EVALUATION OF SELECTED NEW TECHNOLOGIES FOR ANIMAL WASTE POLLUTION CONTROL

A Thesis

by

LYNN ANNE LAZENBY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2006

Major Subject: Biological and Agricultural Engineering

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Approved by:

Chair of Committee,	Saqib Mukhtar
Committee Members,	Ann Kenimer
	Anthony Cahill
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ABSTRACT

Evaluation of Selected New Technologies
for Animal Waste Pollution Control. (August 2006)
Lynn Anne Lazenby, B.S., Texas A&M University
Chair of Advisory Committee: Dr. Saqib Mukhtar

In 1998, two upper North Bosque River segments were designated as impaired due to the nonpoint source (NPS) pollution of phosphorus (P) to these segments in the watershed. As a result, two Total Maximum Daily Loads (TMDLs) were applied which called for the reduction of annual loading and annual average soluble reactive P (Sol P) concentrations by 50 %. This study was conducted to evaluate the efficacy of two prospective new technologies, an Electrocoagulation (EC) system, and a Geotube® dewatering system to potentially aid the dairy farmers in meeting the goals set by the TMDLs.

The EC system analyzed in this study used chemical pretreatment to coagulate and separate solids in effluent pumped from the dairy lagoon; the liquid then flowed over charged iron electrodes giving off ions that cause coagulation and precipitation of P and other metals. Overall, the performance of the system was consistently highly effective in reducing total phosphorus (TP) and Sol P, on average, reducing these constituents by 96% and 99.6% respectively from the dairy lagoon effluent. However this consistency did not hold for the rest of the analytes.

In the Geotube® dewatering system geotextile tubes were utilized to dewater dairy lagoon effluent. Results showed this system performed very well in filtering solids from the dairy lagoon effluent, removing an average of 93.5 % of the total solids between the two pumping and dewatering events of March and April. It was effective in removing nutrients and metals as well. The average percent reduction of TP and Sol P for the two events were very high at 97% and 85 % respectively.

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First and most of all I would like to thank my parents, Floyd and Anne Lazenby. Your patience and support over all of my seven years here at Texas A&M are beyond value. I love you both to a level that cannot be measured.

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Ecoloclean Industries, Inc., Crystal City, Texas is acknowledged for their assistance and support with this study.

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And saving the greatest for last, I thank God for the many blessings he has given me through all of my 25 years. Without His love and the strength He has given me, I would not have made it this far.

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INTRODUCTION

Water quality degradation due to phosphorus (P) nonpoint source pollution from effluent and manure applied to waste application fields (WAF) is a major concern in the Bosque River watershed. In 1998 two upper North Bosque River segments were designated as impaired on the Texas Clean Water Act, Section 303(d) list (TNRCC, 2001). This designation was the result of nutrient loading and aquatic plant growth in those segments. Changes in the status of the Bosque River segments prompted the Texas Commission on Environmental Quality (TCEQ) to apply a Total Maximum Daily Loads (TMDLs) for P to those designated segments. In December 2002, the Texas Commission on Environmental Quality approved the implementation plan of these two TMDLs, and they were approved by the Texas State Soil and Water Conservation Board in January 2003. These TMDLs call for a reduction of the annual loading and annual average concentration of soluble reactive P (SRP) by about 50%.

The United States Environmental Protection Agency (EPA) has cited pollution from nonpoint source agricultural operations (by way of runoff) as the main source of contamination to water bodies. Reducing P from dairy effluent applied to WAF is vital to protecting many of these water bodies.

Runoff from WAFs is not regulated because it is regarded as a nonpoint source. Currently, a number of dairy operations in the Bosque river watersheds are using best management practices (BMPs) to remove P and SRP from the wastewater. However, to meet the goals of these TMDLs new, more effective and efficient BMPs will need to be adopted by these dairies. Two prospective BMPs that could remove pollutants from the effluent being stored and treated in dairy lagoons are an electrocoagulation system and a geotextile dewatering system.

This thesis examines the effectiveness and efficiency of two technologies: (1) an electrocoagulation system and (2) a Geotube® dewatering system.

This thesis follows the style of *Transactions of the ASABE.*

The EC system introduced for evaluation by Ecoloclean Industries, Inc. was set-up to treat the effluent from the secondary lagoon of a 700-head lactating cow dairy in the Bosque River watershed. Manure from the two free-stall barns at this dairy was flushed into the primary lagoon. Effluent from the secondary lagoon was recycled for flushing the barns and irrigating hay and cropland at the dairy operation.

The Geotube® dewatering system was introduced for evaluation by the Miratech Division of Ten Cate Nicolon and General Chemical Corporation. This system uses a chemical pre-treatment to coagulate solids from the lagoon effluent. The mixture is then pumped into two large geotextile filtration tubes that lay on an impervious polyvinyl sheet. On one end (opposite to the influent end in Figure 4) of each tube a felt-type fabric was laid to reduce potential soil erosion from the dewatered effluent flowing off of the polyvinyl sheet. The synthetic fabric acts as a filter when the liquid is pumped into the tube, and a high percentage of the solids are retained as the liquid weeps from pores in the fabric. After the tubes are filled with the liquid-solid mixture to a height of approximately 5’, the pumping of effluent ceases and the tubes are left to dewater for several months. After they are sufficiently dewatered, the residuals are disposed of off-site. The dewatering system, comprised of two 14’ X 50’ tubes was set-up to treat effluent from the primary lagoon of a 2000-head lactating cow open-lot dairy in the Leon River watershed (which is adjacent to the Bosque River watershed). Manure from the milking parlor at this dairy was flushed into the primary lagoon. Effluent from this lagoon was conveyed to a secondary lagoon where it was recycled for flushing the parlor and irrigating hay and cropland at the dairy operation.

LITERATURE REVIEW

BACKGROUND

Problems with Phosphorus

The rapid growth and intensification of agricultural production in many locations have led to both localized and widespread imbalances in the inputs and outputs of phosphorus (Sharpley et al., 2003). Phosphorus accumulations from agricultural operations have resulted in levels being raised above the quantities necessary for crops. Application of animal manure can be beneficial for improving soil structure and increasing percent of plant cover, which in turn can lower the potential for soil erosion and surface runoff. In many areas manure from confined animal feeding operations is applied to fields based on crop nitrogen needs. This results in amounts of P applied at rates grater than the crop's need. If the manure is applied over a long period of time, accumulations of P in the surface horizons of the soil can occur. Runoff from these areas with high levels of P in the soils is of great concern. Specifically in regions with vulnerable water bodies. According to Sharpley et al. (2003), on average the total useable agricultural land in the U.S. is capable of producing in excess of 30 lb/ac from manure applied annually. Because of this, there are serious concerns about the quantity of P being contributed to surface waters via agricultural runoff. Phosphorus in water bodies can greatly accelerate the process of eutrophication. The EPA has cited eutrophication as the most extensive surface water impairment in the U.S. (Kleinman and Sharpley, 2003). Eutrophication is a natural process by which rivers and lakes age due to the input of nutrients (Sharpley et al., 2003). Normally this process takes thousands of years; but in cases where the addition of P through agricultural runoff is an issue, eutrophication can be greatly accelerated. This excess amount of P can induce algal blooms which in turn may result in reduced dissolved oxygen levels from decomposing plant matter and consequently kill fish and other aquatic organisms (USGS, 2006).

The Total Maximum Daily Load Program

It may appear that the TMDL program came into the forefront only a few years ago; it was actually created by section 303(d) of the Clean Water Act which was passed in 1972 (EPA, 2006a; Vergura and Jones, 2000) According to the EPA (2006b), a Total Maximum Daily Load is defined as, “a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources.” This program was not vehemently pursued until the late 80s to early 90s when it became apparent that the National Pollutant Discharge Elimination System (which was created along with the TMDL program in the Clean Water Act of 1972) was not enough to remedy the water quality problems in the United States (Vergura and Jones, 2000).

When a water body with a certain priority is identified as not meeting the applicable water quality standards, TMDLs must be established. The state where the water body is located is required to formulate the TMDLs and submit them to the EPA for approval. The submitted TMDLs must also include a margin of error to account for uncertainties in the behavior of pollutant discharges and water quality (Vergura and Jones, 2000). In this way, a TMDL may be thought of as a “pollution budget” for that particular water body.

Phosphorus in the Bosque River Watershed

The headwaters of the Bosque River lay almost completely within Erath County, which is the top milk-producing county in Texas (McFarland and Hauck, 1999a) (Figure 1). The North Bosque River Watershed (NBRW) covers a land area of approximately 316,600 ha, which comprises 74% of the catchment that drains into Lake Waco (McFarland and Hauck, 1999b). It is known that the NBRW is the main source of P to this lake (McFarland et al., 2001). This is of great concern since the North Bosque River is a water supply for nearly 150,000 people (McFarland and Hauck, 1999b). It was in 1990 that problems in the North Bosque River watershed (NBRW), due to nonpoint source pollution (mainly waste from dairy operations), were first recognized by the Texas Natural Resource Conservation Commission (now the Texas Commission on

Environmental Quality) and the Texas State Soil and Water Conservation Board (McFarland and Hauck, 1999a). In 1998 two upper North Bosque River segments were designated as impaired segments on the Texas Clean Water Act, Section 303(d) list (TNRCC, 2001). This designation was the result of nutrient loading and aquatic plant growth in those segments. The changes in the status of the Bosque River segments prompted the TCEQ to apply a TMDLs for P to the designated segments. In December 2002, the TCEQ approved the implementation plan of these two TMDLs, and they were approved as well by the TSSWCB in January 2003. These TMDLs call for a reduction of the annual loading and annual average soluble reactive P (SRP) concentrations by about 50%.

Dairy operations are the main agricultural practice in the NBRW (McFarland and Hauck, 1999a). These operations are one of the two substantial sources of bioavailable P within the watershed, the other one being the wastewater treatment plant in Stephenville (McFarland et al., 2001). Both of these sources are in the upper section of the catchment. Since the early 1990s, most of the dairies in this area have operated with installed wastewater containment structures (i.e. lagoons and storage ponds). The storage of wastewater in these structures has a very large drawback because if the sludge from these structures is not removed on a regular basis, it will build up over time and compromise their capacity to retain waste in the future (Worley, 2004). In Erath County, lagoon effluent is generally disposed of via broadcasting onto waste application fields (WAFs) (McFarland and Hauck, 1999a). The application of dairy waste on to the WAFs is the most widely used method of disposal (Karthikeyan et al., 2002) These WAFs are considered key nutrient nonpoint sources in the upper North Bosque River watershed (UNBRW) (McFarland and Hauck, 1999a).

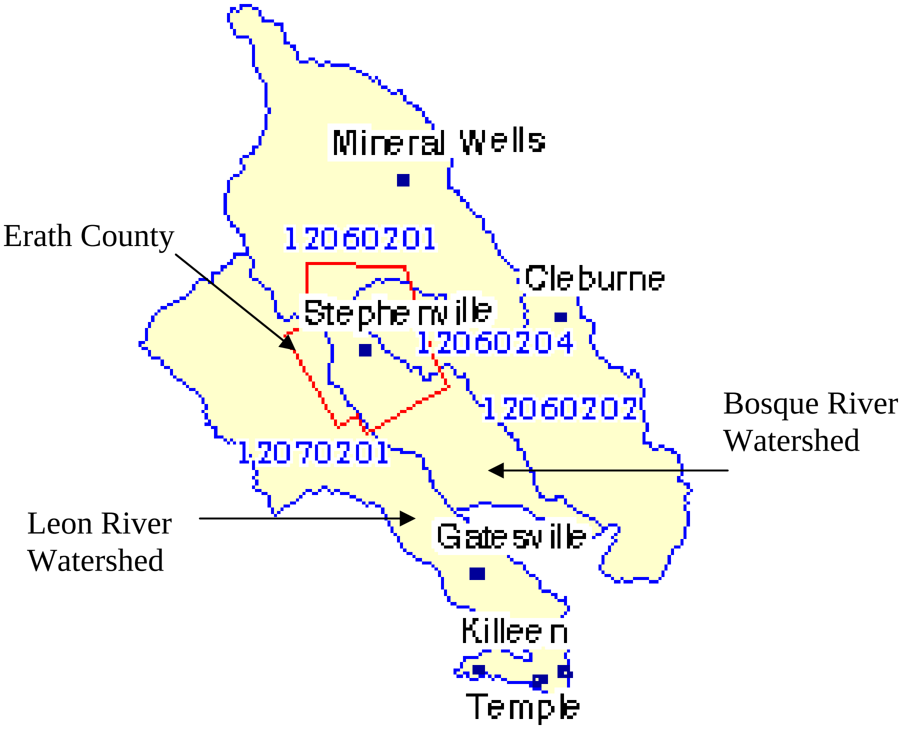


Figure 1. Erath County and surrounding Hydrologic Unit Code watersheds (EPA, 2006b)

Treatment Methods

Mechanical Solid-Liquid Separation

Mechanical separation and sedimentation basins are typically the main methods used on dairy operations for solid-liquid separation of the liquid dairy manure. (Zhang and Lei, 1998). Removing the solids from the liquid dairy manure makes it easier to store, handle, and broadcast it onto waste application fields (Mukhtar et al., 1999). However, the use of mechanical solid-liquid separation methods on average only achieves the removal of 20% of the solids and only 5% of P (Krumpelman, 2005). Because of this low separation efficiency, most of the solids enter the lagoon. Over time this will reduce the storage capacity of the lagoon as the solids settle out. The low separation efficiency of P can also buildup its concentration in the lagoon, steadily increasing the amount of P in the effluent discharged onto the WAFs (Krumpelman, 2005). There are many different types of mechanical separation, three of which are:

- Screen Separators: The method by which this mechanical separation method functions is simple; liquid passes through the screen while the solids are retained on the other side (Mukhtar et al., 1999). Screen separators fall into three different categories:
    - Stationary Screen Separators: This type of mechanical separation method utilizes gravity to carry out the solid-liquid separation process. Typically, a stationary screen is used to remove both the fibrous and coarse particulate matter from the liquid manure.
    - Rotating Screen Separator: A continuously rotating cylindrical screen separates the solids from the liquid manure that it receives at a prescribed rate. To keep the process moving at a steady pace, a scraper removes the solids from the surface of the screen.
    - Vibrating Screen Separator: The screen of this separator vibrates rapidly which prevents solids from clogging the screen. As the liquid passes through the screen, the solids slide off.

- Centrifuges: This type of mechanical separation uses centrifugal force to elevate the settling velocity of suspended solids (Mukhtar et al., 1999). Centrifuges have been used in other areas such as the food processing industry and industrial waste management. According to Sheff et al. (2005), centrifuge removes solids based on the ratio of particle weight to weight of the liquid. This means that the particles whose weight is the same as the liquid in which they are suspended will not separate. A rotating shaft inside the centrifuge's drum delivers the energy to the liquid matrix causing it to spin. The main purpose of using a centrifuge in dairy manure management is to remove the residual solids from an initial separation method such as a screen. However, it is not recommended that a centrifuge be used to remove solids from dairy manure without a primary treatment to remove coarse solids (Sheff et al., 2005). The addition of a polymer can help with flocculation and raising the percentage of the solids removed (Hammer and Hammer, 2001). Currently, centrifuges are being utilized to dewater sludges taken from settling tanks or gravity thickeners at wastewater treatment plants (Hammer and Hammer, 2001). In some cases centrifuges are used along with other technologies. Centrifuges are used in combination with electrocoagulation reactors and coagulants to treat different types of wastewaters (Holt et al, 2004).
- Presses: This type of mechanical separation method is used to further dewater the solid cake of manure that was filtered out by a screen or centrifuge (Mukhtar et al., 1999). Presses typically have greater separation efficiency than do screens. In a study by Gooch et al. (2005) it was observed that by implementing a screw press to treat dairy lagoon effluent a 22-30% liquid reduction could be achieved. Gooch et al. (2005) also found that a maximum of 25% of the P could be partitioned from the effluent stream into the solid cake. This is much more efficient than the maximum of 5% P reduction by screens (Krumpelman, 2005). According to Mukhtar et al. (1999), presses fall in to three different categories:

- Roller Presses: Liquid manure or solid cake is pressed into a bowl shaped screen by either rollers or brushes that force the liquid through the screen.
- Belt Presses: Liquid Manure or solid cake lies on a permeable fabric belt that is run horizontally between rollers. The rollers force the liquid from the solids that are retained by the belt.
- Screw Presses: A screw conveyor brings the solid cake into a cylindrical screen. Here the solids are compacted and dewatered by the compression of the screw.

Sedimentation Basins

These basins are designed to facilitate solid-liquid separation through settling. The efficacy of these settling basins is dependant on the success of the design in lowering the flow velocity of the liquid manure to a velocity below the settling velocity of the particle in the liquid matrix (Haan et al., 1994). Many factors influence the effectiveness of the settling basin other than the flow velocity. These include: the size and shape of the particles, the inter-particle forces, and the concentration of particles in the liquid manure. It has been shown that sedimentation basins are most effective for treating liquid manure with very low percent solids, usually 3% or less (Mukhtar et al., 1999). According to Mukhtar et al. (1999) sedimentation basins in use on dairy operations have been observed to achieve between 39% and 75% reduction of total solids from liquid dairy manure.

Dissolved Air Flotation

In a Dissolved Air Flotation (DAF) unit, micro air bubbles are released into sludge (pumped into the bottom of the DAF tank) which attach to the suspended solids and float them to the surface (Hammer and Hammer, 2001). The thickened sludge is scraped from the surface of the liquid. Through this process, DAFs can recover approximately 85% of the solids. With the addition of chemical coagulants, it is possible to achieve a solids recovery of 95% or more (Hammer and Hammer, 2001). Sometimes

DAF units are used in combination with other technologies. Holt et al. (2004) described that various studies have used dissolved air flotation units in combination with electrocoagulation reactors and coagulants to treat different types of wastewaters.

Chemical Treatment

Generally, chemical are added to wastewater in order to achieve coagulation and flocculation of particulate matter (Hammer and Hammer, 2001; Zhang and Lei, 1998). Typically, the addition of electrolytes and organic polymers are used for this purpose. Most commonly these compounds are based on Al, Fe, and Ca (Hammer and Hammer, 2001; Zhang and Lei, 1998). Treatment of both municipal and industrial wastewater with coagulants such as the salts of Al, Fe, and Ca has been effective in removing P and other types of organic matter (Converse and Karthikeyan, 2002). When added to the wastewater, these chemical coagulants (metal ions) bind to the soluble ions (i.e. soluble phosphorus) to create insoluble precipitates, and aid in the coagulation of suspended solids (Oh et al., 2003).

Aluminum sulfate, also know as alum ($Al_2(SO_4)_3$ - $14.3H_2O$), is the most widely applied coagulant (Hammer and Hammer, 2001). Of the previously mentioned salts, alum is the most commonly used because it is inexpensive and widely available (Lefcourt and Meisinger, 2001; Sinha et al., 2004). Alum, when mixed with wastewater, reacts with hydroxyl ions (OH^-) to form aluminum floc, $Al(OH)_3$ which has a very large surface area (Hammer and Hammer, 2001; Olmsted and Williams, 1997; Zhang and Lei, 1998). As these flocs settle, they aid in the settling of other suspended particles as well. The ions of Al can also bind to phosphate (which has a charge of -3) as well as nitrate and nitrite (both have a charge of -1) in the solution, forming a floc that will precipitate out (Olmstead and Williams, 1997; Zhang and Lei, 2001). This process of coagulation using alum is typically successful within the pH range of 5.5 to 8.0 (Hammer and Hammer, 2001).

Lime ($Ca(OH)_2$), a salt of calcium, is also used as a chemical coagulant (Converse and Karthikeyan et al., 2002; Zhang and Lei, 1998). When it is added to wastewater, the Ca ions attract and bind to the phosphates. The flocs formed in this process precipitate out, settling the other dissolved solids they come into contact with. In a study by Converse and Karthikeyan et al. (2002) it was found that lime was highly effective in removing P from dairy manure, achieving reductions of 90% and higher. Additionally, lime was more effective in removing P from manure with lower solids content (approximately 0.8% TS).

Polymers are often used as flocculants in wastewater treatment in addition to other chemical coagulants (Zhang and Lei, 1998). These polymers are long-chain molecules with a high molecular weight. Due to their long-chain structure that provides an abundance of surface area where particles may attach, polymers are effective flocculating agents. These long molecules are classified by the charge that they carry. They are either anionic, nonionic, or cationic (Zhang and Lei, 1998). Several studies have looked at the utilization of chemical treatments on animal waste. However, many different methods have been used to evaluate the efficacy of these chemicals. Consequently, there is an absence of a standard to which the results of these studies can be compared.

Geotextile Dewatering System

A geotextile is a permeable synthetic fabric made from a petrochemical polymer material such as polypropylene (Miratech, 2006). Synthetic geotextiles have been in use for around 50 years and are used for many purposes. In some cases they are used as a means of erosion control on construction sites, mines, and other land-disturbing operations (Haan et al., 1994). In other capacities, the geotextiles are sewn into tubes and then used to dewater high water content wastes such as dredge material, paper and pulp sludge, industrial sludge, as well as agricultural wastewaters (Moo-Young et al., 2002; Muthukumaran and Ilamparuthi, 2006; Worley et al., 2004). The use of these geotextile tubes is an emergent application of geosynthetics (Moo-Young et al., 2002). Recent studies by Baker et al. (2002) and Worley et al. (2004) have evaluated the use of geotextile tubes for dewatering dairy lagoon effluent. In the study by Worley et al.

(2004), sludge from a dairy lagoon was pumped into the tubes until they were filled to capacity. As the tubes dewatered, more sludge was pumped into the tubes until they were full again. This process was repeated until the tubes could no longer accept any more sludge. Using this procedure, Worley et al. (2004) found that the geotextile tube removed total solids (TS) with an efficiency of 97% and P_2O_5 (equivalent) with an efficiency of 79% from the dairy lagoon. Baker et al. (2002) observed similarly high reduction efficiencies of 87.8% for TS and 86.7% for total phosphorus (TP) from the dairy lagoon effluent. However, the study by Baker et al. (2002) was performed using a hanging bag test. In the study by Worley et al. (2004) it was observed that as the lagoon effluent was pumped into the tubes, the weight of the liquid helped to push the liquid through the pores in the fabric. Also, the formation of a filter cake on the inside surface of the tube occured quickly after pumping began. This helps to increase the efficiency of the geotextile filtration, indicating that the use of geotextile tubes for dewatering dairy lagoon effluent can be successful.

