/2015	4/9/2015	6.4	1574	168	24	64	16	56.9	223.1	109.3		15.8	0.2	1038.84	0.41	4.9	7.3	5.5	226	13	0.06	< DL	0.04	0.03	9.56
4	934	4/8/2015	4/9/2015	6.8	1223	149	18	48	14	23.8	213.7	104.4		34.5	0.1	807.18	0.35	4.9	6.7	5.6	178	28	< DL	< DL	0.02	0.03	4.96
5	935	4/8/2015	4/9/2015	8.7	1551	158	19	49	15	0.2	222.4	84.9	42.3	283.5	0.4	1023.66	0.36	5.1	6.9	5.8	183	303	0.02	< DL	0.01	0.11	5.74
6	937	4/8/2015	4/9/2015	7.8	1307	175	20	50	14	8.3	209.6	119.1		170.3	0.1	862.62	0.38	5.6	7	6.5	184	140	0.03	< DL	0.01	0.05	6.78
7	933	4/8/2015	4/9/2015	7.2	1398	167	20	49	15	28.4	219.5	111.5		91.4	0.2	922.68	0.38	5.4	7	6.2	183	75	0.02	< DL	0.02	0.04	6.73
8	936	4/8/2015	4/9/2015	7.8	1332	162	24	49	15	0.3	221.2	108.8		219	0.2	879.12	0.45	5.2	7.7	6	184	180	0.01	< DL	0.02	0.08	6.13

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	941	4/23/2015	4/24/2015	8.1	1602	166	26	50	16	0.3	240.2	89.4		388.1	0.1	1057.32	0.48	5.3	8	6.1	190	318	0.01	< DL	0.04	0.12	10.99
2	942	4/23/2015	4/24/2015	6.5	1519	163	23	61	16	30.3	237.7	108.6		21.3	0.3	1002.54	0.4	4.8	7.2	5.5	220	17	0.1	< DL	0.04	0.09	8.43
3	943	4/23/2015	4/24/2015	6.8	1635	170	24	65	16	45.3	233.8	111.1		39.4	0.2	1079.1	0.41	4.9	7.3	5.6	227	32	0.05	< DL	0.04	0.08	10.65
4	944	4/23/2015	4/24/2015	6.8	1197	148	18	47	14	22.9	215.4	103.7		32.4	0.1	790.02	0.35	4.9	6.8	5.6	175	27	0.01	0.01	0.02	0.04	5.15
5	945	4/23/2015	4/24/2015	8.1	1468	156	19	55	14	< DL	237	89.8		317.8	0.5	968.88	0.35	4.9	6.8	5.6	195	261	0.02	< DL	0.03	0.13	3.84
6	946	4/23/2015	4/24/2015	7.5	1488	201	20	73	15	12.6	257.3	131.1		161.8	0.1	982.08	0.33	5.6	6.6	6.5	242	133	0.02	< DL	0.01	0.07	6.81
7	947	4/23/2015	4/24/2015	7.5	1480	170	20	63	15	16.9	257.9	111		132.3	0.4	976.8	0.34	5	6.7	5.7	221	108	0.03	< DL	0.01	0.06	7.6
8	948	4/23/2015	4/24/2015	7.6	1307	168	25	51	15	< DL	233.2	111.5		179.1	0.3	862.62	0.46	5.3	7.8	6.1	190	147	0.03	< DL	0.01	0.08	6.51

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	949	5/5/2015	5/6/2015	8.6	1701	177	25	53	16	< DL	234.8	105.8	24.8	382.7	0.1	1122.66	0.45	5.4	7.7	6.3	199	355	< DL	< DL	0.01	0.07	9.01
2	950	5/5/2015	5/6/2015	6.6	1398	152	22	50	14	40.2	229.3	99.4		32.7	0.3	922.68	0.41	4.8	7.4	5.5	185	27	0.08	< DL	0.03	0.06	6.78
3	951	5/5/2015	5/6/2015	4.6	1530	157	23	58	14	54.2	219.5	103.7			0.2	1009.8	0.41	4.8	7.4	5.4	203		0.04	< DL	0.04	0.05	9.54
4	952	5/5/2015	5/6/2015	7.3	1138	129	16	41	12	20	194.9	89.9		43.8	0.1	751.08	0.33	4.6	6.6	5.2	152	36	< DL	< DL	0.02	0.04	4.54
5	953	5/5/2015	5/6/2015	8.5	1566	176	22	65	15	0.1	244.2	117.1	16	298.8	0.4	1033.56	0.38	5.1	7	5.9	224	272	0.04	< DL	< DL	0.16	3.63
6	954	5/5/2015	5/6/2015	8.2	1286	172	18	50	12	13.8	215.4	111		179.8	0.1	848.76	0.35	5.6	6.8	6.5	177	147	0.01	< DL	< DL	0.09	6.03
7	955	5/5/2015	5/6/2015	6.7	1318	143	18	43	14	20.2	213.3	99		32.1	0.2	869.88	0.36	4.9	6.9	5.6	163	26	0.01	< DL	0.01	0.03	6.62
8	956	5/5/2015	5/6/2015	8.3	1370	167	25	44	14	0.1	233	107.7		200.2	0.2	904.2	0.49	5.6	8.1	6.5	169	164	0.02	< DL	< DL	0.08	6.5

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	957	5/19/2015	5/20/2015	7.5	1463	155	22	49	14	1.1	213.1	108.1		177.4	0.1	965.58	0.42	5	7.4	5.7	181	145	0.01	0.03	0.03	0.18	7.71
2	958	5/19/2015	5/20/2015	7.1	1025	115	16	46	13	29.3	157.2	73.6		55.7	0.2	676.5	0.32	3.9	6.5	4.2	167	46	0.05	0.02	0.03	0.1	5.43
3	959	5/19/2015	5/20/2015	7.0	791	86	15	34	9	24.3	117.5	58.7		38.3	0.1	522.06	0.35	3.4	6.8	3.6	120	31	0.03	0.03	0.03	0.83	3.99
4	960	5/19/2015	5/20/2015	7.1	836	103	13	36	10	14.3	146	72.7		45.2	0.1	551.76	0.29	3.9	6.2	4.3	132	37	< DL	< DL	< DL	0.16	3.94
5	961	5/19/2015	5/20/2015	7.4	1342	167	19	58	14	25.9	221.9	124		84.2	0.5	885.72	0.34	5.1	6.7	5.9	202	69	0.05	0.01	0.03	0.12	5.02
6	962	5/19/2015	5/20/2015	7.6	804	112	12	33	10	8.4	115.2	70.2		136.2	0.1	530.64	0.28	4.4	6.1	4.9	124	112	0.01	< DL	0.01	0.47	3.53
7	963	5/19/2015	5/20/2015	7.2	792	85	10	39	13	18.2	115.1	62		66.6	0.1	522.72	0.21	3	5.5	3.1	148	55	0.01	< DL	0.01	0.12	4.01
8	964	5/19/2015	5/20/2015	7.8	960	121	19	39	12	< DL	159.4	79.8		168.7	0.2	633.6	0.4	4.4	7.3	4.9	145	138	0.01	< DL	< DL	0.42	5.12

Samp #	Code#	Date Samp	Date Test	pH	EC	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO3-N (ppm)	Cl (ppm)	SO4 (ppm)	CO3 (ppm)	HCO3 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)	Hardness (ppm)	Alkalinity (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)	ICAP_P (ppm)
1	967	6/9/2015	6/10/2015	7.2	1777	237	28	59	15	6.3	290.9	109.3	0	4.364	0.1							218	0.02	0.00	0.01	0.13	9.08
2	968	6/9/2015	6/10/2015	7.5	527	62	8	32	9	5.0	60.0	25.5	0	2.359	0.1							118	0.01	0.00	0.01	0.23	2.23
3	969	6/9/2015	6/10/2015	6.8	1194	160	17	47	11	30.7	182.5	102.8	0	0.8109	0.1							41	0.01	0.00	0.00	0.14	4.32
4	970	6/9/2015	6/10/2015	7.4	388	39	8	26	6	5.5	44.0	29.6	0	1.13	0.1							57	0.00	0.00	0.01	0.18	2.67
5	971	6/9/2015	6/10/2015	7.0	1355	203	21	68	14	30.8	249.3	132.2	0	0.8839	0.5							44	0.07	0.01	0.01	0.08	6.54
6	972	6/9/2015	6/10/2015	7.7	435	51	9	27	8	3.7	42.4	24.9	0	2.061	0.1							103	0.01	0.00	0.00	1.03	1.80
7	973	6/9/2015	6/10/2015	7.6	736	80	9	42	13	3.1	98.8	56.0	0	2.69	0.1							135	0.01	0.00	0.00	0.13	3.58
8	974	6/9/2015	6/10/2015	7.7	731	84	15	42	10	0.7	115.1	58.4	0	2.294	0.1							115	0.02	0.00	0.00	0.45	4.28