For Baker et al. (2002) and Worley et al, (2004) studies to achieve this success, it was not necessary to add a chemical coagulant or precipitant to the dairy lagoon effluent prior to pumping, but in some cases a chemical coagulant may be needed so the effluent will not clog the tubes. In an e-mail correspondence with Dr. Worley on May 26, 2006, he stated that the only way to determine if a coagulant is needed as a part of the treatment process is to do a hang bag test. More recently, Ten Cate Nicolon (the technology provider for the Geotube® dewatering system) uses a swatch test to determine if it is necessary to add a coagulant to the lagoon effluent. In this test, a small amount of the lagoon effluent is placed in the center of a palm-sized swatch of the geotextile cloth and “squeezed” to determine if the lagoon effluent will clog the tubes. If this is the case, a coagulant is added to a sample of the effluent and the process is repeated until the optimal ratio of chemical is found.

There are many advantages to using a geotextile dewatering system. The geotextile tube dewatering system can be installed on-site and the liquid from the lagoon doesn’t have to be transported off site (Worley et al., 2004). Also, the solids that remain in the tube can be stored in situ and removed at the convenience of the dairy farmer. Using this kind of BMP can lend some flexibility to when the dairy farmer chooses to treat the lagoon effluent and where it can be applied since the residual solids in the tube can be transported more easily than liquid manure (Worley, 2004). These geotextile tubes are available commercially in many different dimensions and lengths that allow the dairy farmer to tailor the system to the size of his operation.

However, there are also some drawbacks to using a geotextile dewatering system. Care must be taken not to over fill the tube so that it will not rupture. Furthermore, these tubes can be used only one time, and can be quite costly. This may deter a dairy farmer who is not willing to make such an investment each and every time he treats the lagoon (Worley, 2004).

Electrocoagulation

Electrocoagulation is not an emerging technology (Holt et al., 2005). Originally patented in the United States in 1909 (Sengil and Ozacar, 2006), it has been in use as a wastewater treatment for the past century; although, over this period of time electrocoagulation’s popularity has waxed and waned (Holt et al., 2005; Sengil and Ozacar, 2006). Because electrocoagulation’s capability to remove a vast array of constituents from wastewaters has been proven, interest has been renewed for its use as an inexpensive method for wastewater treatment (Holt et al., 2005). In more recent years, electrocoagulation has come to the attention of the scientific community as a potentially effective technology for the treatment of dairy lagoon effluent as well as other wastewaters (Can et al., 2006). Some studies have shown electrocoagulation to be successful in the treatment of oily wastewater (Santos et al., 2006), textile wastewater (Can et al., 2006), mechanical polishing wastewater, and the clarification of drinking water. One study by Sengil and Ozacar (2006) found that electrocoagulation is a viable technology for the treatment of wastewater from dairy operations.

A basic electrocoagulation unit is comprised of a sacrificial metal anode and cathode (Holt et al., 2005; Sengil and Ozacar, 2006). There are three principle processes that occur during electrocoagulation: 1. Electrolytic reactions at the surface of the electrodes, 2. Development of coagulants in the aqueous solution (i.e. wastewater), and 3. Adsorption of constituents onto the coagulants (Can et al., 2006). These aggregates are subsequently removed by either sedimentation or flotation (Can et al., 2006). These processes begin by running a current through the anode and the cathode. This causes the anode to oxidize which results in the dissolution of the metal's ions and the cathode reduces which produces OH^- ions. If Al electrodes are used, he metal and hydroxide ions react to form various aluminum hydroxo complexes, all of which eventually transform into $Al(OH)_3$ (Can et al., 2006). This species of aluminum hydroxide has substantial surface area that is advantageous for the successful adsorption of soluble organics and solids (Can et al., 2006). If iron electrodes are used instead of aluminum, $4Fe(OH)_3$ molecules are formed (Sengil and Ozacar, 2006). Then, either the Al(OH)n or Fe(OH)n compounds can remove the constituents in the wastewater stream by complexation or electrostatic attraction at which point they coagulate (Can et al., 2006; Sengil and Ozacar, 2006).

According to Holt et al. (2005) there are many problems with electrocoagulation as a technology. First, even though the design of an electrocoagulation unit is simple, there is no primary reactor design and there is no information comparing and contrasting the plethora of designs in use today (Holt et al., 2005). This is illustrated in Figure 2, which shows the multitude of electrocoagulation systems. Second, there is also a deficiency of information for guidance on design or prediction of effectiveness or efficiency (Holt et al., 2005). Lastly, the performance of the electrocoagulation reactor is dependant on the state of its electrodes (Holt et al. 2005). Over time, the oxidation of electrodes causes an oxide layer to form on the surface inhibiting the dissolution of the ions and reducing the efficiency of the reactor (Holt et al., 2005). This is a serious constraint in cases where inexpensive and low maintenance wastewater treatments are needed (Holt et al., 2005).

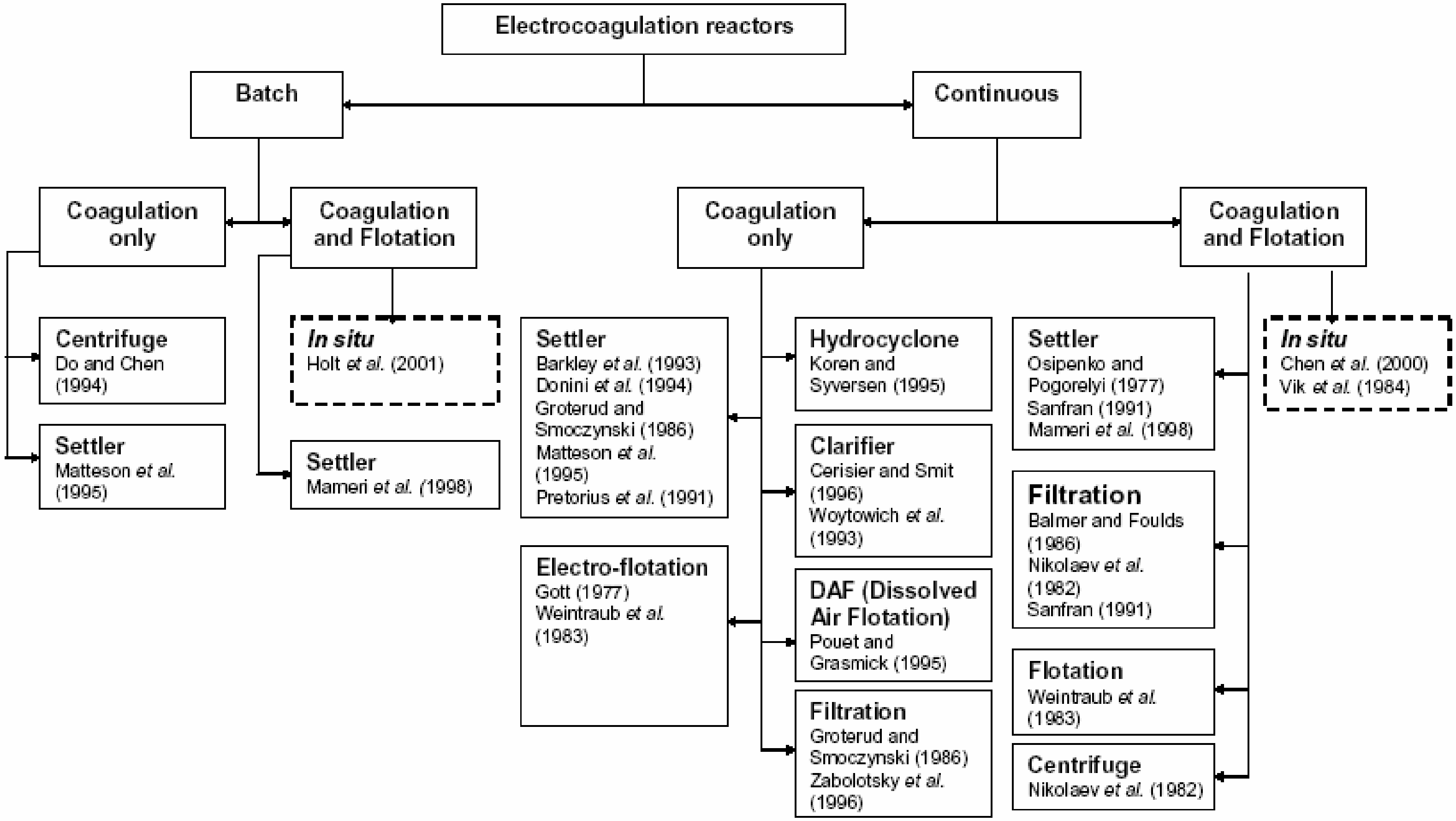


Figure 2. Flowchart classifying different electrocoagulation systems that have been used in various studies.

OBJECTIVES

In 1998, the North Bosque River and Upper North Bosque River were declared as impaired watershed segments because of excessive nutrient content and aquatic plant growth. Further investigation revealed dairy waste application fields as controllable contributors of P with in these watershed segments. This project will investigate ways that the dairies may reduce the amount of P applied to WAFs from their operations.

The following are the objectives for this study:

- Evaluate the efficacy of the EC system presented by Ecoloclean Inc. for its ability to reduce phosphorus and other pollutants from dairy lagoon effluent.

- Evaluate the efficacy of the Geotube® dewatering system presented by Ten Cate Nicolon for its ability to reduce phosphorus and other pollutants from dairy lagoon effluent.

EVALUATION OF THE ELECTROCOAGULATION SYSTEM

INTRODUCTION

Water quality degradation due to phosphorus (P) nonpoint source pollution from effluent and manure applied to waste application fields (WAF) is a major concern in the Bosque River watershed. In 1998 two upper North Bosque River segments were designated as impaired on the Texas Clean Water Act, Section 303(d) list (TNRCC, 2001). This designation was the result of nutrient loading and aquatic plant growth in those segments.

Changes in the status of the Bosque River segments prompted the Texas Commission on Environmental Quality (TCEQ) to apply Total Maximum Daily Loads (TMDLs) for P to those designated segments. In December 2002, the Texas Commission on Environmental Quality approved the implementation plan of two TMDLs, and they were approved by the Texas State Soil and Water Conservation Board in January 2003. These TMDLs call for a reduction of the annual loading and annual average concentration of soluble reactive P (SRP) by about 50%.

The United States Environmental Protection Agency (EPA) has cited pollution from nonpoint source agricultural operations (by way of runoff) as the main source of contamination to water bodies. Reducing P from dairy effluent applied to WAF is vital to protecting many of these water bodies.

Runoff from WAFs is not regulated because it is regarded as a nonpoint source. Currently, a number of dairy operations in the Bosque river watersheds are using best management practices (BMPs) to remove P and SRP from the wastewater. However, to meet the goals of these TMDLs new, more effective and efficient BMPs will need to be adopted by these dairies. Two prospective BMPs that could remove pollutants from the effluent being stored and treated in dairy lagoons are an electrocoagulation system and a geotextile dewatering system.

The EC system introduced for evaluation by Ecoloclean Industries, Inc. was set-up to treat the effluent from the secondary lagoon of a 700-head lactating cow dairy in the Bosque River watershed. Manure from the two free-stall barns at this dairy was flushed into the primary lagoon. Effluent from the secondary lagoon was recycled for flushing the barns and irrigating hay and cropland at the dairy operation.

METHODOLOGY

Facilities

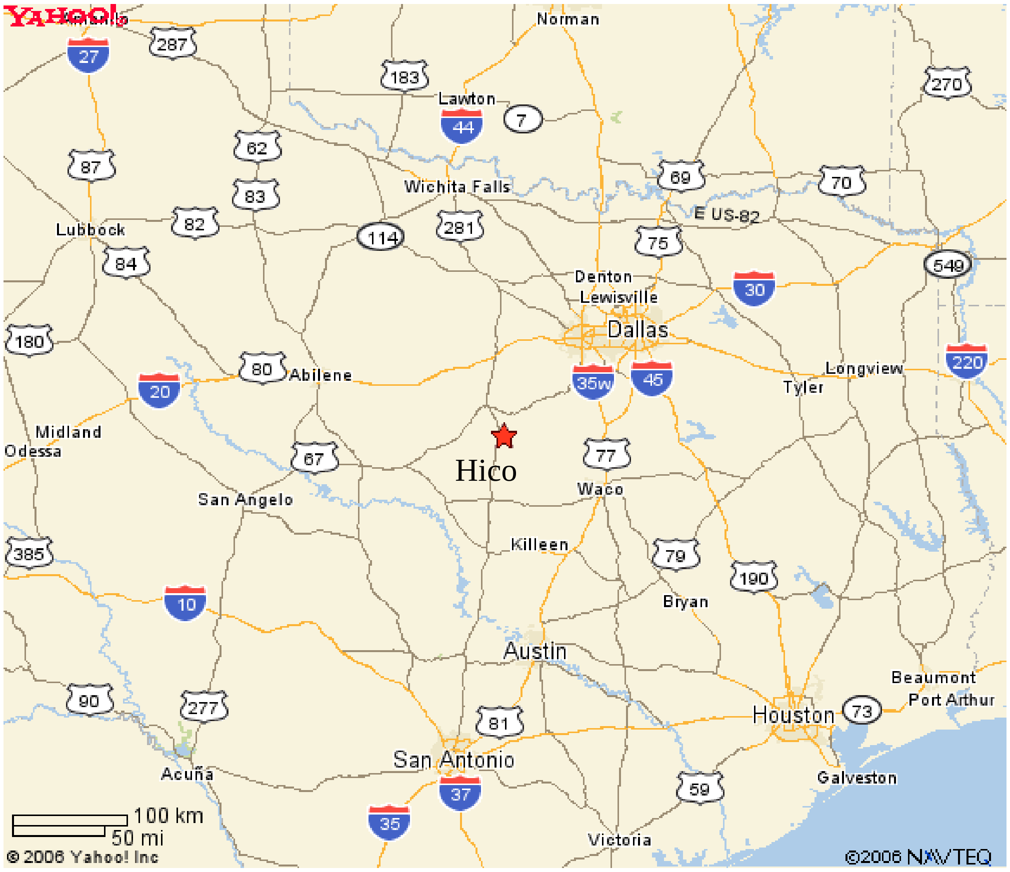


Figure 3. Location of Hico, TX (Yahoo! Maps, 2006a).

The system was set-up to treat the effluent from a secondary lagoon of a 700-head lactating cow dairy in Hico, TX (Figure 3), located in the Bosque River watershed. Manure from the two free-stall barns at this dairy was flushed into the primary lagoon. Effluent from the secondary lagoon was recycled for flushing the barns and irrigating hay and cropland at the dairy operation.

EC System Configuration

The following abbreviations are used in the description of the EC configuration and subsequent sections:

- IF – Influent, the lagoon effluent pumped in to the treatment system
- IFCM – Influent (lagoon effluent) with chemical pretreatment
- PCF – Centrifuge effluent (liquid-solid separation of IFCM)
- EF – Effluent from the treatment system
- RS – Residual Solids, solids separated by the centrifuge

Table 1 provides a side-by-side comparison of the component configuration from event to event. For the first sampling event on June 8th the component configuration was as follows (Figure 4):

- Effluent from the lagoon was pumped at nearly 40 gallons per minute into a large mixing tank.
- Unknown quantities of Alum ($AlSO_4$) and lime (CaOH), and a proprietary anionic emulsion polymer were pumped into the large mixing tank from separate smaller mixing tanks.
- Unknown quantities of a proprietary “mud mixture” was mixed in the Tri-Flow tank, and then pumped into the large mixing tank.
- The mixed slurry (lagoon effluent chemicals and the mud mix) was then pumped to a dissolved air flotation (DAF) unit. The liquid exiting the DAF was then sent to the EC unit.
- The effluent from the EC was pumped into a series of sequential tanks:

  - A reaction tank with a mixer which provides a sufficient amount of time for the completion of chemical reactions and removal of gasses which result from the processes in the EC unit
  - A poly feed tank with a mixer in which the polyelectrolyte flocculent is mixed with the solids precipitated by the EC unit. This is done to coagulate the solids so they will settle more readily
  - And finally, Clarifier Tank A (in this tank the up-flow rate of the water is less than the settling rate of the coagulated solids. Because of this, the solids settle out of the liquid.).
- From these tanks, the liquid drained to the final filter (the last component in the system) after which the resulting product (treated effluent) from the system was sampled.

For the next sampling event (June 27, 2005), the configuration was altered. The changes to Figure 4 are as follows:

- The DAF was replaced by clarifier tank B.
- From the clarifying tank, the mixture was pumped into the EC unit.
- After treatment in the EC, the effluent was pumped into a defoaming tank with a mixer

- From the defoaming tank, the effluent was then pumped to a clarifier tank C.
- The effluent then drained into the final filter it was sampled.

On the next sampling (July 7, 2005) the DAF was returned to its original location in the system's components configuration, and the reaction tank was removed (Figure 5). Also, a centrifuge was placed after the large mixing tank. The liquid exiting the centrifuge tank then proceeded on to the collection/equalization tank and then to the EC unit.

For sampling event on (July 12, 2005), the same configuration was used from the previous sampling on July 7 with the removal of the DAF and the addition of a reaction/defoaming tank directly after the EC unit.

On July 19, 2005, the configuration was the same as the event on July 7, 2005. However, the defoaming tank was placed directly up-stream of the EC unit, and a different DAF was used.

For the next two sampling events (July 26, 2005 and August 8, 2005), this configuration remained exactly the same as that for the July 7, 2005 sampling.

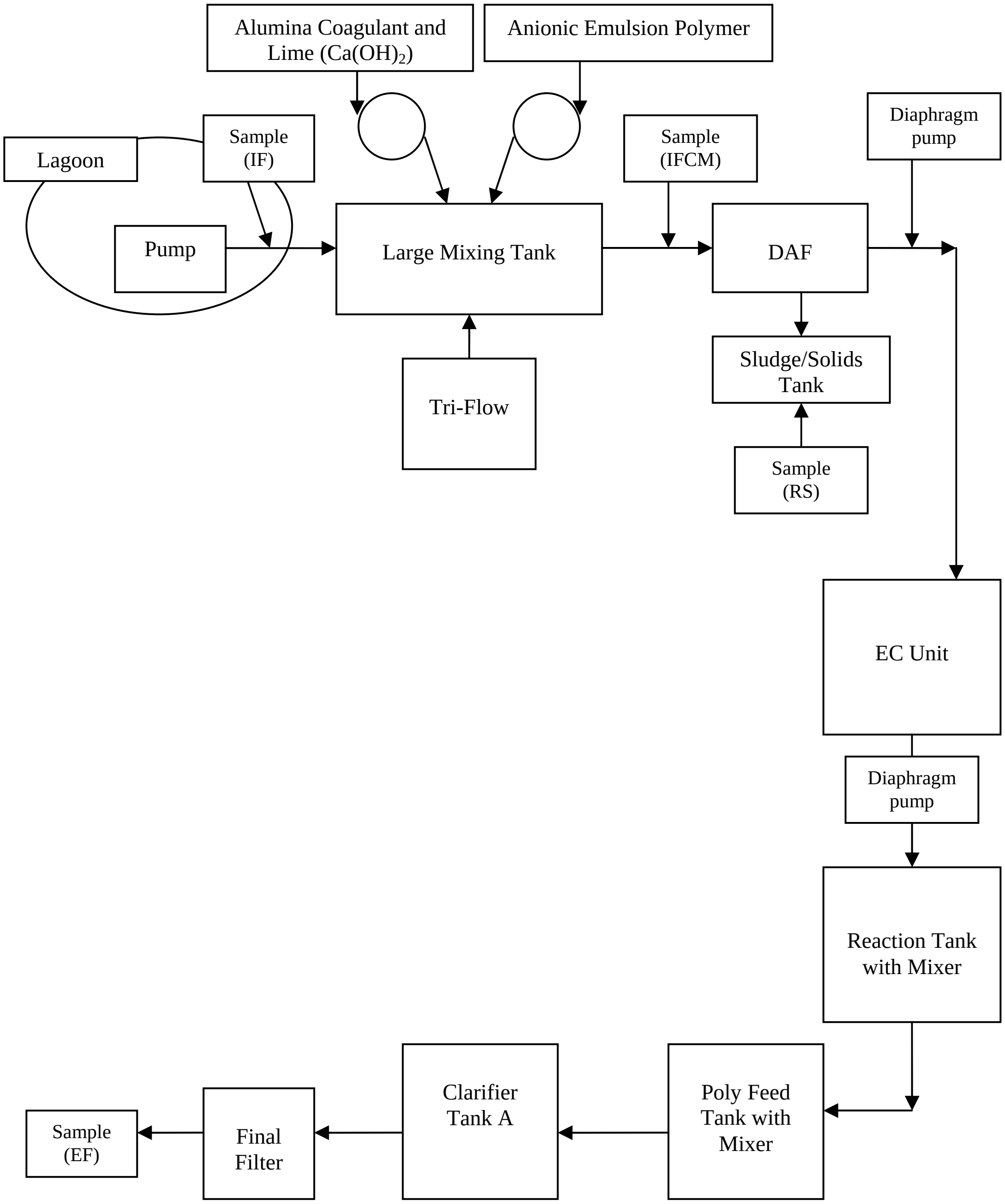


Figure 4. Schematic of EC system's components configuration for the weeks of June 8 and June 27, 2005

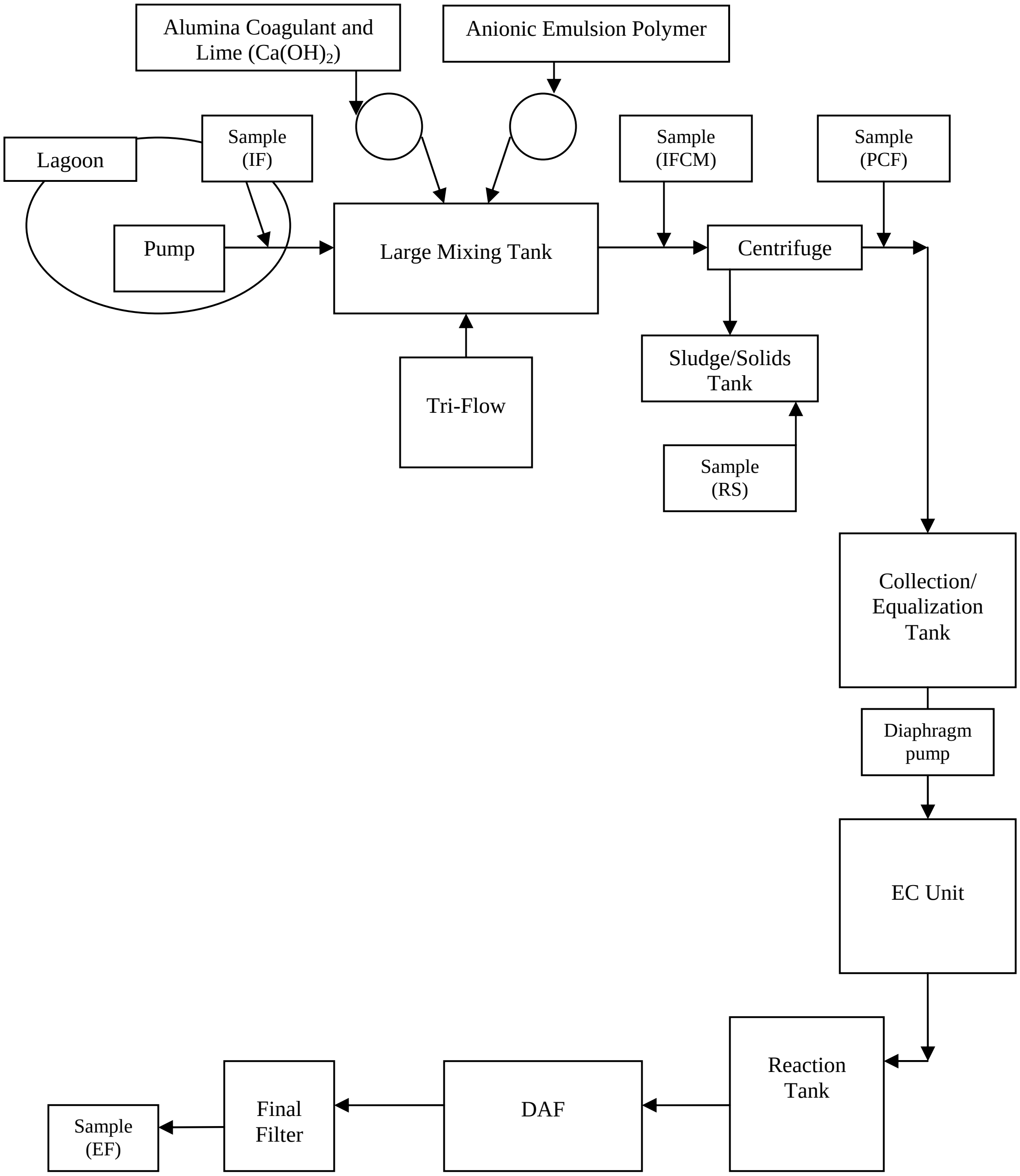


Figure 5. Schematic of EC system’s components configuration for the weeks of July 7 through August 2, 2005

Table 1. Matrix of system components and their order in the system per sampling event.