SWAFL Raw Data

Appendix Table 9.

CaCO3 (g)	Actual CaCO3 (g)	FRC(mg/L)
Blank	0.0	0.2
0.1	0.1	0.3
0.2	0.2	0.6
0.5	0.5	0.9
0.8	0.8	0.8
1.0	1.1	0

Turbidity Short Experiment: Calcium carbonate weights and FRC concentration

Appendix Table 10.

Correlations	FRC
Total Coli	0.03
E. coli	0.11
Samp1 omit	FRC
Total Coli	0.20
E. coli	0.20

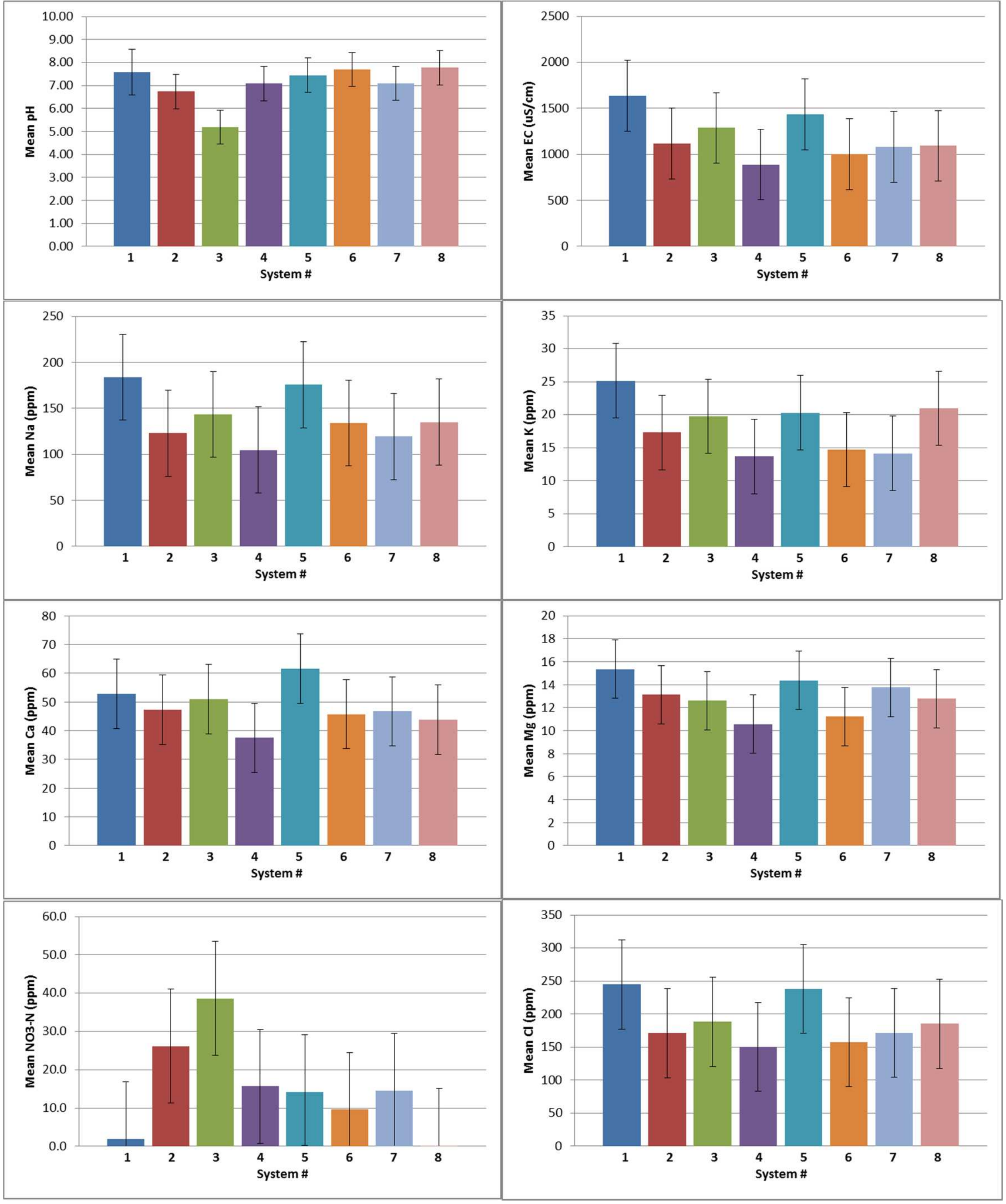
Correlation data (r value -1 - +1) for FRC vs. Total Coliform and *E. coli* across all sample sites and dates