Component/Date.	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
Small Mixing Tanks	1*a**	1a	1a	1a	1a	1a	1a
Tri-Flow	1b**	1b	1b	1b	1b	1b	1b
Large Mixing Tank	2	2	2	2	2	2	2
Centrifuge			3	3	3	3	3
C/E Tank			5	4	5	5	5
Residual Solids Tank							
DAF A	3		4				
DAF B					4	4	4
EC Unit	4	4	6	5	7	7	7
Reaction Tank	5						
Poly-feed Tank	6						
Clarifier Tank A	7						
Clarifier Tank B		3					
Defoaming Tank		5		6	6	6	6
Clarifier Tank C		6					
Final Filter	8	7	7	7	8	8	8

* Numbers indicate the order in which the components were positioned in the system, a blank cell indicates that the component was not used for that sampling event.

** Letters denote that these components were placed parallel to one another in the system. The small mixing tanks and the Tri-Flow both fed into the large mixing tank, but did not interact with each other.

Experimental Plan

Ten sets of 15 (250 mL) grab samples were taken during each sampling event, with the exception of the first. As the system's components configuration changed, the locations at which samples were taken were as follows:

Sampling event 1 (June 8th):

- Three sample sets were taken from the influent (IF) (lagoon effluent entering the system). (Figure 4)
- One set of seven bottles was taken at the effluent outlet (EF). (Only seven bottles could be taken because the system could not be run long enough to fill seven bottles.) (Figure 4)
- Three samples of solids (RS) from the system were taken by fully filling a quart size freezer bag for each sample. (Solid samples were taken from the sludge tank.) (Figure 4)

Sampling event 2 (June 27th):

- Two sample sets were taken from the lagoon effluent entering the system (IF). (Figure 4)
- Two sets were taken from the mixture exiting the large mixing tank (IFCM). (Figure 4)
- Three sample sets were taken at the effluent outlet (EF). (Figure 4)
- Three samples of solids (RS) from the system were taken. (Solid samples were taken from the sludge tank.) (Figure 4)

Sampling events 3 – 7 (July 7th – August 2nd):

- Two sample sets were taken from the lagoon effluent (IF) entering the system. (Figure 5)
- Two sets were taken from the mixture exiting the large mixing tank (IFCM). (Figure 5)
- Two sets were taken from the liquid exiting the centrifuge (PCF). (Figure 5)

- Two samples of solids (RS) exiting the centrifuge were taken by fully filling a quart size freezer bag for each sample. (Figure 5)
- Two sets were taken at the effluent outlet (EF) (Figure 5)

Calculations

- Once the raw data were received from the lab, concentrations of samples treated as solids (IF, IFCM, and RS) were converted from mg/kg dry to mg/L as-is using their respective percent total solids values for each sample.
- Averages and standard deviations of IF concentrations and IFCM concentrations were calculated for both sampling events.

Analysis of the Samples

Samples treated as solids were extracted or acid digested into aqueous form before analysis for the all of the analytes. All of the liquid samples were analyzed using the following methods:

- Total Solids (TS) were measured using a gravimetric oven drying method (SM 2540C). The sample was dried in an oven and the residuals were weighed to determine the amount of TS.
- Total Volatile Solids (TVS) (EPA 160.4) were found gravimetrically using a muffle furnace. The sample was first weighed, then ashed (at 550° C) and then weighed again. The difference in weight indicated the solids that volatilized during the oven drying process.
- Total Fixed Solids (TFS) were determined by subtracting the concentration of TVS from TS.
- Total Suspended Solids (TSS) (EPA 160.2). The sample was poured over a glass fiber filter that was then dried to a constant weight at 103°-105° C. The amount of TSS was determined to be the difference in weight of the dried filter to the clean filter.

- Total Dissolved Solids (TDS) were determined by subtracting the concentration of TSS from the concentration of TS.
- Soluble Phosphorus (Sol P) (EPA 365.2) was determined by direct colorimetry on filtered samples. Ammonium molybdate and antimony potassium tartrate were added to an acid medium along with a dilute solution of the phosphorus to be tested. The orthophosphates reacted with these chemicals to form a blue colored complex. The intensity of the blue color was proportional to the amount of phosphorus.
- Nitrate/Nitrite-Nitrogen (NNN) (EPA 353.2). The sample was filtered then nitrate was reduced to nitrite using granulated copper-cadmium, NNN was then determined colorimetrically.
- Total Phosphorus (TP) (EPA 365.4). The sample was digested using a sulfuric acid, cupric acid and potassium sulfate solution then TP was determined colorimetrically.
- Total Kjeldahl Nitrogen (TKN, EPA 351.2). The sample was digested using a sulfuric acid, cupric acid and potassium sulfate solution then TKN was determined colorimetrically
- Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn), Copper (Cu), Iron (Fe), and Aluminum (Al) were determined using elemental analysis by inductively coupled plasma (EPA 200.7) (APHA, 2005; USEPA, 1983).
- Electrical conductivity (Cond) was determined using a YSI® 3200 conductivity meter
- Potential Hydrogen (pH) was determined using a Accument® AB15 Plus pH meter

RESULTS AND DISCUSSION

Mean concentration and standard deviation were calculated for each sample location for all of seven sampling events. The data from the first sampling event was excluded from the analysis since the composition of the system components was drastically different than in the other six events.

An overall average (O Avg) at each of the sampling points was calculated based on the last six sampling events for the purpose of intra-system comparison. Also, a modified average (Mod Avg) concentration at each sampling point was calculated using only the last three events because the component configuration remained the same for these events.

Generally, concentrations of all physicochemical constituents analyzed in the lagoon effluent (influent pumped to the EC system) varied slightly among sampling events. This variation may be attributed to variation in the inlet location and depth in the lagoon from week to week during these sampling events.

For all sampling events, analyses of the IFCM showed increases in conductivity and all solids, calcium, iron and aluminum concentrations. These increases likely resulted from alum, lime, polymer and the proprietary “mud mix” added to the influent (IF) during the chemical pretreatment process.

The results for the sampling event on June 27th tended to be quite different from the results observed for other sampling events, because the centrifuge had not yet been installed. The technology provider had difficulty with the EC unit functioning properly with the concentration of solids coming directly from the lagoon, even though the solids levels were already very low. Adding the centrifuge drastically altered the way the system performed which was reflected in the lower concentrations observed on the events thereafter.

There were also many unexplainable, uncharacteristic concentrations that did not seem to fit any pattern such as the very small reductions of TP by the centrifuge seen in Table 7 for some of the events. This did not seem to fit the trend of variably larger reductions observed at all of the other sampling events. With metals particularly, there was no apparent trend from event to event. For example, the large variations in the performance of the chemical pretreatment with respect to Mg (Table 13). These inconsistencies were most likely due to the configuration of the system constantly changed (Table 1) from event to event as well as the chemicals used in the pretreatment.

However, some of the inconsistencies in the performance of the system may not be as random as they first appeared. When the behavior of the analytes (between IF and IFCM) which did not experience an increase in concentration due to the chemical pretreatment were compared a trend appeared. It was observed that on the July 19th event NNN, TKN, TP, K, Mg, and Cu experienced uncharacteristic changes in concentration at the stage when the chemical pretreatment was added. The same results were true for TKN, TP, and Cu on the July 7th event. On the event in between these two, July 12th, a substantial reduction was observed for these analytes. The concentration of all analytes was very consistent from event to event, indicating the increases and decreases from the chemical pretreatment per event were the result of the changes in the chemicals used. Although there was verbal communication from the tech provider at the sampling events stating a change in the chemicals used in pretreatment, no information on the identity of these chemicals or when they were changed could ever be obtained from the company. The only know chemicals used in the pretreatment were lime, an anionic emulsion polymer, and their proprietary “mud mix”.

Since it was not possible to take samples before and after every component in the system, it is not possible to ascertain whether or not reductions (or increases) observed during the stage in the system in which the EC unit was located was affected by this component at all. It was equally as likely that the EC unit caused these changes in concentration as if these reductions had occurred as the result of solids settling in the reaction tank or some analytes being removed in the DAF. One certain observation is that the EC unit, with its iron electrodes, was the source of the increase of Fe concentration at this stage in the system because there were no other sources of Fe available.

Solids

Total Solids

The dairy lagoon effluent was pumped from the surface without any means of agitation. As a result, the concentrations of TS in the IF were very low. In fact, the average overall concentration for TS was 0.59% (Table 2a). This concentration was very similar to the one provided by Barker et al. (2001) for TS in the supernatant of an anaerobic dairy lagoon (Table A-1). The average concentrations of TS in the IF were consistent from sampling event to sampling event with only a slight drop of 0.01% to 0.04% being observed for O Ave and Mod Ave (Table 2a), respectively at the end of the sampling events.

As expected, there was an increase in the concentration of TS from IF to IFCM. This increase was due to the addition of the chemical pretreatments added into the large mixing tank. This increase was not consistent. On the July 7th and 12th, and the August 2nd events, the addition of the chemical pretreatment produced a TS concentration that was almost twice that observed in the IF. However, on the July 19th and 26th events, an increase of approximately 130% in TS concentration was observed between the IF and IFCM sampling points (Table 2b). This corroborates the observation made at the site that the technology provider was having difficulty finding the right amount and rate of chemical pretreatment to add to the system, especially on the July 19th and July 26th events. This is also evident from the relatively large standard deviations observed for the TS concentrations at the IFCM sampling point. The inconsistencies at the IFCM sampling point indicate the chemical pretreatment was not injected in to the large mixing tank at a constant rate and therefore, TS concentrations in the liquid flowing out of the large mixing tank carried considerably (Table 2b).

The centrifuge produced the greatest reductions of TS. The amount of TS removed by the centrifuge was not directly proportional to the amount of TS observed in the IFCM (Table 2a), but larger amounts of TS were removed by the centrifuge on the events where the largest concentrations of TS were observed in the IFCM. This indicated that the efficiency of the centrifuge was changed by the amount of coagulant and polymer added in the pretreatment.

The stage in the system where the EC unit was located removed a very small amount of the TS, at most 0.23% TS. It is possible that the EC unit was not responsible for these reductions. Because it was not possible to sample after every component in the stream, it is impossible to conclude specifically where the reduction took place in this final stage.

Table 2a. Overall average concentration and average concentration for the last three sampling events of TS for each sampling point in the system*

TS	**O Avg**	**Mod Avg**
IF (mg/L)	0.59	0.56
IFCM (mg/L)	1.1	1.23
PCF (mg/L)	0.45	0.43
EF (mg/L)	0.32	0.31
RS (mg/Kg)	24	22

*All values are on an as is basis.

Table 2b. Average and standard deviations of TS concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	0.68	0.65	0.61	0.59	0.58	0.56	0.55
	± 0.006	± 0.001	± 0.004	± 0.03	± 0.002	± 0.008	± 0.004
IFCM (mg/L)		0.7	1.1	1.0	1.4	1.3	1.0
		± 0.50	± 0.11	± 0.58	± 0.11	± 0.38	± 0.30
PFC (mg/L)			0.47	0.49	0.39	0.48	0.42
			± 0.01	± 0.11	± 0.04	± 0.14	± 0.03
EF (mg/L)	0.08	0.24	0.40	0.35	0.34	0.39	0.19
		± 0.010	± 0.002	± 0.004	± 0.032	± 0.006	± 0.011
RS (mg/Kg)	1.9	31	27	16	19	24	24
	0.14	2.2	0.4	2.4	8.4	1.7	1.7

*All values are on an as is basis.

Table 2c. Change in concentration (mg/L) of TS between each sampling point in the system as well as the over all percent change of TS in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		0.07	0.50	0.45	0.78	0.73	0.50
IFCM to EF	-0.6	-0.47					
IFCM to PCF			-0.64	-0.54	-0.96	-0.82	-0.63
PCF to EF			-0.08	-0.14	-0.05	-0.08	-0.23
Over All Rd	-0.6	-0.41	-0.21	-0.24	-0.24	-0.16	-0.36

% Change	-89	-63	-35	-40	-41	-29	-65

Total Volatile Solids

The concentration of TVS in the influent was approximately 45% of its corresponding TS concentration for all of the six sampling events. As with TS concentrations, observed average TVS concentrations remained constant from one sampling event to another, only increasing or decreasing by 0.01% between the events.

Similar to TS concentration between the IF and IFCM sampling points, there was an increase in the concentration of TVS between these points as well but the magnitude of this increase was smaller than that for the TS. For each of the six sampling events the most reduction of TVS in the system was from the centrifuge. This was expected because the highest reduction in TS concentration resulted from the centrifuge. While concentrations of TS observed at the PCF sampling point were not consistent from event to event, concentrations of TVS at this sampling point were fairly consistent from event to event. The reductions of TVS observed in the stage of the system where the EC unit was located were minimal (0.04% TVS on average).

For each of the six sampling events the main reduction of TVS in the system was from the centrifuge. This was expected because the same outcome was observed for the TS concentrations. Although the concentrations of TS observed at the PCF sampling point were not consistent from event to event, this was not the case for the TVS concentrations. Instead, average concentrations of TVS at this sampling point were reasonably consistent from event to event. It also does not appear that the concentration of TVS entering the centrifuge had any bearing on the amount removed therein. This indicated that the amount of coagulant or polymer added in the pretreatment might not have had any effect on the amount of TVS removed from the liquid matrix by the centrifuge. The reductions of TVS observed in the stage of the system where the EC unit was located were minimal (0.04% TVS on average).

Table 3a. Overall average concentration and average concentration for the last three sampling events of TVS for each sampling point in the system*

TVS	O Avg	Mod Avg
IF (mg/L)	0.25	0.24
IFCM (mg/L)	0.3	0.33
PCF (mg/L)	0.13	0.12
EF (mg/L)	0.08	0.08
RS (mg/Kg)	5.3	4.48

*All values are on an as is basis

Table 3b. Average and standard deviations of TVS concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	0.31	0.26	0.27	0.27	0.25	0.24	0.23
	± 0.006	± 0.002	± 0.004	± 0.004	± 0.002	± 0.004	± 0.004
IFCM (mg/L)		0.20	0.37	0.30	0.39	0.34	0.27
		± 0.16	± 0.04	± 0.19	± 0.02	± 0.09	± 0.07
PFC (mg/L)			0.13	0.15	0.11	0.13	0.12
			± 0.008	± 0.016	± 0.020	± 0.042	± 0.008
EF (mg/L)	0.03	0.05	0.09	0.10	0.10	0.10	0.05
		± 0.002	± 0.002	± 0.001	± 0.003	± 0.002	± 0.009
RS (mg/Kg)	0.57	8	7	4	5	5	4
	± 0.03	± 0.25	± 0.03	± 0.35	± 2.14	± 0.15	± 0.21

*All values are on an as is basis.

Table 3c. Change in concentration (mg/L) of TVS between each sampling point in the system as well as the over all percent change of TVS in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-0.07	0.10	0.03	0.13	0.10	0.04
IFCM to EF	-0.28	-0.15					
IFCM to PCF			-0.24	-0.14	-0.28	-0.21	-0.15
PCF to EF			-0.04	-0.05	-0.01	-0.03	-0.07
Over All Rd	-0.28	-0.22	-0.17	-0.16	-0.16	-0.14	-0.18

% Change	-89	-83	-66	-61	-62	-59	-78

Total Fixed Solids

As expected as a result of the addition of the chemical pretreatment, there was a substantial increase in TFS concentrations between IF and IFCM for all of the sampling events. This increase in concentrations was inconsistent from event to event due to differences in quantities of chemicals used in pretreatment.

The centrifuge affected the largest reductions of TFS of any stage in the system (Table 4b). However, the amount removed by the centrifuge was approximately equal to the increase in concentration observed as a result of the addition of the chemical pretreatment. One possibility for this result is that the TFS in the dairy lagoon effluent was of the same weight as the liquid matrix and that the fixed solids added in the chemical pretreatment were of a different density. If this was the case, the TFS from the lagoon would remain in the effluent stream and the solids from the chemical pretreatment would be removed (Hammer and Hammer, 2001).The stage in the system where the EC unit was located was associated with only marginal reductions to TFS concentrations in the liquid matrix, at most 0.16% TFS was removed (Table 4c).

Overall, the amount of TFS removed by the system was highly inconsistent, ranging from 56% to 7% over the six sampling events. This indicated that the system was not particularly well suited to reduction of TFS from this dairy lagoon.

Table 4a. Overall average concentration and average concentration for the last three sampling events of TFS for each sampling point in the system*

TFS	O Avg	Mod Avg
IF (mg/L)	0.34	0.32
IFCM (mg/L)	0.8	0.90
PCF (mg/L)	0.32	0.31
EF (mg/L)	0.24	0.23
RS (mg/Kg)	18.0	17.14

*All values are on an as is basis.

Table 4b. Average and standard deviations of TFS concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	0.37	0.39	0.35	0.32	0.32	0.32	0.32
	± 0	± 0.001	± 0.0	± 0.03	± 0.004	± 0.004	± 0.008
IFCM (mg/L)		0.52	0.75	0.74	0.97	0.95	0.78
		± 0.33	± 0.08	± 0.39	± 0.08	± 0.30	± 0.23
PFC (mg/L)			0.35	0.34	0.28	0.34	0.30
			± 0.02	± 0.09	± 0.02	± 0.10	± 0.03
EF (mg/L)	0.04	0.20	0.31	0.25	0.25	0.29	0.14
		± 0.008	± 0.004	± 0.003	± 0.03	± 0.004	± 0.001
RS (mg/Kg)	1.3	24	20	13	15	19	18
	± 0.12	± 1.99	± 0.44	± 2.0	± 6	± 1.6	± 0.60

*All values are on an as is basis.

Table 4c. Change in concentration (mg/L) of TFS between each sampling point in the system as well as the over all percent change of TFS in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		0.13	0.40	0.42	0.64	0.64	0.46
IFCM to EF	-0.33	-0.32					
IFCM to PCF			-0.40	-0.40	-0.69	-0.61	-0.48
PCF to EF			-0.04	-0.09	-0.03	-0.05	-0.16
Over All Rd	-0.33	-0.19	-0.04	-0.07	-0.08	-0.02	-0.18

% Change	-88	-49	-12	-23	-24	-7	-56

Total Suspended Solids

The overall average TSS concentration in the dairy lagoon effluent was 0.06%. This was much lower than one standard deviation away from the TSS mean provided by Barker et al. (2001) (Table A-1). This is not surprising since the IF was pumped from very close to the surface of the lagoon. Here, it is very possible that the TSS concentration would be lower than if the IF were pumped from somewhere closer to the center of the supernatant's profile.

There was a large increase in concentration of TSS (due to the addition of the chemical pretreatment) between the IF and IFCM sampling points observed at all sampling events (Table 5c). However, standard deviations at this stage in the system and all others for each sampling event were extremely large, approximately 100% of their mean. Therefore, these observations have been made only for the purposes of argument and under the assumption that the standard deviations do not indicate the averages are imprecise.

It was observed that the centrifuge removed the largest amount of TSS from the liquid matrix compared to other stages (Table 5c). As observed for the TFS, the concentration of TSS removed by the centrifuge was approximately equal to the increase in concentration seen as a result of chemical pretreatment.

The performance of the stage in the system where the EC unit was located was highly inconsistent from event to event (Table 5b and 5c). On the July 7th and July 12th events there was a very slight increase in TSS concentration at this stage. Only on the July 19th event was there a reasonable decrease in concentration. This indicates that the type of chemicals added in the pretreatment possibly had a bearing on the efficiency of this stage.

The overall percentage change of TSS affected by the EC system was highly inconsistent. One reason for this is that the initial concentrations of TSS were so small to begin with, any slight change from event to event would appear as an inconsistent performance of the system.

Table 5a. Overall average concentration and average concentration for the last three sampling events of TSS for each sampling point in the system*

TSS	O Avg	Mod Avg
IF (mg/L)	0.06	0.05
IFCM (mg/L)	0.9	0.97
PCF (mg/L)	0.09	0.14
EF (mg/L)	0.05	0.05

*All values are on an as is basis

Table 5b. Average and standard deviations of TSS concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)		0.09	0.07	0.05	0.06	0.06	0.04
		± 0.03	± 0.07	± 0.05	± 0.06	± 0.06	± 0.04
IFCM (mg/L)				0.65	1.06	1.01	0.84
				± 0.65	± 1.06	± 1.01	± 0.08
PFC (mg/L)			0.03	0.02	0.06	0.27	0.08
			± 0.03	± 0.02	± 0.06	± 0.27	± 0.08
EF (mg/L)	4	0.01	0.09	0.03	0.04	0.09	0.02
		± 0.004	± 0.09	± 0.03	± 0.04	± 0.09	± 0.02

*All values are on an as is basis

Table 5c. Change in concentration (mg/L) of TSS between each sampling point in the system as well as the over all percent change of TSS in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM				0.60	1.00	0.96	0.80
IFCM to EF			-0.05				
IFCM to PCF				-0.63	-1.00	-0.74	-0.76
PCF to EF			0.06	0.01	-0.02	-0.19	-0.06
Over All Rd		-0.08	0.02	-0.01	-0.02	0.03	-0.01

% Change	N/A	92	-18	31	32	-46	40

Total Dissolved Solids

Barker et al. (2001) does not provide a TDS concentration with which to compare the numbers for this study. Without any benchmark for comparison, it cannot be determined if this lagoon is representative to others with respect to TDS.

Substantial reductions in the concentration of TDS were observed between the IF and the IFCM sampling points. This indicated that chemical pretreatment was effectively removing dissolved matter from the liquid matrix in the large mixing tank. These observed reductions were, however, of varying degrees; possibly because of the changes in the chemicals used from event to event.

With the exception of the July 26th event, an increase in the concentration of TDS was observed as a result of the centrifuge. One possibility for this increase is that the energy imparted to the liquid matrix by the centrifuge re-dissolved some of the solids that were initially bound by chemical pretreatment. Conversely, the energy given to the liquid matrix by the centrifuge could result in dissolving of particles that had not reacted with the chemicals in the pretreatment.

The changes in concentration of TDS affected by the stage in the system where the EC unit was located were inconsistent (Table 6b and 6c). It would seem that this was the result of changes to the component configuration in that stage of the system. However, the greatest inconsistency was observed during the last three events when the component configuration for the entire system was static. These inconsistencies may indicate that the performance of this stage in the system with respect to TDS is highly dependant on the effectiveness of chemical pretreatment.

Table 6a. Overall average concentration and average concentration for the last three sampling events of TDS for each sampling point in the system*

TSS	O Avg	Mod Avg
IF (mg/L)	0.53	0.51
IFCM (mg/L)	0.3	0.26
PCF (mg/L)	0.38	0.32
EF (mg/L)	0.27	0.26

*All values are on an as is basis.

Table 6b. Average and standard deviations of TDS concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)		0.56	0.54	0.54	0.52	0.50	0.52
		± 0.03	± 0.03	± 0.03	± 0.02	± 0.002	± 0.01
IFCM (mg/L)				0.39	0.30	0.28	0.21
				± 0.19	± 0.08	± 0.16	± 0.01
PFC (mg/L)			0.45	0.47	0.33	0.21	0.43
			± 0.01	± 0.10	± 0.07	± 0.19	± 0.09
EF (mg/L)	0.08	0.23	0.31	0.32	0.31	0.31	0.17
		± 0.007	± 0.01	± 0.002	± 0.02	± 0.001	± 0.005

*All values are on an as is basis.

Table 6c. Change in concentration (mg/L) of TDS between each sampling point in the system as well as the over all percent change of TDS in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM				-0.15	-0.22	-0.22	-0.30
IFCM to EF			-0.09				
IFCM to PCF				0.08	0.03	-0.07	0.22
PCF to EF			-0.14	-0.15	-0.03	0.10	-0.26
Over All Rd		-0.33	-0.23	-0.22	-0.22	-0.19	-0.35

% Change	N/A	-58	-42	-41	-41	-38	-67

Nutrients

Total Phosphorus

The average concentration of TP in the dairy lagoon effluent observed in this study (Table 7a) was 64% lower than the average found for dairy lagoon supernatant by Barker et al. (2004), putting the IF concentration barely within one standard deviation of the mean provided by Barker et al. (2001). However, the IF concentration of TP was much higher than the minimum concentration observed by Barker et al. (2001) of 1.9 mg/L. This indicates that although this lagoon's TP concentration was low in comparison to the average found in Barker et al. (2001), it could still be considered representative of other dairy lagoons as it is apparent that TP is highly variable from lagoon to lagoon.

The majority of the overall reduction of TP by this system occurred from addition of chemical pretreatment only on the June 27th, July 12th and the July 26th events. Although the term reduction is used to describe the drop in concentration due to the addition of the chemical pretreatment, it still remains in the liquid matrix, only bound in a different form which does not effect the concentrations observed in the lab analysis. The amount of TP reduced by addition of chemical pretreatment was always highly variable from event to event. It is possible that this is due to chemical pretreatment changed through the course of the study. Another possibility is that the rate at which chemical pretreatment was added to the large mixing tank was not consistent which could have effected the coagulation within. This is supported by two observations: first, at many of the sampling events there were difficulties in achieving proper coagulation, and second, the standard deviations of the average IFCM concentrations were quite large in comparison with the mean. The fact that there was some variation in the concentration of the IFCM samples taken per event could have been the result of variable rates of the chemical pretreatment addition.

For the July 7th, July 19th and August 2nd events, the centrifuge removed the majority of the TP concentration. The amount of TP removed as a result of pretreatment and centrifuge combined was approximately the same from one event to another. This indicates that the centrifuge was still able to remove the same amount of TP regardless of the efficacy of the chemical pretreatment to bind P.

For all of the events, with the exception of July 7th when a small increase occurred, the PCF to EF (or IFCM to EF for June 26th) stage in the system only achieved very small reductions in TP. In this stage where the EC unit was located these small reductions may not be an indication of the potential performance of the system since the concentrations of TP were already reduced to such low values there was not much left to remove at this point. The same case is seen for Sol P. The TP concentrations of the lagoon has already been shown to be low in comparison to other lagoons and they were lower still when they reached the EC unit.

The overall average percent reduction in TP was consistently high, approximately 96%, from event to event. This shows that for the conditions in this lagoon, this EC system was highly effective at reducing the concentration of TP. Because of these high reductions, it is very possible that this technology would aid in helping dairy operations meet TMDLs in the UNBR watershed.

The average TP concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 144 mg/L which is many times higher than the average observed concentration in the EF (Table 7a). This indicates that the EF would have the potential for reuse in flushing the milking parlor and lanes with respect to P. Because the concentrations of TP in the EF were reduced to almost zero, recycling the EF to flush manure should not cause the concentration of TP in the lagoon to rise.

Table 7a. Overall average concentration and average concentration for the last three sampling events of TP for each sampling point in the system*

TP	O Avg	Mod Avg
IF (mg/L)	51	55
IFCM (mg/L)	27	35
PCF (mg/L)	5	7
EF (mg/L)	1.9	2.1
RS (mg/Kg)	1203	1101

*All values are on an as is basis

Table 7b. Average and standard deviations of TP concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	58	37	52	55	55	54	54
	± 2.3	± 35	± 5.1	± 0.6	± 2.2	± 0.1	± 0.2
IFCM (mg/L)		10	42	2	44	21	41
		± 8	± 0.8	± 2	± 9	± 12	± 13
PFC (mg/L)			1.1	1.5	4.1	10	7
			± 0.07	± 0.64	± 3.7	± 9.8	± 4.7
EF (mg/L)	0.03	0.74	3.8	0.82	0.98	4.2	1.04
		± 0.33	± 0.93	± 0.18	± 0.24	± 0.18	± 0.85
RS (mg/Kg)	66	1712	1500	703	1030	1196	1077
	± 6	± 11	± 30	± 89	± 433	± 21	± 48

*All values are on an as is basis.

Table 7c. Change in concentration (mg/L) of TP between each sampling point in the system as well as the over all percent change of TP in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-27	-10	-52	-10	-34	-13
IFCM to EF	-58	-9					
IFCM to PCF			-41	-1	-40	-10	-35
PCF to EF			3	-0.6	-3	-6	-6
Over All Rd	-58	-36	-48	-54	-54	-50	-53

% Change	-99.9	-98	-93	-98	-98	-92	-98

Soluble Phosphorus

The overall average concentration of Sol P in dairy lagoon effluent observed in this study was 96% lower than the average found for dairy lagoon supernatant in Barker et al. (2001), which places this EF concentration well below one standard deviation of the Barker et al. (2001) mean (Table A-1). This large difference is not surprising since there was also a large concentration difference between the IF and the Barker et al. (2001) numbers. This concentration difference suggests that the lagoon used in the EC system study was not representative of other dairy lagoons with respect to Sol P concentrations. Very low Sol P concentrations could have serious implications on this project because it is one of the main focuses in this study. Where as this lagoon was not representative of others (with respect to Sol P) it was difficult to make any conclusions on whether or not this technology could successfully be applied to other lagoons.

Almost all of the Sol P reduction in the system occurred as the result of the chemical pretreatment. As stated by Zhang and Lei (1998), when added to the liquid matrix in the large mixing tank, calcium ions from the lime will attach to both phosphate (which carries a negative charge) and hydroxyl ions in the wastewater. When the ions attach to phosphate, which makes up a portion of the TP concentration, they render it immobile. Alternatively when the metal ions attach to OH^- ions in the liquid matrix, they create a floc that aids in the precipitation of dissolved solids. As seen in Table 8c, the large reductions in Sol P indicate the effectiveness of chemical pretreatment in attracting and binding it.

The reductions of Sol P in the centrifuge and in the stage of the system where the EC unit was located were insignificant in comparison to those from chemical pretreatment. As was the case with TP, the concentrations of Sol P were so low by the time the liquid matrix reached the stage where the EC unit was located, it was not feasible to draw any conclusions as to the effectiveness of this stage in the system.

Table 8a. Overall average concentration and average concentration for the last three sampling events of Sol P for each sampling point in the system*

Sol P	**O Avg**	**Mod Avg**
IF (mg/L)	4.7	5
IFCM (mg/L)	0.2	0.11
PCF (mg/L)	0.10	0.15
EF (mg/L)	0.02	0.01
RS (mg/Kg)	1.9	1.5

*All values are on an as is basis.

Table 8b. Average and standard deviations of Sol P concentrations for each sampling point in the system*

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF (mg/L)	21	4.1	4.6	4.6	5.7	4.1	5.3
	± 0.3	± 0.13	± 0.10	± 0.11	± 0.07	± 0.02	± 1.4
IFCM (mg/L)		0.50	0.05	0.05	0.07	0.12	0.15
		± 0.35	± 0.009	± 0.04	± 0.002	± 0.06	± 0.11
PFC (mg/L)			0.05	0.01	0.11	0.22	0.11
			± 0.004	± 0.002	± 0.067	± 0.012	± 0.095
EF (mg/L)	0.008	0.06	0.02	0.01	0.01	0.01	0.007
		± 0.046	± 0.007	± 0.001	± 0	± 0.004	± 0
RS (mg/Kg)	0.04	6.8	0.25	0.20	1.7	0.28	2.4
	± 0.04	± 1.4	± 0.06	± 0.12	± 0.77	± 0.03	± 0.30

*All values are on an as is basis.

Table 8c. Change in concentration (mg/L) of Sol P between each sampling point in the system as well as the over all percent change of Sol P in the system (IF to EF)

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF to IFCM		-3.6	-4.5	-4.6	-5.6	-4.0	-5.1
IFCM to EF	-21	-0.4					
IFCM to PCF			-0.01	-0.04	0.04	0.09	-0.04
PCF to EF			-0.03	-0.01	-0.10	-0.21	-0.10
Over All Rd	-21	-4.0	-4.6	-4.6	-5.7	-4.1	-5.3

% Change	-99.9	-98	-99.7	-99.9	-99.9	-99.8	-99.9

Total Kjeldahl Nitrogen

The overall average concentration of TKN in dairy lagoon effluent taken at the IF sampling point was observed to be only 3% lower than the average concentration found for TKN in Barker et al. (2001), placing it well within one standard deviation of the Barker et al. (2001) mean (Table A-1). This indicates that the lagoon used in the evaluation of the EC system was representative of other dairy lagoons with respect to TKN.

The stage in the system that affected the most reduction of TKN was variable from event to event (Table 9b and 9c). On the June 26th, July 12th and July 27th events the majority of TKN was removed from the system by chemical pretreatment. However, on the July 7th and July 19th events it was the centrifuge that caused the largest reduction. Moreover, on the August 2nd event it was the stage in the system where the EC unit was located that was the most efficient. The inconsistencies in the performance of the system's stages from event to event are most likely attributed to the changes in component configuration and chemical pretreatment.

Table 9a. Overall average concentration and average concentration for the last three sampling events of TKN for each sampling point in the system*

TKN	**O Avg**	**Mod Avg**
IF (mg/L)	564	535
IFCM (mg/L)	404	422
PCF (mg/L)	360	354
EF (mg/L)	277	234
RS (mg/Kg)	4211	3712

*All values are on an as is basis.

Table 9b. Average and standard deviations of TKN concentrations for each sampling point in the system*

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF (mg/L)	81	631	559	587	519	562	525
	± 0.7	± 49	± 50	± 8	± 13	± 6	± 5
IFCM (mg/L)		124	556	482	444	395	426
		± 38	± 7	± 71	± 48	± 64	± 60
PFC (mg/L)			344	395	328	379	356
			± 130	± 39	± 13	± 35	± 20
EF (mg/L)	5.6	308	355	297	280	272	149
		± 80	± 1.2	± 28	± 59	± 17	± 8
RS (mg/Kg)	165	6251	5316	2566	3120	3693	4322
	± 18	± 133	± 102	± 304	± 1020	± 31	± 167

*All values are on an as is basis

Table 9c. Change in concentration (mg/L) of TKN between each sampling point in the system as well as the over all percent change of TKN in the system (IF to EF)

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF to IFCM		-507	-3	-105	-76	-167	-99
IFCM to EF	-75	184					
IFCM to PCF			-212	-86	-116	-16	-70
PCF to EF			11	-99	-48	-106	-206
Over All Rd	-75	-323	-204	-290	-239	-289	-376

% Change	-93	-51	-37	-49	-46	-52	-72

Nitrate Nitrite-Nitrogen

Barker et al. (2001) reports an average NO_3N concentration of 0.05 mg/L in dairy lagoon sludge and 2.8 mg/L in lagoon supernatant. Presence of a much higher concentration of NO_3N in the supernatant than the sludge attests to the high solubility of NO_3N. Because the analyte NNN also includes Nitrate (NO_2) concentrations, Barker et al. (2001) concentrations cannot be used for comparison in the EC study.

On the July 7th, July 12th and the August 2nd sampling events the largest reduction of NNN in the system occurred as a result of chemical pretreatment. On the other sampling events the largest reductions occurred in the stage of the system where the EC unit was located, but only by a marginal amount. This irregularity in the performance of the system was most likely due to the change in the component configuration or the changes in chemical pretreatment.

Although the amount by which the NNN concentration was reduced by chemical pretreatment from event to event appears to be inconsistent, upon closer examination it becomes evident that reduction in concentration is proportional to the concentration of the IF per event. This indicates that the amount of NNN removed by the chemical pretreatment is dependent on the concentration in the IF.

Table 10a. Overall average concentration and average concentration for the last three sampling events of NNN for each sampling point in the system*

NNN	O Avg	Mod Avg
IF (mg/L)	0.18	0.16
IFCM (mg/L)	0.1	0.07
PCF (mg/L)	0.08	0.11
EF (mg/L)	0.04	0.03
RS (mg/Kg)	2.1	0.12

*All values are on an as is basis.

Table 10b. Average and standard deviations of NNN concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	1.7	0.18	0.29	0.13	0.09	0.25	0.14
	± 0.6	± 0.04	± 0.041	± 0.009	± 0.006	± 0.005	± 0.007
IFCM (mg/L)		0.14	0.12	0.04	0.04	0.13	0.05
		± 0.15	± 0.01	± 0.01	± 0.009	± 0.10	± 0.03
PFC (mg/L)			0.03	0.05	0.09	0.18	0.04
			± 0.003	± 0.014	± 0.018	± 0.096	± 0.02
EF (mg/L)	0.09	0.04	0.03	0.04	0.03	0.04	0.04
		± 0.007	± 0.020	± 0.005	± 0.002	± 0.004	± 0.007
RS (mg/Kg)	0.74	8.1	3.4	0.6	0.1	0.2	0.1
	± 0.37	± 3.6	± 1.5	± 0.02	± 0.06	± 0.14	± 0.10

*All values are on an as is basis.

Table 10c. Change in concentration (mg/L) of NNN between each sampling point in the system as well as the over all percent change of NNN in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-0.04	-0.17	-0.10	-0.05	-0.13	-0.08
IFCM to EF	-1.61	-0.10					
IFCM to PCF			-0.09	0.01	0.05	0.06	-0.01
PCF to EF			-0.0003	-0.01	-0.06	-0.15	-0.01
Over All Rd	-1.61	-0.13	-0.26	-0.10	-0.06	-0.22	-0.10

% Change	-95	-76	-89	-71	-67	-86	-73

Potassium

The average concentration of K in dairy lagoon effluent taken at the IF sampling point was observed to be approximately 28% higher than the average concentration of K provided by Barker et al. (2001), placing it well within one standard deviation of the mean provided by Barker et al. (2001) (Table A-1). This indicated that the lagoon used in the evaluation of the EC system is representative of other dairy lagoons with respect to K.

The stage in the system that affected the most reduction of K was variable from event to event (Table 11b and 11c). The performance of the chemical pretreatment varied from an increase of 39 mg/L to a reduction of 201 mg/L. This same type of variability was observed for each of the other two stages in the system as well.

The average K concentration observed in the supernatant from dairy lagoons provided by Barker et al. (2001) was 648 mg/L, which was 138 mg/L higher than the observed overall average concentration of K in the EF (Table 11a). Nevertheless, the EF concentration was still within one standard deviation of the mean given by Barker et al. (2001). On only two sampling events (July 19th and August 2nd) an overall percent reduction of better than 50% was achieved. It is very possible that a buildup concentration of K may occur in the dairy lagoon if the EF were to be used for flushing manure.

Table 11a. Overall average concentration and average concentration for the last three sampling events of K for each sampling point in the system*

K	O Avg	Mod Avg
IF (mg/L)	821	764
IFCM (mg/L)	738	736
PCF (mg/L)	690	659
EF (mg/L)	510	392
RS (mg/Kg)	2047	1426

*All values are on an as is basis.

Table 11b. Average and standard deviations of K concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	957	914	861	858	736	776	780
	± 25	± 10	± 12	± 10	± 0.7	± 23	± 2
IFCM (mg/L)		768	659	795	775	716	719
		± 201	± 115	± 21	± 0.7	± 5	± 6
PFC (mg/L)			750	721	655	674	649
			± 6	± 10	± 54	± 4	± 6
EF (mg/L)	12	565	752	569	255	624	296
		± 28	± 12	± 37	± 293	± 23	± 8
RS (mg/Kg)	79	2189	4071	1744	1165	1326	1785
	± 58	± 68	± 3195	± 1749	± 1229	± 26	± 21

*All values are on an as is basis.

Table 11c. Change in concentration (mg/L) of K between each sampling point in the system as well as the over all percent change of K in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-146	-201	-64	39	-61	-61
IFCM to EF	-945	-203					
IFCM to PCF			90	-74	-120	-42	-70
PCF to EF			2	-153	-400	-51	-353
Over All Rd	-945	-349	-109	-290	-480	-153	-484

% Change	-99	-38	-13	-34	-65	-20	-62

Metals

If any reductions of metal concentrations occurred between the IF and IFCM sampling points, it was not a result of lime addition. The positive metal ions would not be attracted to or bind with the metals analyzed in this study. Instead, reductions should be attributed to the addition of the anionic polymer in chemical pretreatment. The negative charge on this polymer would attract and bind the positive metal ions in the dairy lagoon effluent. It was observed that Ca, Fe, and Al were the only metals whose concentrations increased, albeit inconsistently, between IF and IFCM on each sampling event. For the remaining metals, both increases and decreases of varying magnitudes were observed. This is most likely due to changes in the chemicals used for pretreatment or irregularities in the amounts and rates at which they were added during the treatment process.

The overall percent change of these metals, with the exception of Mg and Fe, was highly inconsistent. Fe had an increase of very large magnitude on each sampling event due to the addition of iron ions from the surface of the electrodes in the EC unit. And, although the overall percent change gave the appearance of inconsistency. When compared with increases in Fe concentration observed between the PCF and IFCM sampling points, it can be seen that a fairly consistent increase in concentration occurred (with the exception of the first and last sampling event).

The component which removed the highest concentrations of all metals was the centrifuge. With the exception of sodium, the amount of metals removed from the liquid matrix was many times greater than the amount reduced by any other stage in the system. In the case of Na, reductions in concentration by the centrifuge were erratic. This was most likely due to its high solubility. For each of the other metals, however, the magnitude by which the centrifuge reduced their concentrations was quite consistent from event to event.

Calcium

The average concentration of Ca in dairy lagoon effluent taken at the IF sampling point was observed to be 21 mg/L higher than the value provided by Barker et al. (2001) for average Ca concentration of dairy lagoon supernatant (Table A-1). This suggests that the lagoon used for analysis of this EC system was representative of other dairy lagoons with respect to Ca.

As a result of addition of lime in chemical pretreatment, the very large spike in concentration from the IF to IFCM sampling points was expected (Table 12b and 12c). This increase in concentration was not consistent from event to event, which corroborates the observation from the field that there were difficulties in finding an optimal amount and rate at which to add chemical pretreatment.

The average Ca concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 230 mg/L which was slightly more than double the concentration of that observed in the EF of the EC system. This indicates that it might be possible to utilize the EF for flushing manure. However, since this technology has demonstrated that, in this case, it can only reduce the Ca concentration by about half. There could be a build up of Ca concentration in the lagoon over time if the EF were used to flush manure.

Table 12a. Overall average concentration and average concentration for the last three sampling events of Ca for each sampling point in the system*

Ca	O Avg	Mod Avg
IF (mg/L)	251	231
IFCM (mg/L)	1381	1387
PCF (mg/L)	191	192
EF (mg/L)	107	124
RS (mg/Kg)	27509	19798

*All values are on an as is basis.

Table 12b. Average and standard deviations of Ca concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	274	296	265	256	237	228	227
	± 18	± 9	± 3	± 6	± 0	± 6	± 4
IFCM (mg/L)		701	1383	2040	1540	1685	937
		± 712	± 220	± 283	± 382	± 530	± 217
PFC (mg/L)			207	175	158	235	183
			± 18	± 109	± 18	± 56	± 18
EF (mg/L)	82	32	153	87	106	188	77
		± 3	± 4	± 10	± 11	± 30	± 8
RS (mg/Kg)	1173	46818	39002	19839	21888	20639	16868
	± 1804	± 3493	± 1761	± 4440	± 30019	± 1390	± 1296

*All values are on an as is basis.