Appendix Table 11.

Analysis	p-value	Sig. Diff.
Liquid Vs. Tablet Total Coliform	0.02	Yes
Liquid Vs. Tablet *E. coli*	0.18	No
Liquid Vs. Tablet FRC	0.37	No
Analysis Standard for Systems	p-value	Pass Std
FRC Vs. EPA	0.998	Yes
E. coli Vs. EPA	0.02	No
Cattle Water Standards	p-value	Pass Std
Total Coliform	0.99	Yes
E. Coli	0.02	No
pH (lower)	0.92	Yes
pH (upper)	0.14	Yes
EC	0.99	Yes
Na	1	Yes
K	0.96	Yes
Ca	1	Yes
Mg	1	Yes
NO3-N	1	Yes
Cl	1	Yes
SO4	1	Yes
HCO3	1	Yes
B	1	Yes
TSS	1	Yes
Hardness	1	Yes
Alkalinity	1	Yes
Zn	1	Yes
Cu	1	Yes
Mn	1	Yes
Fe	0.99	Yes

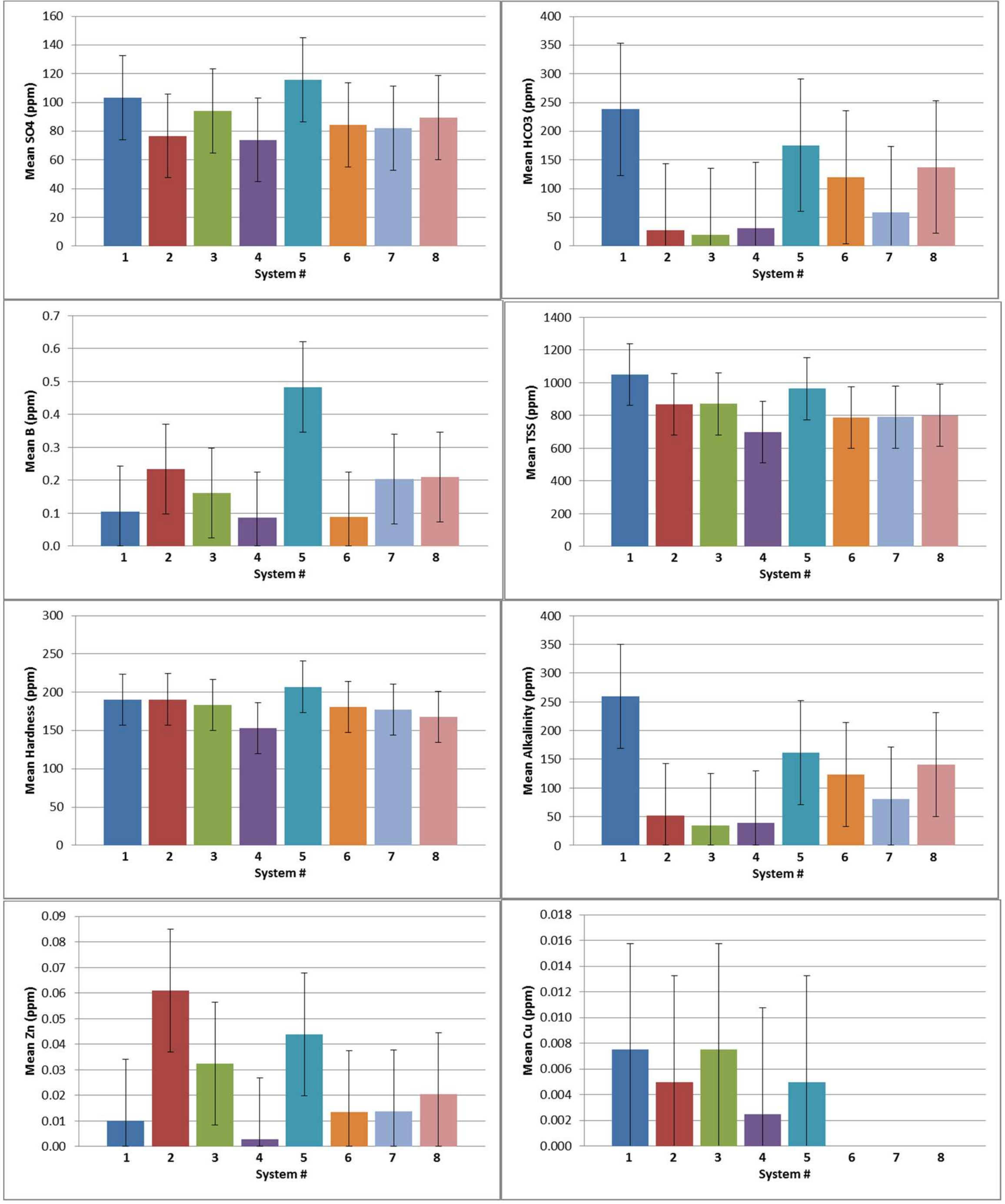
T-test and Z- test results across all sample sites and dates

Appendix Figures 1-8.



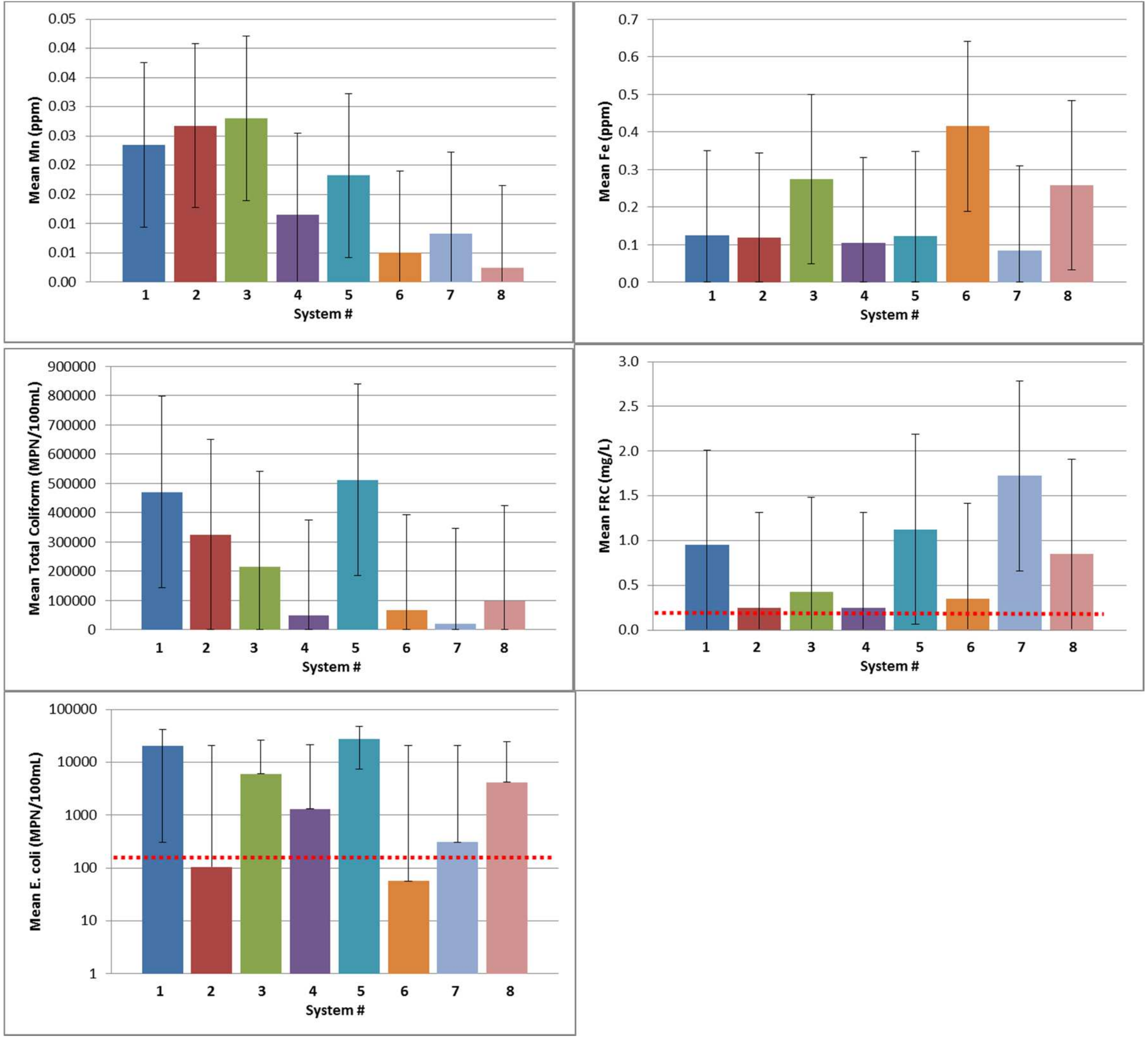
Water Quality Parameter Means across each system, using all sample sites and dates. Error bars indicate +/- 1 standard deviation.