Table 12c. Change in concentration (mg/L) of Ca between each sampling point in the system as well as the over all percent change of Ca in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		405	1118	1784	1303	1458	710
IFCM to EF	-192	-668					
IFCM to PCF			-1177	-1865	-1383	-1451	-754
PCF to EF			-54	-88	-51	-47	-106
Over All Rd	-192	-263	-112	-169	-131	-40	-150

% Change	-70	-89	-42	-66	-55	-17	-66

Magnesium

The average concentration of Mg in dairy lagoon effluent taken at the IF sampling point was observed to be 50 mg/L higher than the value provided by Barker et al. (2001) for average Mg concentration of dairy lagoon supernatant, putting the observed concentration of Mg in the IF well within the limits of one standard deviation that Barker et al. (2001) reports (Table A-1). This implies that the lagoon used for the analysis of this EC system was representative of other dairy lagoons with respect to Mg.

The average Mg concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 154 mg/L which is slightly higher than the observed overall average concentration of the EF (Table 13a). Because this EC system did not substantially reduce the concentration of Mg, it is possible that a buildup of Mg concentration could occur over time.

Table 13a. Overall average concentration and average concentration for the last three sampling events of Mg for each sampling point in the system*

Mg	**O Avg**	**Mod Avg**
IF (mg/L)	204	183
IFCM (mg/L)	182	198
PCF (mg/L)	113	121
EF (mg/L)	88	84
RS (mg/Kg)	2035	1514

*All values are on an as is basis.

Table 13b. Average and standard deviations of Mg concentrations for each sampling point in the system*

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF (mg/L)	208	238	219	218	185	182	184
	± 8	± 6	± 3	± 4	± 0.71	± 6	± 0.71
IFCM (mg/L)		148	176	172	195	218	182
		± 88	± 28	± 5	± 23	± 22	± 8
PFC (mg/L)			119	80	107	130	128
			± 3	± 17	± 4	± 1.4	± 8
EF (mg/L)	34	97	105	74	80	105	68
		± 6	± 1.4	± 4	± 9	± 2	± 3
RS (mg/Kg)	92	3552	2671	1446	1489	1636	1418
	± 84	± 287	± 391	± 471	± 1712	± 84	± 89

*All values are on an as is basis.

Table 13c. Change in concentration (mg/L) of Mg between each sampling point in the system as well as the over all percent change of Mg in the system (IF to EF)

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF to IFCM		-89	-43	-46	11	36	-2
IFCM to EF	-174	-51					
IFCM to PCF			-57	-92	-89	-88	-54
PCF to EF			-14	-6	-27	-26	-59
Over All Rd	-174	-140	-114	-143	-105	-78	-115

% Change	-84	-59	-52	-66	-57	-43	-63

Sodium

The average concentration of Na in dairy lagoon effluent taken at the IF sampling point was observed to be 53 mg/L higher than the value provided by Barker et al. (2001) for average Na concentration of dairy lagoon supernatant (Table A-1). This small difference places the observed overall average concentration of Na well within the limits of one standard deviation reported in Barker et al. (2001). It also indicates that the lagoon used for the analysis of this EC system was representative of other dairy lagoons with respect to Na.

The average Na concentration observed in supernatant from dairy lagoons used in the Barker et al. (2001) study was198 mg/L which was slightly lower than the observed overall average concentration of the EF (Table 14a). This indicates that it might be possible to utilize the EF for flushing manure, with respect to Na concentrations. Because this EC system did not substantially reduce the concentration of Na, it is possible that a buildup in its concentration would occur over time.

Table 14a. Overall average concentration and average concentration for the last three sampling events of Na for each sampling point in the system*

Na	**O Avg**	**Mod Avg**
IF (mg/L)	251	210
IFCM (mg/L)	259	252
PCF (mg/L)	235	204
EF (mg/L)	206	171
RS (mg/Kg)	2397	3790

*All values are on an as is basis.

Table 14b. Average and standard deviations of Na concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	357	324	285	268	214	212	205
	± 14	± 40	± 7	± 6	± 0	± 5	± 2
IFCM (mg/L)		305	204	289	268	241	247
		± 54	± 31	± 16	± 4	± 30	± 46
PFC (mg/L)			297	265	205	205	201
			± 21	± 6	± 7	± 4	± 6
EF (mg/L)	40	225	304	196	179	203	131
		± 13	± 8	± 9	± 16	± 5	± 10
RS (mg/Kg)	37	755	1545	713	10361	441	568
	± 11	± 34	± 1343	± 774	± 13618	± 30	± 19

*All values are on an as is basis.

Table 14c. Change in concentration (mg/L) of Na between each sampling point in the system as well as the over all percent change of Na in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-19	-81	21	54	29	43
IFCM to EF	-317	-80					
IFCM to PCF			93	-24	-63	-36	-46
PCF to EF			7	-70	-26	-2	-71
Over All Rd	-317	-99	19	-73	-35	-9	-74
% Change	-89	-31	7	-27	-16	-4	-36

Manganese

The overall average concentration of Mn in dairy lagoon effluent taken at the IF sampling point was observed to be 1.06 mg/L which was just at one standard deviation of the average concentration of Mn in lagoon supernatant provided by Barker et al. (2001). This suggests that the lagoon used for the analysis of this EC system was not quite representative of other dairy lagoons with respect to Mn. However, since Mn is not the focus of our study, this should not affect the outcome of this study.

The average Mn concentration observed in the supernatant from dairy lagoons found in Barker et al. (2001) was 4.9 mg/L that was much higher than the observed overall average concentration of the EF (Table 15a). This indicates that it might be possible to utilize the EF for flushing the milking parlor or free stalls without resulting in a build up of Mn in the dairy lagoon over time.

Table 15a. Overall average concentration and average concentration for the last three sampling events of Mn for each sampling point in the system*

Mn	**O Avg**	**Mod Avg**
IF (mg/L)	1.06	0.96
IFCM (mg/L)	1.3	1.4
PCF (mg/L)	0.11	0.17
EF (mg/L)	0.80	0.70
RS (mg/Kg)	31	26

*All values are on an as is basis.

Table 15b. Average and standard deviations of Mn concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	1.5	1.2	1.1	1.2	0.8	0.99	1.1
	± 0.09	± 0.02	± 0.04	± 0.02	± 0.13	± 0.01	± 0.005
IFCM (mg/L)		0.8	1.3	1.1	1.2	1.9	1.2
		± 0.86	± 0.22	± 0.33	± 0.41	± 0.23	± 0.19
PFC (mg/L)			0.04	0.02	0.06	0.28	0.16
			± 0.002	± 0.02	± 0.06	± 0.23	± 0.06
EF (mg/L)	1	0.2	1.3	1.2	0.4	1.2	0.4
		± 0.02	± 0.02	± 0.19	± 0.63	± 0.24	± 0.08
RS (mg/Kg)	2.4	59	37	15	23	26	27
	± 0.8	± 1.9	± 4.0	± 4.1	± 18	± 1.9	± 0.392

*All values are on an as is basis.

Table 15c. Change in concentration (mg/L) of Mn between each sampling point in the system as well as the over all percent change of Mn in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-0.4	0.2	-0.1	0.3	0.9	0.1
IFCM to EF	-0.5	-0.6					
IFCM to PCF			-1.3	-1.0	-1.1	-1.6	-1.0
PCF to EF			1.3	1.1	0.4	0.9	0.3
Over All Rd	-0.5	-1.0	0.2	-0.04	-0.4	0.2	-0.6

% Change	-35	-83	20	-3	-45	24	-60

Iron

The average concentration of Fe in the dairy lagoon effluent taken at the IF sampling point was observed to be 46 mg/L lower than the value provided by Barker et al. (2001) for average Fe concentration of dairy lagoon supernatant, placing the observed Fe concentration well within the very large standard deviation given in Barker et al. (2001) (Table A-1). This implies that Fe typically varies widely from lagoon to lagoon and that this lagoon was generally representative of others with respect to Fe concentrations

The overall average of Fe in the EF was 60 mg/L (Table 16a). This is approximately 10 mg/L higher than the average concentration provided by Barker et al. (2001). In as much, the observed concentration of Fe was much lower than the maximum observed by Barker et al. (2001) of 207 mg/L. This indicates that the use of the EF for flushing manure from the milking parlor or free stalls is a viable option with respect to Fe concentrations. Because this EC system did not substantially reduce the concentration of Fe, it is possible that a buildup in its concentration would occur over time.

Table 16a. Overall average concentration and average concentration for the last three sampling events of Fe for each sampling point in the system*

Fe	O Avg	Mod Avg
IF (mg/L)	3.7	3.5
IFCM (mg/L)	15	20
PCF (mg/L)	1.0	1.6
EF (mg/L)	60	59
RS (mg/Kg)	521	606

*All values are on an as is basis.

Table 16b. Average and standard deviations of Fe concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	6.4	4.5	3.8	3.4	3.7	3.6	3.3
	± 0.09	± 0.25	± 0.11	± 0.08	± 0.01	± 0.09	± 0.05
IFCM (mg/L)		9	15	9	16	28	15
		± 9.6	± 3.3	± 4.0	± 5.3	± 3.2	± 0.1
PFC (mg/L)			0.03	0.1	0.7	2.7	1.3
			± 0.0	± 0.1	± 0.7	± 2.9	± 1.4
EF (mg/L)	2.3	6	82	94	71	86	21
		± 2	± 3	± 20	± 14	± 25	± 3
RS (mg/Kg)	118	672	451	186	697	553	567
	± 77	± 29	± 26	± 67	± 376	± 97	± 25

*All values are on an as is basis.

Table 16c. Change in concentration (mg/L) of Fe between each sampling point in the system as well as the over all percent change of Fe in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		4.8	11	6	12	24	12
IFCM to EF	-4.1	-3.6					
IFCM to PCF			-15	-9	-15	-25	-14
PCF to EF			82	94	70	83	20
Over All Rd	-4.1	1.2	78	90	67	82	18

% Change	-65	28	2052	2627	1798	2270	552

Copper

The average concentration of Cu in dairy lagoon effluent taken at the IF sampling point was observed to be approximately the same as the value provided by Barker et al. (2001) for average Cu concentration of dairy lagoon supernatant. This indicates that the lagoon used for the analysis of this EC system was representative of other dairy lagoons with respect to Cu.

The average Cu concentration observed in supernatant from dairy lagoons used in the Barker et al. (2001) study was 1.1 mg/L, which was approximately four times greater than the overall average Cu concentration observed for the EF (Table 17a). This shows that it might be possible to utilize the EF; however, there is the possibility that build up of Cu in the lagoon would occur over a very long period of time.

Table 17a. Overall average concentration and average concentration for the last three sampling events of Cu for each sampling point in the system*

Cu	**O Avg**	**Mod Avg**
IF (mg/L)	1.07	0.97
IFCM (mg/L)	1.0	1.12
PCF (mg/L)	0.17	0.25
EF (mg/L)	0.28	0.47
RS (mg/Kg)	26	22

*All values are on an as is basis.

Table 17b. Average and standard deviations of Cu concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (mg/L)	2.24	1.21	1.16	1.16	0.93	0.92	1.1
	± 0.09	± 0.04	± 0.00	± 0.04	± 0.07	± 0.03	± 0.008
IFCM (mg/L)		0.7	1.3	0.8	1.2	1.5	0.7
		± 0.61	± 0.29	± 0.30	± 0.36	± 0.15	± 0.20
PFC (mg/L)			0.08	0.01	0.13	0.31	0.31
			± 0.04	± 0.006	± 0.09	± 0.3	± 0.14
EF (mg/L)	0.05	0.09	0.12	0.05	1.05	0.15	0.20
		± 0.04	± 0.01	± 0	± 1.4	± 0.01	± 0.007
RS (mg/Kg)	3.4	39	33	15	29	19	19
	± 0.6	± 1.4	± 2.8	± 3.7	± 3.5	± 0.4	± 0.3

*All values are on an as is basis.

Table 17c. Change in concentration (mg/L) of Cu between each sampling point in the system as well as the over all percent change of Cu in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		-0.51	0.19	-0.32	0.23	0.55	-0.35
IFCM to EF	-2.19	-0.61					
IFCM to PCF			-1.27	-0.82	-1.03	-1.16	-0.41
PCF to EF			0.04	0.04	0.93	-0.16	-0.11
Over All Rd	-2.19	-1.12	-1.04	-1.11	0.13	-0.77	-0.87

% Change	-98	-92	-90	-96	14	-84	-81

Aluminum

The study by Barker et. al. (2001) does not provide data on the concentration of Al in the supernatant of dairy lagoons. Because of this, it cannot be determined if the lagoon used in EC system study is representative of other Central Texas dairy lagoons with respect to Al concentrations.

Without comparable information, it cannot be determined if use of the EF to flush manure would cause a build up of Al over time. According to both Bennett (1993) and Mortvedt et al. (1991), excessive quantities of Al can be toxic especially in acidic soils. However, neither text gives a threshold level for the toxicity of Al to crop plants.

Table 18a. Overall average concentration and average concentration for the last three sampling events of Al for each sampling point in the system*

Al	**O Avg**	**Mod Avg**
IF (mg/L)	1.9	1.8
IFCM (mg/L)	194	172
PCF (mg/L)	14	19
EF (mg/L)	9.38	9.36
RS (mg/Kg)	5593	6137

*All values are on an as is basis.

Table 18b. Average and standard deviations of Al concentrations for each sampling point in the system*

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF (mg/L)	2.0	2.2	1.8	1.7	1.8	2.5	1.3
	± 0.1	± 0.3	± 0.1	± 0.3	± 0.0	± 0.1	± 0.1
IFCM (mg/L)		75	300	274	242	160	115
		± 67	± 43	± 172	± 69	± 1	± 24
PFC (mg/L)			5	8	11	32	13
			± 0.3	± 0.4	± 6	± 36	± 15
EF (mg/L)	2.5	2	23	3	10	16	2
		± 1.3	± 3.8	± 0.8	± 7.6	± 0.1	± 2.8
RS (mg/Kg)	1305	4451	7158	3537	9615	4732	4064
	± 521	± 353	± 2654	± 1939	± 4045	± 360	± 582

*All values are on an as is basis

Table 18c. Change in concentration (mg/L) of Al between each sampling point in the system as well as the over all percent change of Al in the system (IF to EF)

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF to IFCM		73	298	272	240	157	114
IFCM to EF	0.5	-73					
IFCM to PCF			-295	-266	-231	-127	-102
PCF to EF			18	-5	-1.3	-17	-11
Over All Rd	0.5	-0.09	21	1.4	8	13	1.2

% Change	-25	-4	1185	84	456	538	89

pH

The average pH of dairy lagoon supernatant found in Barker et al. (2001) was 7.5 (± 0.27). This places the overall average pH of the IF barely within one standard deviation above the mean provided by Barker et al. (2001). This indicates that this particular dairy lagoon is representative of other lagoons with respect to pH.

It is possible that the increase in pH observed between the IF and IFCM sampling points (Table 19b and 19c) and the decrease in pH after the effluent stream goes through the centrifuge is due to solids buffering the probe used to measure pH. The increase in pH in the stage where the EC unit is located is most likely due to the addition of OH^- ions as the cathodes reduce in the EC reactor.

According to Bennett (1993), both Al and Mn have the potential to become toxic in acidic soils; Mn especially in soils with a pH lower than 5. However, the application of EF to cropland should not detrimentally affect the pH of soil as it is considered to be a neutral pH.

Table 19a. Overall average and average for the last three sampling events of pH level for each sampling point in the system*

pH	O Avg	Mod Avg
IF	7.83	7.83
IFCM	8.1	7.80
PCF	7.81	7.87
EF	8.04	7.94
RS	8.1	8.03

*All values are on an as is basis.

Table 19b. Average and standard deviations of pH concentrations for each sampling point in the system*

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF	8.09	7.8	7.8	7.9	7.8	7.8	7.9
	± 0.02	± 0.01	± 0.03	± 0.03	± 0.01	± 0.03	± 0.01
IFCM		8.8	8.1	8.2	7.7	7.9	7.8
		± 0.06	± 0.01	± 0.93	± 0.00	± 0.45	± 0.08
PFC			7.6	7.9	8.2	7.7	7.7
			± 0.04	± 0.42	± 0.56	± 0.10	± 0.23
EF	6.9	8.3	8.0	8.1	8.0	7.8	8.1
		± 0.03	± 0.03	± 0.04	± 0.02	± 0.04	± 0.01
RS	6.9	8.5	8.0	8.4	8.1	7.9	8.1
	± 0.22	± 0.11	± 0.12	± 0.36	± 0.23	± 0.007	± 0.007

*All values are on an as is basis.

Table 19c. Change in pH between each sampling point in the system as well as the over all percent change of pH in the system (IF to EF)

Date	8-Jun	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM		1.0	0.2	0.3	-0.1	0.1	-0.1
IFCM to EF	-1.19	-0.5					
IFCM to PCF			-0.5	-0.3	0.5	-0.2	-0.1
PCF to EF			0.5	0.2	-0.2	0.1	0.3
Over All Rd	-1.19	0.5	0.2	0.3	0.1	0.0	0.2

% Change	-15	7	2	3	2	0	2

Conductivity

The overall average conductivity of dairy lagoon effluent observed in this study was 3.4 standard deviations above the mean provided by Barker et al. (2001). This is quite unexpected because none of the metals or solids analyzed was comparatively higher than their corresponding mean. This implies that the lagoon used in the analysis of the EC system is not representative of other lagoons with respect to conductivity level.

The addition of chemical pretreatment caused a reduction of conductivity (Tables 20b and 20c). Possibility because of solids, causing a buffering effect to the probe, coagulate and precipitate out of the liquid matrix at this stage in the system. It is also possible that some of the solids removed were salts. The removal of these salts would cause a drop in conductivity.

With the exception of the sampling event on July 19th, an increase in the conductivity level was observed as a result of the centrifuge. This could be a parallel occurrence to the one observed for TDS at this stage in the system. It is possible that the force of liquid spinning in the centrifuge caused solids to dissolve (especially electrolytes which are highly soluble) resulting in an increase in conductivity.

Large, yet inconsistent, increases in conductivity were observed due to the stage in the system where the EC unit was located. That the largest decrease in conductivity occurred at this stage of the system is particularly perplexing because there were no other large reductions of analytes which would have bearing on the conductivity level.

Table 20a. Overall average and average for the last three sampling events of Cond level for each sampling point in the system*

Cond.	**O Avg**	**Mod Avg**
IF (µS/cm)	6683	6923
IFCM (µS/cm)	6218	6141
PCF (µS/cm)	6355	6557
EF (µS/cm)	4750	4995

*All values are on an as is basis.

Table 20b. Average and standard deviations of Cond concentrations for each sampling point in the system*

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF (µS/cm)		7605	7200	6685	6810	6610	6630
		± 361	± 212	± 106	± 42	± 42	± 14
IFCM (µS/cm)				5910	6650	5945	6060
				± 467	± 42	± 403	± 14
PFC (µS/cm)			7070	6650	6180	6470	6415
			± 14	± 382	± 580	± 127	± 247
EF (µS/cm)	0.09	5173	5715	4830	5195	5675	3380
		± 70	± 304	± 212	± 559	± 134	± 71
RS (µS/cm)		7605	7200	6685	6810	6610	6630
		± 361	± 212	± 106	± 42	± 42	± 14

*All values are on an as is basis

Table 20c. Change in con between each sampling point in the system as well as the over all percent change of conductivity in the system (IF to EF)

Date	**8-Jun**	**27-Jun**	**7-Jul**	**12-Jul**	**19-Jul**	**26-Jul**	**2-Aug**
IF to IFCM				-775	-160	-665	-570
IFCM to EF			-130				
IFCM to PCF				740	-470	525	355
PCF to EF			-1355	-1820	-985	-795	-3035
Over All Rd		-2432	-1485	-1855	-1615	-935	-3250

% Change	N/A	32	21	28	24	14	49

Utilization of Effluent

According to the toxicity thresholds provided by Bennett (1993) (Table A-3), all of the analyte concentrations in the effluent from the EC system are below toxic levels to crop plants. This indicates that land application of the EF to meet the water needs of crop plants is a viable option.

Residual Solids (Tables 2-18)

Of all of the analytes included in this study, only the overall average concentrations of Ca and Cu exceeded the sufficient level as provided by Bennett (1993) in Table A-3. Of these two constituents, only Cu can be toxic at the observed overall average. The Cu level found in the RS of this study was only 6 mg/kg above the toxicity threshold provided in Table A-3. Most likely all of the Cu will not be immediately available to the plant, so applying the RS to land should not be detrimental to the crop. Also, according to the EPA’s 503 biosolids rule (1994) the maximum allowable concentration of Cu for land application of a biosolid is 4300 mg/kg. Deferring to this regulation, it does not appear that the application of the RS from the EC system will be damaging to the environment.

CONCLUSIONS

Due to the designation of the two upper North Bosque River segments as impaired from nonpoint source (NPS) pollution of phosphorus in the watershed, action must be taken towards the reduction of P from sources such as dairy lagoon effluent applied to the waste application fields. The best management practices currently in use are not sufficient to bring about the needed reductions; therefore, many new technologies are being researched.

- The results from all sampling events showed that this system was effective in reducing both TP and Sol P
    - but the section where the EC unit was located (PCF to EF) contributed only marginally to this success.
- It is uncertain whether or not these results could be duplicated at a dairy operation with a lagoon whose Sol P concentration is close to the average given by Barker et al. (2001).
- Without the inclusion of a centrifuge (not originally described in the proposal submitted by the technology provider), this system would not have succeeded in achieving the goals set-forth for the North Bosque River Watershed.

FUTURE RESEARCH

The effect that different chemicals had on the EC system was apparent through the varying performance from sampling event to sampling event. Repeating this study with a system configuration and pretreatment that does not change will be beneficial in determining if this technology is truly effective.

Also, repeat samplings at a lagoon with a more representative total phosphorus and soluble phosphorus concentration would be recommended. This would better establish whether or not the large reduction in these analytes observed in the analysis of the EC system could be reproduced at other dairy operations.

EVALUATION OF THE GEOTUBE® DEWATERING SYSTEM

INTRODUCTION

Water quality degradation due to phosphorus (P) nonpoint source pollution from effluent and manure applied to waste application fields (WAF) is a major concern in the Bosque River watershed. In 1998 two upper North Bosque River segments were designated as impaired on the Texas Clean Water Act, Section 303(d) list (TNRCC, 2001). This designation was the result of nutrient loading and aquatic plant growth in those segments. Changes in the status of the Bosque River segments prompted the Texas Commission on Environmental Quality (TCEQ) to apply a Total Maximum Daily Loads (TMDLs) for P to those designated segments. In December 2002, the Texas Commission on Environmental Quality approved the implementation plan of these two TMDLs, and they were approved by the Texas State Soil and Water Conservation Board in January 2003. These TMDLs call for a reduction of the annual loading and annual average concentration of soluble reactive P (SRP) by about 50%.