Appendix Figures 9-16.



Water Quality Parameter Means across each system, using all sample sites and dates (continued)

Appendix Figures 17-21.



Water Quality Parameter Means across each system, using all sample sites and dates (continued)

Appendix Table 12.

Liquid Vs. Tablet Total Coliform	
p-value	0.02
Sig. Diff.	Yes

Liquid Vs. Tablet *E. coli*	
p-value	0.18
Sig. Diff.	No

Liquid Vs. Tablet FRC	
p-value	0.37
Sig. Diff.	No

FRC Vs. EPA Standard for Systems	
Z-test p-value	0.998
Meets Standard	Yes

pH (upper) Vs. Cattle Water Standards	
Z-test p-value	0.14
Meets Standard	Yes

EC Vs. Cattle Water Standards	
Z-test p-value	0.99
Meets Standard	Yes

Na Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

K Vs. Cattle Water Standards	
Z-test p-value	0.96
Meets Standard	Yes

SO4 Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

HCO3 Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

B Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

TSS Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Mn Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Iron Vs. Cattle Water Standards	
Z-test p-value	0.99
Meets Standard	Yes

Total Coliform Vs. Cattle Water Standards	
Z-test p-value	0.99
Meets Standard	Yes

E. coli Vs. Cattle Water Standards	
Z-test p-value	0.02
Meets Standard	No

E. coli Vs. EPA Standard for Systems	
Z-test p-value	0.02
Meets Standard	No

pH (lower) Vs. Cattle Water Standards	
Z-test p-value	0.92
Meets Standard	Yes

Ca Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Mg Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

NO3-N Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Cl Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Hardness Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Alkalinity Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Zn Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Cu Vs. Cattle Water Standards	
Z-test p-value	1
Meets Standard	Yes

Water Constituent vs. Water Quality Standard Z-test p-values

VITA

LaRee Christine oden

Candidate for the Degree of

Master of Science

Thesis: DETERMINING THE FEASIBILITY OF UTILIZING RECYCLED HOUSEHOLD WASTEWATER FROM AEROBIC TREATMENT SYSTEMS FOR CATTLE WATERING

Major Field: Plant and Soil Science

Biographical:

Education:

Completed the requirements for the Master of Science in Plant and Soil Science at Oklahoma State University, Stillwater, Oklahoma in August, 2015.

Completed the requirements for the Bachelor of Science in Environmental Science at Oklahoma State University, Stillwater, Oklahoma in 2013.

Experience:

Graduate Teaching Assistant at Oklahoma State University from May 2013 – August 2015.
Laboratory Assistant at Oklahoma State University from May 2013 – August 2015.
Aviation Electrician, United States Navy from August 1999- September 2003.