The United States Environmental Protection Agency (EPA) has cited pollution from nonpoint source agricultural operations (by way of runoff) as the main source of contamination to water bodies. Reducing P from dairy effluent applied to WAF is vital to protecting many of these water bodies.

Runoff from WAFs is not regulated because it is regarded as a nonpoint source. Currently, a number of dairy operations in the Bosque river watersheds are using best management practices (BMPs) to remove P and SRP from the wastewater. However, to meet the goals of these TMDLs new, more effective and efficient BMPs will need to be adopted by these dairies. Two prospective BMPs that could remove pollutants from the effluent being stored and treated in dairy lagoons are an electrocoagulation system and a geotextile dewatering system.

The Geotube® dewatering system was introduced for evaluation by the Miratech Division of Ten Cate Nicolon and General Chemical Corporation. This system uses a chemical pre-treatment to coagulate solids from the lagoon effluent. The mixture is then pumped into two large geotextile filtration tubes that lay on an impervious polyvinyl sheet. On one end (opposite to the influent end in Figure 4) of each tube a felt-type fabric was laid to reduce potential soil erosion from the dewatered effluent flowing off of the polyvinyl sheet. The synthetic fabric acts as a filter when the liquid is pumped into the tube, and a high percentage of the solids are retained as the liquid weeps from pores in the fabric. After the tubes are filled with the liquid-solid mixture to a height of approximately 5’, the pumping of effluent ceases and the tubes are left to dewater for several months. After they are sufficiently dewatered, the residuals are disposed of off-site. The dewatering system, comprised of two 14’ X 50’ tubes was set-up to treat effluent from the primary lagoon of a 2000-head lactating cow open-lot dairy in the Leon River watershed (which is adjacent to the Bosque River watershed). Manure from the milking parlor at this dairy was flushed into the primary lagoon. Effluent from this lagoon was conveyed to a secondary lagoon where it was recycled for flushing the parlor and irrigating hay and cropland at the dairy operation.

METHODOLOGY

Facilities

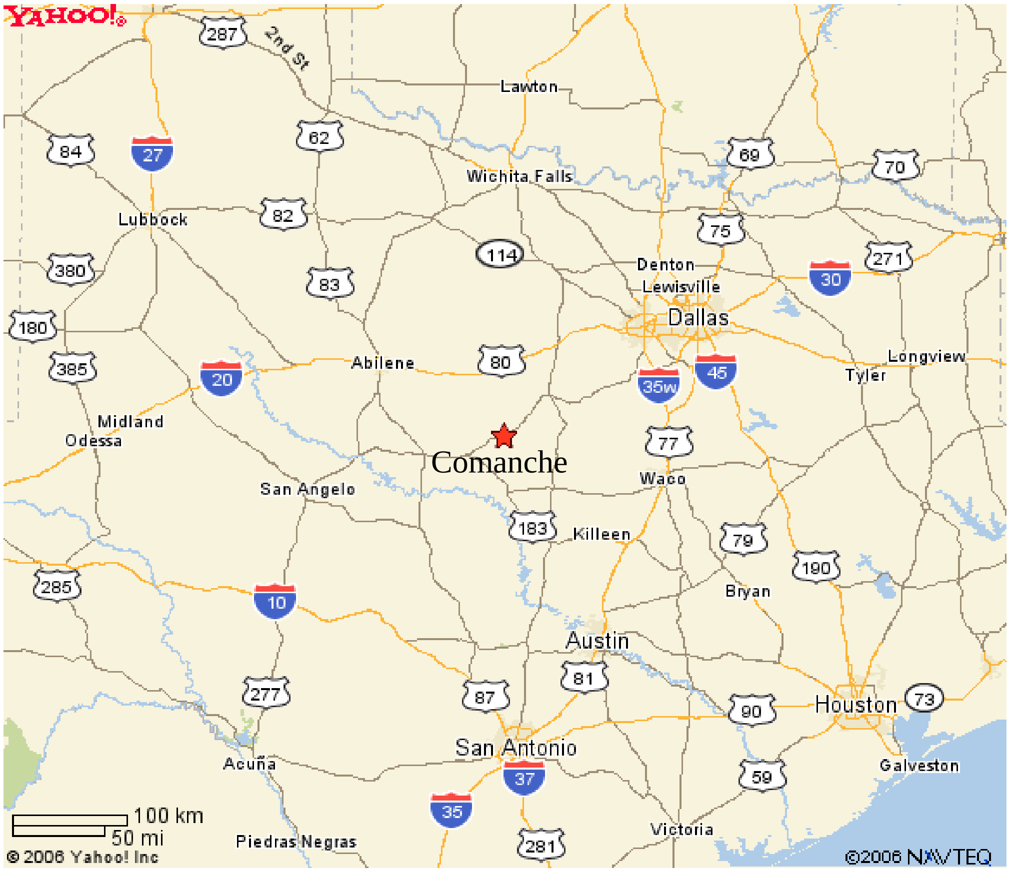


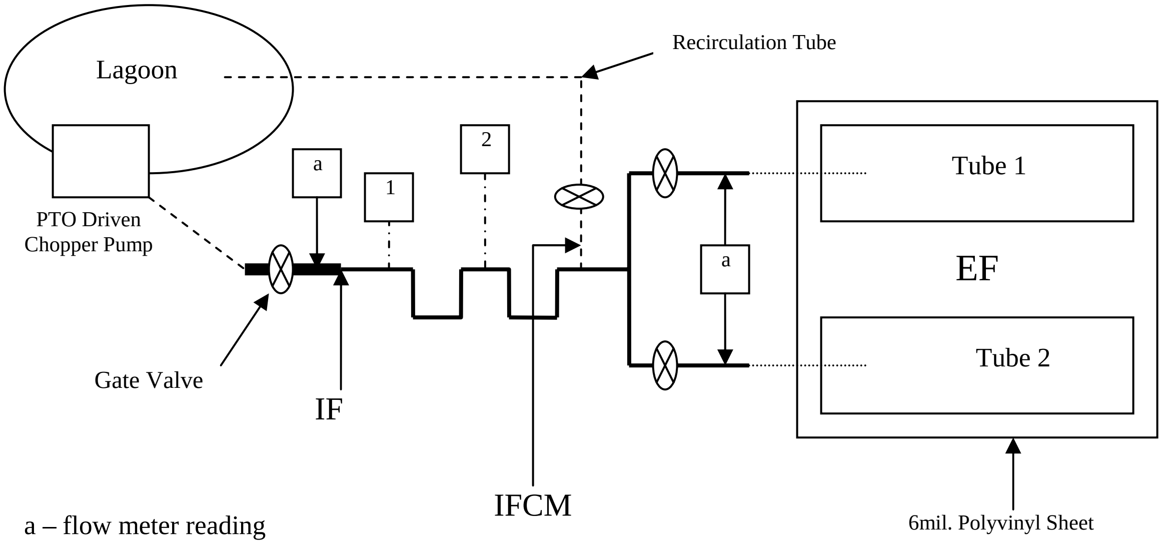
Figure 6. Location of Comanche, TX (Yahoo! Maps, 2006b)

The dewatering system was setup to treat the effluent from the primary lagoon of a 2000-head lactating cow open-lot dairy in Comanche, TX (Figure 1) located within the Leon River watershed (adjacent to the Bosque River watershed). Manure from the milking parlor at this dairy was flushed into the primary lagoon. Effluent from this lagoon was conveyed to a secondary lagoon where it was recycled for flushing the parlor and irrigating hay and cropland at the dairy operation.

GT System Configuration

For the sampling events on March 30, 2005, and April 6, 2005, the system's configuration was as follows (Figure 2):

- The lagoon was agitated using a PTO-driven chopper pump for a minimum of 2 hours prior to pumping a well mixed raw effluent to the tubes.
- Effluent from the lagoon was pumped at approximately 400 gpm into a 6" schedule 40 PVC pipe via a 6" reinforced vinyl fire hose. A total of 186,000 and 182,000 gallons of raw lagoon effluent was pumped into tube 1 and tube 2 for the two sampling events, respectively (volumes were estimated from the flow rate measurements).
- The pipe reduced from a 6" schedule 40 PVC to a 4" schedule 40 PVC.
- Alum and then a cationic polymer were injected as a chemical pre-treatment into the pipe as the liquid flowed through a series of 90° elbows that served to mix the liquid with the pre-treatment.
- The pipe then divides in two, one pipe going to tube one and the other pipe going to tube two, each filling their respective tubes with chemically treated effluent via a 4" reinforced vinyl fire hose.



a – flow meter reading

1 – Injection of alum

2 – Injection of polymer

Figure 7. Schematic of the Geotube® dewatering system components (not to scale)

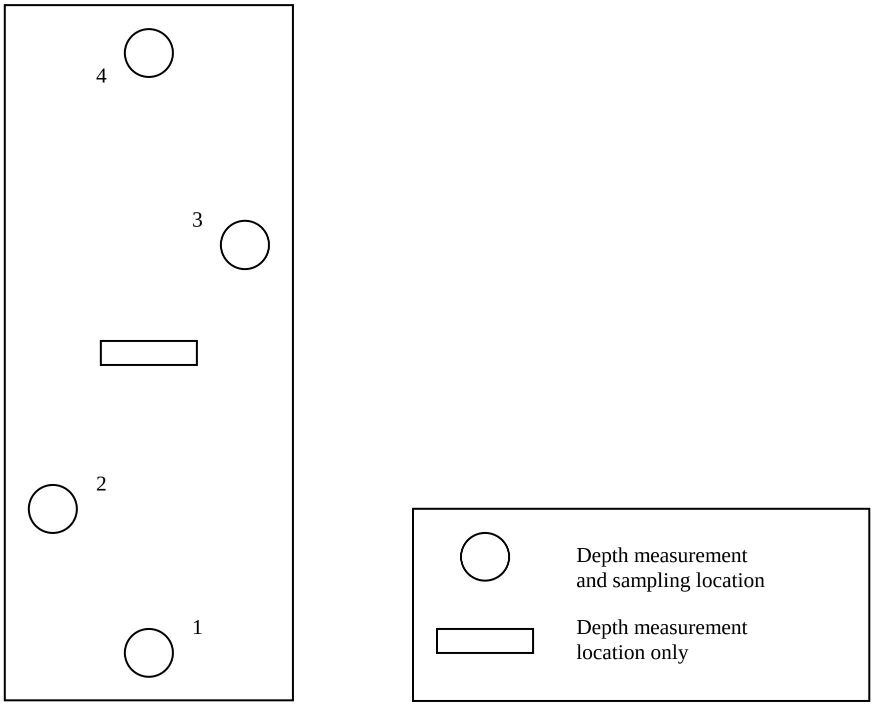


Figure 8. Location of residual samples (RS) and depth measurements for tubes 1 and 2.

Experimental Plan

Ten sets of 15 (250 mL) grab samples were taken at each of the sampling events of March 30 and April 6, 2005. However, on the second sampling event there was only enough effluent weeping from tube 2 to take two instead of three sets of effluent samples. Each set of 15 grab samples were mixed in the laboratory and analyzed as one composite sample. Additionally, four samples each from tubes 1 and 2 were randomly taken on October 3, after both tubes had dewatered for six months. These residual solids (RS) were taken from the entire profile after the tubes had dewatered. The sampling methods for influent, effluent, residual solids, and flow rates are as follows:

- Two sets of effluent from the lagoon being pumped into the system were taken from a port in the 4” PVC pipe. This was called influent (IF). (Figure 2).
- Two sets of the liquid mixture were taken from a port in the 4” PVC pipe after the chemical pretreatment of lagoon effluent. This was called influent with chemical (IFCM). (Figure 2).
- Six sets (three from tube 1 and three from tube 2) of effluent weeping from the tubes were taken by placing the bottles under the edge of the tube to catch the effluent (EF) (Figure 2).
- Measurements of residual solids depth were taken at each of the four RS sampling locations in each tube as well as a depth measurement taken in the center of each tube (Figure 3). Each sample was mixed thoroughly in a plastic bucket and a portion of this sample was put into a freezer bag.
- Samples were put on ice and transported to the TiAER laboratory at Tarleton State University within a few hours of each sampling event for analysis
- Flow rate measurements into tube 1 and tube 2 were made with a Greyline PDFM 4 Doppler flow meter at approximately half hour intervals for the duration of the system’s operation (Figure 2)

Analysis of the Samples

Samples treated as solids were extracted or acid digested into aqueous form before analysis for the all of the analytes. All of the liquid samples were analyzed using the following methods:

- Total Solids (TS) were measured using a gravimetric oven drying method (SM 2540C). The sample was dried in an oven and the residuals were weighed to determine the amount of TS.
- Total Volatile Solids (TVS) (EPA 160.4) were found gravimetrically using a muffle furnace. The sample was first weighed, then ashed and then weighed again. The difference in weight indicated the solids that volatilized during the oven drying process.
- Total Fixed Solids (TFS) were determined by subtracting the concentration of TVS from TS.
- Total Suspended Solids (TSS) (EPA 160.2). The sample was poured over a glass fiber filter that was then dried to a constant weight at 103°-105° C. The amount of TSS was determined to be the difference in weight of the dried filter to the clean filter.

- Total Dissolved Solids (TDS) were determined by subtracting the concentration of TSS from the concentration of TS.
- Soluble Phosphorus (Sol P) (EPA 365.2) was determined by direct colorimetry on filtered samples. Ammonium molybdate and antimony potassium tartrate were added to an acid medium along with a dilute solution of the phosphorus to be tested. The orthophosphates reacted with these chemicals to form a blue colored complex. The intensity of the blue color was proportional to the amount of phosphorus.
- Nitrate/Nitrite-Nitrogen (NNN) (EPA 353.2) was filtered then nitrate was reduced to nitrite using granulated copper-cadmium, NNN was then determined colorimetrically.
- Total Phosphorus (TP) (EPA 365.4) was digested using a sulfuric acid, cupric acid and potassium sulfate solution then determined colorimetrically.
- Total Kjeldahl Nitrogen (TKN, EPA 351.2) was digested using a sulfuric acid, cupric acid and potassium sulfate solution then determined colorimetrically
- Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn), Copper (Cu), Iron (Fe), and Aluminum (Al) were determined using elemental analysis by inductively coupled plasma (EPA 200.7) (APHA, 2005; USEPA, 1983).
- Electrical conductivity (Cond) was determined using a YSI® 3200 conductivity meter
- Potential Hydrogen was determined using a Accument® AB15 Plus pH meter

RESULTS AND DISCUSSION

In the following section, results for each analyte are reported using the following abbreviations (See Figures 2 and 3 for locations where the samples were taken):

- IF – Influent, the lagoon effluent pumped into the treatment system
- IFCM – Influent (lagoon effluent) with chemical pretreatment
- EF – Effluent (Water weeping from the tube)
- RS – Residual Solids (solids taken from the dewatered tubes)

Calculations

- Once the raw data were received from the lab, concentrations of samples treated as solids (IF, IFCM, and RS) were converted from mg/kg dry to mg/L as-is using their respective percent total solids values for each sample.
- Averages and standard deviations of IF concentrations and IFCM concentrations were calculated for both sampling events.
- Pooled averages and standard deviations of EF concentrations using both tubes were calculated for both sampling events.
- From the RS samples taken on 3-Oct, pooled averages and standard deviations were calculated using concentrations from both tubes.
- Percent change in concentration for each week were calculated using the following equation:
    - {(IFavg-EFavg)/(IFavg)}*100 (Eq. 1)
- Where IFavg and EFavg are average concentrations of analytes in influent and effluent, respectively and calculated from all IF and EF composite samples analyzed for tubes 1 and 2.

Table 21. Average concentration and percent change (%Cng) of solids and pH.*

	30-Mar				**6-Apr**			
	TS (%)	TVS (%)	TFS (%)	pH	TS (%)	TVS (%)	TFS (%)	pH
IF	**6.01**	**3.45**	**2.71**	**7.85**	**6.08**	**3.23**	**2.86**	**7.52**
	± 0.03	± 0.21	± 0.03	± 0.13	± 0.05	± 0.06	± 0.01	± 0.01
IFCM	**6.87**	**3.38**	**3.34**	**7.65**	**6.64**	**3.23**	**2.91**	**7.38**
	± 0.30	± 0.12	± 0.21	± 0.04	± 0.63	± 0.01	± 0.07	± 0.30
EF	**0.36**	**0.08**	**0.28**	**7.18**	**0.45**	**0.10**	**0.34**	**7.39**
	± 0.36	± 0.08	± 0.28	± 0.18	± 0.10	± 0.02	± 0.09	± 0.17

%Cng	-94	-98	-90	-8	-93	-97	-88	-2

	03-Oct			
	TS (%)	TVS (%)	TFS (%)	pH
RS	**26.7**	**11.8**	**14.9**	**7.3**
	± 1.4	± 0.6	± 0.9	± 0.3

*****all values are reported on an as-is basis

Table 22. Average concentrations and percent change (%Cng) of nutrients.*

	30-Mar				
	Sol P (mg/L)	TP (mg/L)	TKN (mg/L)	NNN (mg/L)	K (mg/L)
IF	41.7	337	2031	0.44	560
	4.2	4.8	9.6	0.02	31
IFCM	18.3	326	2094	0.30	592
	2.7	31	102	0.06	17
EF	4.9	10	308	0.06	295
	1.6	4.7	16	0.02	5.6

% Cng	88	97	85	87	47
	6-Apr				
	Sol P (mg/L)	TP (mg/L)	TKN (mg/L)	NNN (mg/L)	K (mg/L)
IF	43.4	333	1992	0.77	603
	3.7	13	130	0.01	2.0
IFCM	23.2	317.00	1899	0.26	557
	27.7	0.18	11	0.18	23
EF	8.4	14	337	0.34	372.0
	3.0	5.0	7.8	0.36	3.0

% Cng	81	96	83	62	38
	3-Oct				
	Sol P (mg/L)	TP (mg/L)	TKN (mg/L)	NNN (mg/L)	K (mg/L)
RS	4.1	2469	5232	213	1219
	1.1	109	356	94	135

*****all values are reported on an as-is basis

Table 23. Average concentrations and percent change (%Cng) of metals.*

30-Mar

	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)
IF	**3261**	**384**	**200**	**21**	**184**	**6.03**
	± 88	± 7.1	± 2.5	± 0.52	± 8.5	± 0.11
IFCM	**3754**	**430**	**197**	**23**	**246**	**6.29**
	± 98	± 2.8	± 11	± 0.32	± 18	± 0.49
EF	**301**	**132**	**143**	**1.40**	**1.9**	**0.03**
	± 49	± 2.0	± 6.8	± 0.32	± 1.7	± 0.06
%Cng	-91	-66	-29	-93	-99	-99

6-Apr

	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)
IF	**3466**	**410**	**210**	**22**	**217**	**5.73**
	± 15	± 1.2	± 8.2	± 0.17	± 9.5	± 0.10
IFCM	**3304**	**382**	**206**	**20**	**179**	**5.42**
	± 107	± 13	± 2.2	± 0.69	± 7.9	± 0.26
EF	**282**	**191**	**222**	**0.99**	**0.66**	**0.01**
	± 34	± 48	± 53	± 0.21	± 0.23	± 0.01
%Cng	-92	-54	5	-95	-99	-99

3-Oct

	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)
RS	**16532**	**1346**	**298**	**81**	**1118**	**33**
	± 1986	± 123	± 31	± 8.9	± 122	± 3.1

*****all values are reported on an as-is basis

Table 24: Average conductivity*

	30-Mar (μS/cm)	6-Apr (μS/cm)
	Cond.	Cond.
EF	5347	6300
	±140	±806

*****all values are reported on an as-is basis

Table 25: Average total suspended solids and total dissolved solids*

	30-Mar		**6-Apr**	
	TSS (%)	TDS (%)	TSS (%)	TDS (%)
EF	0.36	0.31	0.45	0.43
	0.05	0.03	0.10	0.11

*****all values are reported on an as-is basis

Mass Balance

The mass of dairy lagoon effluent pumped into the tubes for both sampling events was determined by first calculating the volume of the effluent from the flow meter measurements taken at each event. The average specific gravity (found from the samples sent to the lab) of the influent samples was used to find the density of influent to be 948 kg/m^3. From the density and volumes found, the mass of dairy lagoon effluent pumped into the system for both tubes on both sampling events were found. The mass of residual solids was determined by estimating the volume of the solids remaining in the tubes from length, width and height measurements taken on the 3-Oct sampling event (Figure 3). The RS samples were not analyzed for specific gravity, so density could not be found empirically. In the Worley et al. (2004) study, it was found that the density of the influent and the density of the residual solids in the Geotube only differed by 4 kg/m^3, so for our analysis we used the influent density (948 kg/m^3) to calculate the mass of the solids remaining in the tubes. The mass of the effluent from each tube was found by subtracting the mass of the residuals from the mass of the influent pumped into each tube. The total (tube 1 + tube 2) masses of IF, RS and EF were subsequently used to determine the masses of each analyte they contained (Table 26). Separation efficiencies (S.E.) (Eq. 2), mass balance (M.B.) (Eq. 3) and mass balance error (M.B.E.) (Eq. 4) were then calculated as (Table 26):

Eq. 2: $\text{S.E.} = [(IF_m - EF_m) / IF_m]*100$

Eq. 3: $\text{M.B.} = IF_m - EF_m - RS_m$

Eq. 4: $\text{M.B.E.} = (\text{M.B.} / IF_m) * 100$

IF_m is the mass of an analyte from the total dairy lagoon effluent pumped into both tubes on March 30th and April 6th. EF_m is the mass of an analyte in the total amount of effluent from the tubes on March 30th and April 6th. RS_m is the mass of an analyte in the total amount of residual solids remaining in the tubes on October 3rd.

Table 26. Average mass of solids, nutrients and metals from IF, EF and RS of tubes 1 and 2, and separation efficiencies (S.E), mass balance (M.B.), and mass balance error (M.B.E.).

		Solids (kg)			**Nutrients (kg)**				
Parameter		**TS**	**TVS**	**TFS**	**Sol P**	**TP**	**TKN**	**NNN**	**K**
3-Mar	**IF**	13737	7885	6194	9.5	77	464	0.10	128
		± 64	± 145	± 16	± 0.96	± 1.1	± 2.2	0.004	± 7.1
6-Apr	**IF**	2845	1510	1337	2.03	16	93	0.04	28
		± 23	± 30	± 3.3	± 0.17	± 0.6	± 6.1	0.0003	± 0.09
3-Oct	**RST1**	5003	2218	2784	0.08	24	96	4.4	22
		± 82	± 41	± 93	± 0.02	± 1.3	± 2.2	± 3	± 1.1
3-Oct	**RST2**	4870	2144	2726	0.1	24	97	4	23
		± 193	± 95	± 106	± 0.03	± 1.8	± 4.1	± 1	± 1.2
	EFT1	476	114	380	0.6	1.14	42	0.04	42
		± 149	± 10	± 115	± 0.23	± 0.23	± 2.2	± 0.02	± 9.96
	EFT2	399.9	99	302.7	0.81	1.76	42	0.01	39
		± 48	± 14	± 33	± 0.44	± 0.68	± 2.6	± 0.01	± 2.1
	S.E.	95	97	91	88	97	85	65	48
	M.B.	5833	4820	1338	10	43	281	-8	30
	M.B.E.	35	51	18	87	46	50	-5757	19

Table 26 (cont): Average mass of solids, nutrients and metals from IF, EF and RS of tubes 1 and 2, and separation efficiencies (S.E), mass balance (M.B.), and mass balance error (M.B.E.).

Parameter		**Metals (kg)**					
		Ca	**Mg**	**Na**	**Mn**	**Fe**	**Cu**
3-Mar	**IF**	745	87.7	46	4.7	42	1.4
		± 20.0	± 1.6	± 0.56	± 0.12	± 1.9	± 0.02
6-Apr	**IF**	162	19	10	1.02	10	0.27
		± 0.71	± 0.06	± 0.38	± 0.01	± 0.44	± 0.004
3-Oct	**RST1**	310	25	5.29	1.46	20	0.60
		± 53.8	± 2.0	± 0.4	± 0.2	±1.4	± 0.04
3-Oct	**RST2**	302	25	6	1.52	21	0.63
		± 11.2	± 1.3	± 0.06	± 0.09	± 1.2	± 0.01
	EFT1	37	20	21	0.2	0.1	0.0004
		± 3.2	± 7.1	± 9.1	± 0.03	± 0.03	± 0.0
	EFT2	43	18	20	0.20	0.30	0.006
		± 6.6	± 0.85	± 2.1	± 0.05	± 0.19	± 0.01
	S.E.	91	65	26	94	99	100
	M.B.	216	20	3.6	2.4	11	0.4
	M.B.E.	24	18	6	42	20	25

Concentrations of all analytes in the influent (IF) were consistent between the two sampling events (Tables 21-25). There were only small variations in concentrations of an analyte between the two events. This indicated that the chopper pump effectively mixed the effluent in the lagoon as it was pumped into the system for both events. However, average concentrations of solids, nutrients and metals in EF varied substantially from one sampling event to the other. Therefore, it is possible that amounts of these analytes in EF fluctuated as the tubes continued to dewater for 6 months after the second pumping event in April 6th. Hence, the results should be considered a snapshot of the performance of this system at the time of the sampling events.

Separation efficiencies (Table 26) found for all analytes were similar to the values for percent reductions shown in Tables 21-25 Separation efficiencies for the solids were very high; this, in conjunction with the high percent reductions observed for these solids, indicates that the Geotube® dewatering system was highly effective in separating solids from the dairy lagoon effluent. Overall, high separation efficiencies indicate that the Geotubes were successful in reducing most nutrients and metals in EF.

Solids

It was observed that the average from both pumping events of total solids in the lagoon effluent was 6% (Table 21). As mentioned in the previous discussion on solids in the EC system, anaerobic lagoon sludge contains on average 7.3% total solids (± 4.6%), while the supernatant contains 0.52% of total solids (± 0.29%) (Barker et al., 2001). Observed total solids values in this study were closer to the total solids concentrations in the sludge rather than the supernatant indicates the chopper pump was effective in mixing the lagoon sludge and supernatant well. This indicated that the lagoon was a good representation of other lagoons in use on other dairy operations with respect to solids concentrations.

The TVS concentrations in IF were on average 55% of the total solids (Table 21). This ratio dropped dramatically in the EF where TVS only comprised 22% of the total solids (Table 21). Also, after 6 months of dewatering, TVS concentrations in the residual solids were lower than TFS. These drastic declines in TVS concentration were due to the loss of these solids in EF or their volatilization from the tubes to the atmosphere. A small increase in the concentrations was seen from IF to IFCM for only TS and TFS. This increase was expected due to the addition of solids from chemical pre-treatment.

The percent reduction of TS from the lagoon effluent by the Geotube® system was very high, about 94%, at both the May 30th and April 6th sampling events (Table 21). This result differed only slightly from the Worley et al. (2004) and Baker et al (2002) studies that observed separation efficiencies for TS of 97% and 87%, respectively. Thus the results achieved by this study accurately represent the performance of a Geotube® dewatering system when applied to an anaerobic dairy lagoon. The large reductions in solids concentrations observed in this study demonstrate the effectiveness of the Geotube® as a filter. This is reinforced by the separation efficiencies found for both TS and TFS which are strikingly similar to the percent reductions observed for these two analytes (Table 21).

Since samples taken from the IF and IFCM sampling points were treated as solids, they were not analyzed for TSS or TDS. Mukhtar et al. (2004) (Table A-2) did not provide data on these analytes in their study either. However, Barker et al. (2001) reported that in the supernatant of an anaerobic dairy lagoon the average concentration of TSS was 0.16%, which is approximately half of TSS concentration observed in this study. This indicates that the geotextile fabric used in the tubes may not be as effective in filtering out TSS as it is with TS.

Barker et al. (2001) did find that in the supernatant of an anaerobic dairy lagoon the average concentration of TSS was 0.16%, which was much lower than the 0.45% observed in the EF from the tubes. The concentration of TSS observed in the EF from the tubes was well outside one standard deviation above the mean and even higher than the maximum concentration observed for TSS in the Barker et al. (2001) study. This indicated utilization of the EF for flushing manure would most likely cause a build up of TSS over time. It might also be possible that this would accelerate the rate at which storage capacity was lost as excess TSS settled out.

Nutrients

Phosphorus

The average concentration of TP in dairy lagoon effluent observed in this study was lower than the average found in Mukhtar et al. (2004). However, the concentration of TP was still well within one standard deviation of the mean. Again, indicating this lagoon was representative of other Central Texas dairy lagoons with respect to TP concentrations.

A very small reduction in average TP concentration between the IF and IFCM sampling points was observed. Comparing TP concentration between the IF and IFCM sampling points to the observed reductions of Sol P (OPO4-P) between those same points, reductions of TP and Sol P are similar (TP dropped an average of 14 mg/L per event and Sol P dropped an average of 22 mg/L per event). This may indicate that the only portion of TP immobilized by the addition of alum was Sol P. The reduction of Sol P from IF to IFCM was attributed to addition of alum during chemical pre-treatment. The positively charged aluminum ions (given off when the alum is added to the liquid) bind to the negatively charged OPO4-P (Sol P) rendering most of it insoluble (Zhang and Lei, 1998). The AL(OH)3 flocs which are formed when the metal ions of Al react with the hydroxyl ions in the wastewater also aid in coagulation because of their large surface area (Olmstead and Williams, 1997; Zhang and Lei, 1998).

The overall reduction of P concentrations for both Sol P and TP was very high at 84.5% and 96.5%, respectively (averaged between both events). The majority of this reduction occurred between the IFCM and EF sampling points. This, along with the reductions of TP and Sol P observed between the IF and IFCM, show that the chemicals added in pretreatment were binding a large portion of the available forms of P and the Geotubes® were effectively retaining these analytes. The Worley et al. (2004) study achieved a 79% separation efficiency. In comparison with the separation efficiency of 97% observed in this study, it appears that using a coagulant does make a difference in the effectiveness of this system with respect to capturing P.

A very large mass balance error of approximately 87% was observed for Sol P. This is most likely due to Sol P binding to the alum, it is then no longer a soluble form of P and would not appear as such in the tests performed on the residual solids. The same applies to the mass balance error seen for TP with respect to the amount of its concentration comprised from soluble forms. The exact amount of alum injected to the system on each sampling event is not known, making it impossible to determine the efficiency of the chemical pretreatment at immobilizing soluble forms of P.

The average TP concentration observed in supernatant from dairy lagoons used in the Barker et al. (2001) study was 144 mg/L which is much higher than the average observed concentration observed in the EF from the Geotubes® in this study (Table 22). This indicates that the EF from the Geotube® system could be used to flush the milking parlor and lanes with respect to P. Because the concentrations of TP in the EF are much lower than those found in dairy lagoon supernatant, recycling the EF should not cause P levels in the lagoon to grow unreasonably. Typically, dairy lagoons are not agitated when liquid is pulled off for application to fields. Because of this, TP concentrations observed in the EF (Table 22) were 82% lower than those found in Barker et al. (2001). This shows that the Geotube® dewatering system has the potential to aid in meeting the TMDLs which call for a reduction of Sol P and TP by 50%. The same is true for Sol P, Barker et al. (2001) shows that the average concentration of Sol P in the supernatant is 115.5 mg/L which is drastically higher than the Sol P concentrations found in the EF from the Geotubes®.

Total Kjeldahl Nitrogen

The average concentration of TKN in dairy lagoon effluent taken at the IF sampling point was observed to be approximately 120 mg/L higher than the average concentration found for TKN in the study done by Mukhtar et al. (2004). However, the average TKN concentration was still well within the standard deviation provided by Mukhtar et al. (2004), indicating that this lagoon was representative of other Central Texas dairy lagoons with respect to TKN.

The behavior of TKN concentrations was inconsistent between the May 30th event and the April 6th event. On the first event, there was a 63 mg/L increase in the average TKN concentration between the IF and IFCM sampling points. However, on the second event, there was a 93 mg/L decrease in the average concentration between these two sampling points. The increase of TKN on the first event was within one standard deviation of the mean of the average concentration at the IFCM sampling point and the decrease on the second event fell within one standard deviation of the average concentration at the IF sampling point. This indicated that the increases and decreases might not have actually occurred and could be explained by the size of the standard deviations. This could only have been determined by having more repetition of pumping events to obtain a more representative average. Inconsistencies in performance like this may be due to difficulties experienced in maintaining a constant flow rate when the gate valves cyclically clogged with solids, then were opened all the way to flush out the clog. The resultant rise and fall in flowrate may have effected the concentrations observed at the IFCM sampling point.

The average (of the May 30th and April 6th) overall percent reduction observed for TKN was fairly high, 84.5%. This percent reduction closely corresponds to the separation efficiency of approximately 85% found from the mass balance for TKN (Table 26). This shows that the Geotube® dewatering system analyzed in this study performed very efficiently with the coagulation and reduction of TKN from the dairy lagoon effluent. The Worley et al. (2004) study achieved an 80% separation efficiency. Comparison to the separation efficiency of 85% observed in this study, it appears that using a coagulant might make a difference in the effectiveness of this system with respect to capturing TKN. Future research should be conducted to make any definite conclusions as to whether a coagulant would help to capture more TKN in the system.

The average TKN concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 582 mg/L which is 45% the concentration of TKN observed in the EF from the Geotubes®. Because of this, the EF from the Geotubes has the potential to be recycled for use in flushing manure. This difference in concentration between lagoon supernatant and the EF would also be beneficial for the EF being applied to fields to help meet the water needs of crops, especially during times of rainfall deficit. In this case, more EF from Geotubes® could be applied than could lagoon supernatant before creating an excess of nutrients not needed by the crop.

Nitrate Nitrite Nitrogen

Barker et al. (2001) reports an average NO_3N concentration of 0.05 mg/L in dairy lagoon sludge and 2.8 mg/L in the lagoon supernatant. The higher concentration of NO_3N in the supernatant than the sludge attests to the high solubility of NO_3N. Because the analyte NNN also includes concentrations of Nitrates (NO_2), the Barker et al. (2001) concentrations cannot be used for comparison in the EC study.

Although the concentrations in the IF were small, substantial reductions in concentrations of NNN were observed both between the IF and IFCM sampling points and the IFCM and EF sampling points on both events (Table 22). These reductions are probably not due to lab error in the analysis of NNN because the range created by the standard deviations about the mean concentrations found at the IF and IFCM sampling point did not overlap on either sampling event. The reduction observed between IF and IFCM shows that the aluminum ions, from the addition of alum were attracting and binding some of the nitrogen as well as the phosphorus, while the reductions seen between IFCM and EF indicate that the Geotubes® were effectively functioning as a filter in retaining the bound and NNN within the coagulated solids.

The overall average concentration of NNN observed in the EF (0.2 mg/L) was much lower than the concentration observed in the supernatant from the Barker et al. (2001) study. The substantially lower concentration found in the EF indicates that it could be recycled for use in flushing the milking parlor or free stalls without seeing a rapid build up in NNN concentrations in the lagoon.

Potassium

The average concentration of K in the dairy lagoon effluent taken at the IF sampling point was observed to be approximately 300 mg/L lower than one standard deviation away from the average K concentration found in Mukhtar et al. (2004). This is definitely a significant difference and implies that this lagoon was not representative of other Central Texas lagoons with respect to K. However, since the performance of the geotube® dewatering system with respect to P is the main focus of this project and not K, this anomaly in concentrations will not hinder the results and conclusions of this study.

As was the case for TKN, the behavior of K concentrations of IF and IFCM sampling points was inconsistent between the May 30th and the April 6th sampling events. On the first event, there was a 32 mg/L increase in concentration from the IF to IFCM sampling points. On the April 6th event, there was a 46 mg/L reduction in concentration from the IF to IFCM sampling points. However, unlike the instance with TKN, the reduction observed on the second sampling event cannot be discounted because the ranges (created by the standard deviations) around the averages for IF and IFCM do not overlap. This reduction is unprecedented due to the fact that both alum and K ions are positively charged. It would be unexpected to find that the alum in the chemical pretreatment is responsible for the reductions seen between the IF and IFCM sampling points. However, if the polymer that was also added as a part of the chemical pretreatment to aid in coagulation was anionic, it may be the cause of the observed reduction. Unfortunately, it is not know whether this polymer was anionic or cationic so this cannot be determined.

The average (of the May 30th and April 6th) overall percent reduction observed for K was moderate, 42.5%. This percent reduction corresponds well to the separation efficiency of approximately 48% found from the mass balance for K (Table 26). The Worley et al. (2004) study achieved a 36% separation efficiency. In comparison with the separation efficiency observed in this study, it appears that using a coagulant might possibly make a slight difference in the effectiveness of this system with respect to capturing K. Future research should be conducted in order to make any definite conclusions as to whether a coagulant does help to capture more K in the system.

The average K concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 648 mg/L which was approximately double the concentration observed in the EF from the tubes. This indicates that the use of the EF for flushing manure is a viable option. Over long periods of time there is a possibility that a buildup of K in the lagoon would occur.

Metals

The purpose of analyzing the concentration of metals at all sampling points in the system was to determine if any were being added at toxic levels. In order to determine the viability of recycling the EF from the geotubes® (with respect to metal concentrations) the average observed values of EF for Ca, Mg, Na, Mn, Fe, and Cu from this study are compared to the average concentrations found in the Barker et al. (2001) in Table A-1.

There were no appreciable reductions observed in any of the concentrations of metals due to the addition of alum in the chemical pretreatment. This was expected since the positive metal ions would not be attracted to the positively charged molecules of alum. However, it was observed that some of the metals were reduced by large amounts. This was the result of the effective coagulation of solids and the fact that these geotubes® functioned as very effective filters as evidenced by the high percent reductions and separation efficiencies observed for solids (Tables 21 and 26). It was observed that all metals, with the exception of Na and Mg, had percent reductions of 90% or higher (Table 23). These reductions are corroborated by the equally high separation efficiencies found from the mass balance for these metals (Table 26). In the case of Mg, a moderately high percent reduction and separations efficiency (both approximately 65%) was observed. However, Na had very low reductions (Tables 23), possibly due to its extremely high solubility that would allow it to escape from the tube dissolved in the EF.

Calcium

The average concentration of Ca in the dairy lagoon effluent taken at the IF sampling point was observed to be much higher than the average found in Mukhtar et al. (2004), almost outside one standard deviation above the mean. However, it can be surmised from the very large standard deviation observed in the Mukhtar et al. (2004) study that Ca concentration varies greatly between dairy lagoons. Because of this large variation, there does not seem to be a “representative” lagoon with respect to Ca concentrations.

The average Ca concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 230 mg/L which is approximately 60 mg/L lower than the overall average concentration in the EF. If the EF were to be used for flushing manure, there would possibly be a build up of Ca in the dairy lagoon over a very long period of time.

Magnesium

The average concentration of Mg in the dairy lagoon effluent taken at the IF sampling point was observed to be extremely close to the average Mg concentration found in Mukhtar et al. (2004), differing by only 3 mg/L. This indicates that the dairy lagoon used in the study on the geotube® dewatering system is a representative lagoon of others in Central Texas with respect to Mn concentrations.

The average Mg concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 69.7 mg/L which is much lower than the value observed in the EF from the geotubes® of 162 mg/L. If the EF from the geotubes® was recycled for use in flushing the milking parlor or free stalls, it is possible that a substantial increase in Mg concentration would occur over time.

Sodium

The average concentration of Na in the dairy lagoon effluent taken at the IF sampling point was observed to be lower than one standard deviation of the mean Na concentration found in Mukhtar et al. (2004) by approximately 34 mg/L. While this may not seem like a very large difference, the standard deviation for Na was 30% of the mean. So, an average falling 34 mg/L below one standard deviation can be considered unrepresentative. However, since Na is not the focus of this study this should not drastically impact the results.

The average Na concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 90 mg/L that is approximately half of the concentration observed in the EF (Table 23). If the EF from the geotubes® was recycled for use in flushing the milking parlor or free stalls, it is possible that a substantial increase in Na concentration would occur over time.

Manganese

The average concentration of Mn in the dairy lagoon effluent taken at the IF sampling point was observed to be 4.5 mg/L above the average Mn concentration found in the study by Mukhtar et al (2004). The concentration of Mn observed at the IF sampling point was within one standard deviation of the mean provided in Mukhtar et al. (2004) indicating that this lagoon is representative of other Central Texas dairy lagoons with respect to Mn concentrations.

The average Mn concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 2.2 mg/L, which is approximately twice the average concentration of Mn observed in the EF. This indicates that using the EF to flush manure would cause an eventual build up of Mn concentration in the lagoon. However, it would take some time before the concentrations reached levels toxic to crop plants, approximately 300 mg/L (assuming that all Mn would be immediately available to the crop). So with respect to Mn, care should be taken when considering the use of EF to flush the milking parlor or free stalls.

Iron

The average concentration of Fe in the dairy lagoon effluent taken at the IF sampling point was observed to be extremely high (12.5 standard deviations) above the average concentration observed by Mukhtar et al. (2004). Although this lagoon may not be representative of other Central Texas dairy lagoons, FE is not the focus of this study. So the fact that the Fe concentration seems to be an anomaly should not affect the results.

The average Fe concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 22 mg/L, which is much larger than the average concentration of 1.3 mg/L observed in the EF. This indicates that utilizing the EF to flush manure is a viable option with respect to Fe.

Copper

The average concentration of Cu in the dairy lagoon effluent taken at the IF sampling point was observed to be only 0.5 mg/L lower than the average found by Mukhtar et al. (2004). A very large standard deviation of Cu concentrations observed by Mukhtar et al. (2004) in combination with the very slight difference in Cu concentrations between the two studies indicates that this lagoon is representative of other Central Texas dairy lagoons with respect to Cu.

The average Cu concentration observed in the supernatant from dairy lagoons used in the Barker et al. (2001) study was 0.44 mg/L, which is 22 times higher than the average concentration of Cu observed in the EF. This indicates that the use of EF to flush manure is a viable option with respect to Cu.

Aluminum

The IF, IFCM and EF samples taken on the May 30th and April 6th events were not analyzed for Al and the study by Mukhtar et. al. (2004) does not provide an average concentration of Al for the Central Texas lagoons in their study, nor does the study by

Barker et. al. (2001). Because of this, it cannot be determined if the lagoon used in the Geotube® dewatering study is representative of other Central Texas dairy lagoons with respect to Al concentrations. It also cannot be determined if the use of the EF to flush manure would cause a build up in the concentration of Al over time.

pH

The average pH found in Mukhtar et al. (2004) (Table A-2) was 7.48 with a very tight standard deviation of ±0.28. The average overall pH observed from the IF samples was 7.69 which is close to one standard deviation away from the value presented in the Mukhtar et al. (2004) study, but still within its limits. This indicates that the dairy lagoon used in the Geotube® study is representative of other dairy lagoons in Central Texas with respect to pH.

The decreases in pH observed between both the IF and IFCM sampling points and the IFCM and EF sampling points is most likely due to the coagulation and removal of solids which could cause a buffering effect around the probe used to measure pH.

According to Bennett (1993), both Al and Mn have the potential to become toxic in acidic soils, especially Mn in soils with a pH lower than 5. However, the application of EF to cropland should not detrimentally affect the pH of the soil as it is considered a neutral pH.

Conductivity

Because samples of the dairy lagoon effluent were treated as solids, the conductivity level was not determined. For comparison purposes, the average lagoon conductivity value, of 7324 µS/cm, from Mukhtar et al. (2004) will be used. The conductivity level observed in the EF was 5824 µS/cm, which if this were a representative lagoon, would mean that there was an average overall percent reduction in the conductivity level of approximately 20%. It is not surprising that this low percent reduction is roughly the same as the reduction seen for Na on the May 30th event since conductivity is an indication of salt concentrations. So, similar percent reductions of both Na and conductivity levels is not unprecedented.

Utilization of Effluent

According to the toxicity thresholds provided by Bennett (1993) (Table A-3), all of the analyte concentrations in the effluent from the Geotubes are below toxic levels to crop plants. This indicates that land application of the EF to meet the water needs of crop plants is a viable option.

Residual Solids

It can be seen for all of the analytes that there was a spike in the concentration from the IF to the RS that was proportionately large to the concentration of the analyte in the dairy lagoon effluent (Tables 21, 22, and 23). When compared with the mass balance, it confirms that for all of the analytes (with the exception of Na), a vast majority of the mass comprised of solids was retained in the tubes. This exhibited that the geotubes® functioned efficiently and effectively as filters.

When comparing the concentrations in the RS from tables 21, 22 and 23 with the toxicity concentrations in Table A-3 it can be seen that the observed concentration of Cu in the RS was the only analyte found to be in the “toxic range”. However, it is uncertain what amount of any one of the analytes in the RS is immediately plant available or at what rate it would be made available. Most likely they are not all initially plant available. Because of this, the RS has the potential to be used as a land application and would not necessarily need to be disposed of in a land fill. Also, according to the EPA's 503 biosolids rule (1994) the maximum allowable concentration of Cu for land application of a biosolid is 4300 mg/kg. Deffering to this regulation, it does not appear that the application of the RS from the Geotube® will be damaging to the environment.

Economics

Economic information for this Geotube® Dewatering was furnished by Ed Puck from EnviroWaste, who was present at some of the sampling events and represented the technology provider. The following estimates for treating the primary lagoon effluent at this dairy with a Geotube® Dewatering System.

It was estimated that ten 45' x 232' Geotubes will be used in conjunction with 15,000 gallons of alum and 600 gallons of Cytec #1883 or Cytec #4512 polymer to treat an estimated 1.9 million gallons of effluent from this lagoon. He reported that:

"Estimated costs could be about $90,000 to dewater and contain 15+ year old nutrients in the Geotubes from the retention lagoon. If consideration is allowed for costs per year, the real costs amount to less than $10,000 per year, or less than $5 per cow!"

CONCLUSIONS

In contrast, the Geotube® dewatering system was highly effective in reducing P from dairy lagoon effluent. Achieving reductions that were well above the goal of 50% reduction (for phosphorus) set by the TMDLs. This system was also successful in filtering TS from the lagoon effluent with a 95% separation efficiency.

Although, this system was successful with respect to the removal of P, solids, and other constituents in the raw lagoon effluent, this was not an optimized system. The technology provider had difficulty in determining the appropriate quantities of alum and polymer for pretreatment of raw effluent. Maintaining a constant flow rate was also an issue. Because gate valves were used to control flow, solids in the lagoon clogged the valves over time, steadily reducing the flow of effluent to the tubes. As a result, the valves had to be frequently readjusted for the desired flow rate.

The Geotube® system was effective in removing P and other constituents from the dairy lagoon effluent; however, it must be optimized to be implemented as a best management practice for animal waste pollution control.

FUTURE RESEARCH

The effect that different chemicals had on the EC system was apparent through the varying performance from sampling event to sampling event. More sampling of this system while using different chemicals with many replications would aid in understanding how they bear on the efficacy of the system.

Also, repeat samplings at a lagoon with a more representative total phosphorus and soluble phosphorus concentration would be recommended. This would better establish whether or not the large reduction in these analytes observed in the analysis of the EC system could be reproduced at other dairy operations.

Due to circumstances beyond our control, more sampling events could not be had for the Geotube® dewatering system. Repeating these sampling events, both at this lagoon and at others, would aid in establishing a standard to which the performance of a Geotube® dewatering system could be compared.

In addition, replicating these tests at lagoons, whose effluent does not need a coagulant, using a control set and a set of tubes treated with chemicals would aid in determining the degree to which these chemical coagulants enhance the performance of the Geotube® dewatering system.

SUMMARY

Due to the designation of the two upper North Bosque River segments as impaired from nonpoint source (NPS) pollution of phosphorus in the watershed, action must be taken towards the reduction of P from sources such as dairy lagoon effluent applied to the waste application fields. The best management practices currently in use are not sufficient to bring about the needed reductions; therefore, many new technologies are being researched.

- The results from all sampling events showed that this system was effective in reducing both TP and Sol P
    - but the section where the EC unit was located (PCF to EF) contributed only marginally to this success.
- It is uncertain whether or not these results could be duplicated at a dairy operation with a lagoon whose Sol P concentration is close to the average given by Barker et al. (2001).

Without the inclusion of a centrifuge (not originally described in the proposal submitted by the technology provider), this system would not have succeeded in achieving the goals set-forth for the North Bosque River Watershed.

In contrast, the Geotube® dewatering system was highly effective in reducing P from dairy lagoon effluent. Achieving reductions that were well above the goal of 50% reduction (for phosphorus) set by the TMDLs. This system was also successful in filtering TS from the lagoon effluent with a 95% separation efficiency.

Although, this system was successful with respect to the removal of P, solids, and other constituents in the raw lagoon effluent, this was not an optimized system. The technology provider had difficulty in determining the appropriate quantities of alum and polymer for pretreatment of raw effluent. Maintaining a constant flow rate was also an issue. Because gate valves were used to control flow, solids in the lagoon clogged the valves over time, steadily reducing the flow of effluent to the tubes. As a result, the valves had to be frequently readjusted for the desired flow rate.

The Geotube® system was effective in removing P and other constituents from the dairy lagoon effluent; however, it must be optimized to be implemented as a best management practice for animal waste pollution control.

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APPENDIX A

REFERENCE TABLES

Table A-1. Average concentrations and standard deviations for dairy lagoon sludge and supernatant provided by Barker et al. (2001)

	Supernatant		Sludge	
	Avg.	SD	Avg.	SD
TS (%)	0.52	0.29	7.3	4.6
TSS (%)	0.16	0.12	4.2	0.43
TVS (%)	0.27	0.05	N/A	N/A
TKN (mg/L)	582	309	2276	1042
TP (mg/L)	144	100	2197	1726
Sol P (mg/L)	115	14	1318	335
K (mg/L)	648	401	926	725
Ca (mg/L)	230	176	2156	1557
Cu (mg/L)	1.1	0.75	55	44
Fe (mg/L)	49	49	887	539
Mg (mg/L)	154	97	899	479
Mn (mg/L)	4.9	3.8	79	53
Na (mg/L)	198	97	347	192
Cond (µS/cm)	3738	939	3649	726

Table A-2. Average concentration and standard deviations of selected constituents as reported by Mukhtar et al. (2004).

	Avg.	SD
TS (%)	4.32	2.63
TVS(%)	2.43	0.58
P (mg/L)	470	238
TKN (mg/L)	1892	828
K (mg/L)	1379	499
Ca (mg/L)	1800	1600
Mg (mg/L)	400	100
Na (mg/L)	357	123
Fe (mg/L)	17.8	16.3
Cu (mg/L)	12.3	14.4
Mg (mg/L)	17	10.1
Conductivity (µS/cm)	7324	2913

Table A-3. Nutrient and micronutrient deficiencies and toxicities as reported by Bennett (1993)

	Critical Level	Sufficient Range	Toxicity Level
N (%)	<2	2-5	Nontoxic
P (%)	<0.2	0.2-0.5	Nontoxic
K (%)	<1	1-5	Nontoxic
Ca (mg/L)	<0.1	0.1-1	Nontoxic
Mg (mg/L)	<0.1	0.1-0.4	Nontoxic
Mn (mg/L)	10-20	20-300	>300
Fe (mg/L)	<50	50-250	Nontoxic
Cu (mg/L)	3-5	5-20	>20
Na (mg/L)	<1	1-10	Nontoxic

APPENDIX B

EC RAW DATA

Table B-1. Concentrations of nutrients (mg/L), solids (mg/L) and pH for the 6/27/05 and the 7/7/05 sampling events.

site	Sample Date	Nitrate-Nitrite Nitrogen, dissolved EPA 353.2	Orthophosphate Phosphorus, dissolved EPA 365.2	Total Phosphorus EPA 365.4 mod	Total Kjeldahl Nitrogen EPA 351.2 mod	Total Suspended Solids EPA 160.2	Total Volatile Solids SM 2540 E	Total Fixed Solids SM 2540E	Total Dissolved Solids SM 2540C	Total Solids SM 2540B	pH EPA 150.1
IF1	6/27/2005	0.205	3.99	61.60	666	1060	2640	3850	5430	6490	7.77
IF2	6/27/2005	0.151	4.18	11.9	596	655	2610	3860	5820	6470	7.75
EF1	6/27/2005	0.035	0.117	1.12	388	112	478	2022	2390	2500	8.27
EF2	6/27/2005	0.050	0.048	0.574	228	53	448	1962	2360	2410	8.29
EF3	6/27/2005	0.044	0.028	0.519	308	41	430	1870	2260	2300	8.32
IF1	7/7/2005	0.319	4.51	55.8	595	560	2680	3480	5600	6160	7.82
IF2	7/7/2005	0.262	4.65	48.6	524	925	2620	3480	5170	6100	7.86
PCF1	7/7/2005	0.030	0.050	1.20	436	274	1220	3600	4550	4820	7.53
PCF2	7/7/2005	0.034	0.043	1.10	252	237	1330	3340	4430	4670	7.59
EF1	7/7/2005	0.018	0.020	4.46	356	970	900	3100	3030	4000	8.03
EF2	7/7/2005	0.046	0.010	3.15	354	785	922	3048	3180	3970	7.99

Table B-2. Concentrations of conductivity and metals (mg/L) for the 6/27/05 and the 7/7/05 sampling events.

site	Sample Date	Conductivity EPA 120.1	Potassium EPA 200.7	Calcium EPA 200.7	Magnesium EPA 200.7	Sodium EPA 200.7	Manganese EPA 200.7	Iron EPA 200.7	Copper EPA 200.7	Aluminum EPA 200.7
IF1	6/27/2005	7350	921	302	242	352	1.20	4.66	1.24	2.40
IF2	6/27/2005	7860	907	289	233	296	1.17	4.30	1.18	1.93
EF1	6/27/2005	5240	586	35.0	101	232	0.228	8.59	0.112	3.62
EF2	6/27/2005	5180	576	30.4	99.5	233	0.182	4.30	0.114	1.41
EF3	6/27/2005	5100	534	30.9	90.6	210	0.191	4.29	<0.05	1.20
IF1	7/7/2005	7350	869	267	221	280	1.08	3.90	1.16	1.89
IF2	7/7/2005	7050	852	263	217	290	1.14	3.74	1.16	1.71
PCF1	7/7/2005	7080	754	219	121	312	0.045	<0.03	0.103	4.94
PCF2	7/7/2005	7060	745	194	117	282	0.042	<0.03	<0.05	4.52
EF1	7/7/2005	5500	743	156	104	310	1.35	84.6	0.13	25.8
EF2	7/7/2005	5930	760	150	106	298	1.32	79.8	0.11	20.5

Table B-3. Concentrations of nutrients (mg/L), solids (mg/L) and pH for the 7/12/05 and the 7/19/05 sampling events.

site	Sample Date	Nitrate-Nitrite Nitrogen, dissolved EPA 353.2	Orthophosphate Phosphorus, dissolved EPA 365.2	Total Phosphorus EPA 365.4 mod	Total Kjeldahl Nitrogen EPA 351.2 mod	Total Suspended Solids EPA 160.2	Total Volatile Solids SM 2540 E	Total Fixed Solids SM 2540E	Total Dissolved Solids SM 2540C	Total Solids SM 2540B	pH EPA 150.1
IF1	7/12/2005	0.128	4.70	54.9	593	507	2700	3020	5210	5720	7.85
IF2	7/12/2005	0.141	4.54	54.10	581	453	2670	3450	5660	6120	7.89
IFCM1	7/12/2005	0.050	0.079	1.08	432	3630	1600	4640	2610	6240	8.84
IFCM2	7/12/2005	0.029	0.021	3.76	532	9330	4330	10170	5230	14500	7.53
PCF1	7/12/2005	0.037	0.016	1.01	368	160	1430	2750	4020	4180	8.2
PCF2	7/12/2005	0.058	0.012	1.91	423	283	1660	4010	5390	5670	7.61
EF1	7/12/2005	0.042	0.006	0.949	277	367	1040	2520	3190	3560	8.11
EF2	7/12/2005	0.036	0.005	0.688	316	297	1030	2480	3220	3510	8.16
IF1	7/19/2005	0.086	5.76	56.4	528	707	2560	3210	5060	5770	7.82
IF2	7/19/2005	0.095	5.67	53.2	510	410	2530	3270	5390	5800	7.84
IFCM1	7/19/2005	0.049	0.073	37.8	410	11900	4040	10260	2460	14300	7.72
IFCM2	7/19/2005	0.036	0.069	50.9	477	9280	3720	9080	3550	12800	7.72
PCF1	7/19/2005	0.103	0.157	6.67	337	780	952	2688	2860	3640	8.57
PCF2	7/19/2005	0.077	0.062	1.46	319	360	1230	2940	3810	4170	7.78
EF1	7/19/2005	0.032	0.006	1.15	238	316	952	2258	2900	3210	7.96
EF2	7/19/2005	0.028	0.006	0.814	322	440	988	2672	3220	3660	7.99

Table B-4. Concentrations of conductivity and metals (mg/L) for the 7/12/05 and the 7/19/05 sampling events.

site	Sample Date	Conductivity EPA 120.1	Potassium EPA 200.7	Calcium EPA 200.7	Magnesium EPA 200.7	Sodium EPA 200.7	Manganese EPA 200.7	Iron EPA 200.7	Copper EPA 200.7	Aluminum EPA 200.7
IF1	7/12/2005	6760	851	252	215	272	1.18	3.38	1.13	1.41
IF2	7/12/2005	6610	865	260	220	264	1.21	3.50	1.18	1.90
IFCM1	7/12/2005	5580	809	1840	168	300	0.836	6.56	0.621	152
IFCM2	7/12/2005	6240	780	2240	175	278	1.30	12.2	1.04	396
PCF1	7/12/2005	6380	714	97.7	68.2	261	0.003	<0.03	0.015	8.48
PCF2	7/12/2005	6920	728	252	91.7	269	0.038	0.179	0.007	7.93
EF1	7/12/2005	4680	542	94.3	71.5	189	1.30	108	<0.05	3.59
EF2	7/12/2005	4980	595	79.5	76.8	202	1.02	79.6	<0.05	2.49
IF1	7/19/2005	6840	736	237	184	214	0.901	3.72	0.972	1.78
IF2	7/19/2005	6780	735	237	185	214	0.717	3.71	0.880	1.73
IFCM1	7/19/2005	6620	775	1270	179	265	0.86	12.3	0.901	193
IFCM2	7/19/2005	6680	774	1810	211	270	1.44	19.7	1.41	291
PCF1	7/19/2005	5770	693	145	104	209	0.101	1.25	0.189	15.5
PCF2	7/19/2005	6590	617	170	109	200	0.013	0.204	0.064	6.68
EF1	7/19/2005	4800	462	98.1	73.2	168	0.887	60.5	0.077	4.37
EF2	7/19/2005	5590	48.1	114	86	190	<0.001	80.5	2.03	15.1

Table B-5. Concentrations of nutrients (mg/L), solids (mg/L) and pH for the 7/26/05 and the 8/2/05 sampling events.

site	Sample Date	Nitrate-Nitrite Nitrogen, dissolved EPA 353.2	Orthophosphate Phosphorus, dissolved EPA 365.2	Total Phosphorus EPA 365.4 mod	Total Kjeldahl Nitrogen EPA 351.2 mod	Total Suspended Solids EPA 160.2	Total Volatile Solids SM 2540 E	Total Fixed Solids SM 2540E	Total Dissolved Solids SM 2540C	Total Solids SM 2540B	pH EPA 150.1
IF1	7/26/2005	0.251	4.15	54.5	566	540	2380	3120	4960	5500	7.78
IF2	7/26/2005	0.258	4.13	54.4	557	630	2440	3180	4990	5620	7.82
IFCM1	7/26/2005	0.197	0.163	11.9	350	14000	3990	11610	1650	15600	8.2
IFCM2	7/26/2005	0.053	0.085	29.4	440	6290	2770	7430	3940	10200	7.57
PCF1	7/26/2005	0.250	0.208	17.2	403	5080	1600	4170	694	5770	7.78
PCF2	7/26/2005	0.114	0.225	3.31	354	390	1010	2720	3440	3730	7.64
EF1	7/26/2005	0.034	0.008	4.09	261	907	1010	2960	3060	3970	7.76
EF2	7/26/2005	0.040	0.013	4.35	284	807	984	2906	3080	3890	7.81
IF1	8/2/2005	0.132	4.26	54.5	522	385	2340	3150	5100	5490	7.85
IF2	8/2/2005	0.142	6.30	54.2	529	320	2280	3270	5230	5550	7.87
IFCM1	8/2/2005	0.073	0.225	32.1	384	6300	2200	6160	2060	8360	7.74
IFCM2	8/2/2005	0.036	0.069	50.9	469	10400	3220	9380	2230	12600	7.85
PCF1	8/2/2005	0.027	0.044	3.35	341	258	1150	2830	3700	3980	7.56
PCF2	8/2/2005	0.059	0.178	10.0	370	1330	1260	3200	4910	4460	7.88
EF1	8/2/2005	0.032	0.007	1.63	143	256	565	1435	1750	2000	8.04
EF2	8/2/2005	0.042	0.007	0.436	155	168	436	1414	1680	1850	8.06

Table B-6. Concentrations of conductivity and metals (mg/L) for the 7/26/05 and the 8/2/05 sampling events.

site	Sample Date	Conductivity EPA 120.1	Potassium EPA 200.7	Calcium EPA 200.7	Magnesium EPA 200.7	Sodium EPA 200.7	Manganese EPA 200.7	Iron EPA 200.7	Copper EPA 200.7	Aluminum EPA 200.7
IF1	7/26/2005	6580	760	223	178	209	0.979	3.56	0.900	2.40
IF2	7/26/2005	6640	792	232	186	215	1.00	3.69	0.937	2.58
IFCM1	7/26/2005	5660	719	2060	233	220	2.10	29.8	1.57	159
IFCM2	7/26/2005	6230	712	1310	202	262	1.76	25.3	1.36	161
PCF1	7/26/2005	6380	677	274	131	207	0.450	4.79	0.521	57.8
PCF2	7/26/2005	6560	671	195	129	202	0.119	0.646	0.097	7.11
EF1	7/26/2005	5580	607	209	103	200	1.40	103	0.158	15.9
EF2	7/26/2005	5770	640	167	106	207	1.06	68.4	0.142	15.8
IF1	8/2/2005	6640	781	224	184	206	1.08	3.23	1.08	1.39
IF2	8/2/2005	6620	778	230	183	203	1.09	3.30	1.07	1.19
IFCM1	8/2/2005	6050	723	783	176	280	1.07	15.6	0.584	98.4
IFCM2	8/2/2005	6070	714	1090	187	215	1.34	15.4	0.867	132
PCF1	8/2/2005	6590	644	196	133	206	0.119	0.296	0.213	2.61
PCF2	8/2/2005	6240	653	170	122	197	0.203	2.29	0.409	23.8
EF1	8/2/2005	3330	290	82.6	66.1	123	0.377	23.6	0.210	4.43
EF2	8/2/2005	3430	302	70.7	70.5	138	0.496	19.0	0.199	0.451

Raw Data: Concentrations of analytes for samples treated as solids

Table B-7. Concentrations of nutrients (mg/L), solids (%) and pH for all of the six sampling events.

Site ID	Date	Extractable Nitrate/Nitrite Nitrogen SSSA 38	Soluble Phosphorus SSSA 32	Total Phosphorus EPA 365.4 mod	Total Kjeldahl Nitrogen EPA 351.2 mod	% Total Volatile Solids SM2540G	% Total Fixed Solids SM2540G	% Total Solids SM2540G	pH EPA 150.1
IFCM1	6/27/2005	3.13	69.2	1443	9062	0.31	0.75	1.07	8.76
IFCM2	6/27/2005	68.8	69.8	1131	41927	0.08	0.28	0.36	8.84
RS1	6/27/2005	20.1	16.4	5377	19139	7.42	24.59	32.01	8.51
RS2	6/27/2005	42.1	26.5	5897	22167	7.32	21.51	28.83	8.36
RS3	6/27/2005	16.9	22.8	5195	18892	7.79	25.22	33.01	8.57
IFCM1	7/7/2005	11.0	5.01	3616	46300	0.39	0.8	1.19	8.06
IFCM2	7/7/2005	10.9	4.61	4063	54522	0.34	0.69	1.03	8.05
RS1	7/7/2005	8.86	0.79	5685	20136	6.93	19.82	26.76	8.04
RS2	7/7/2005	16.4	1.08	5414	19195	6.89	20.44	27.32	7.87
RS1	7/12/2005	3.71	1.58	4289	15571	3.9	13.96	17.86	8.62
RS2	7/12/2005	4.35	0.75	4420	16249	3.4	11.08	14.47	8.11
RS1	7/19/2005	8.77	1.36	5321	15299	6.05	19.06	25.11	7.9
RS2	7/19/2005	8.40	2.88	5440	18035	3.02	10.28	13.3	8.22
RS1	7/26/2005	0.32	1.20	4685	14569	4.84	20.36	25.2	7.92
RS2	7/26/2005	1.24	1.15	5321	16329	4.63	18.12	22.75	7.93
RS1	8/2/2005	0.23	2.66	4944	19921	4.02	17.08	21.1	8.1
RS2	8/2/2005	0.84	2.24	5000	19972	4.31	17.93	22.23	8.09

Table B-8. Concentrations of metals (mg/kg dry) for all of the six sampling events.

Site ID	Date	Potassium EPA6010B	Calcium EPA6010B	Magnesium EPA6010B	Sodium EPA6010B	Manganese EPA6010B	Iron EPA6010B	Copper EPA6010B	Aluminum EPA6010B
IFCM1	6/27/2005	85100	112500	19660	32100	132.50	1501	106	11450
IFCM2	6/27/2005	174000	54842	23853	74000	57.26	698	75.2	7800
RS1	6/27/2005	6970	147600	11230	2342	183.50	2052	123	14860
RS2	6/27/2005	7320	149600	11260	2510	196.50	2265	132	14100
RS3	6/27/2005	6740	151700	11560	2399	183.20	2135	124	13730
IFCM1	7/7/2005	62200	129300	16430	18950	126.00	1422	131	27770
IFCM2	7/7/2005	56100	119200	15200	17650	115.60	1194	111	26120
RS1	7/7/2005	6770	150400	8950	2226	150.20	1752	129	33760
RS2	7/7/2005	23170	138200	10790	9130	126.40	1582	112	19330
RS1	7/12/2005	2841	93500	6230	926	68.40	777	69.4	12130
RS2	7/12/2005	20600	158800	12290	8710	124.90	1617	122	33920
RS1	7/19/2005	8100	171700	10750	2914	143.10	1715	124	26900
RS2	7/19/2005	2224	4972	2093	150300	82.00	7240	198	93800
RS1	7/26/2005	5190	85800	6730	1666	97.60	1923	73.5	17770
RS2	7/26/2005	5910	86400	6930	2032	119.70	2735	84.2	21920
RS1	8/2/2005	8390	75600	6420	2628	127.70	2604	90.6	17310
RS2	8/2/2005	8100	80000	6660	2616	123.70	2631	88.0	20130

APPENDIX C

GT RAW DATA

Concentrations of analytes for samples treated as liquid

Table C-1. Concentrations of nutrients, solids, and pH for the sampling event on 3/30/05.

Site ID	Date	OPO4P mg/L	NO23N mg/L	TP mg/L	TKN mg/L	TSS mg/L	Total Solids mg/L	Total Vol. Solids mg/L	mg/L Fixed Solids	TDS mg/L	pH
EF1T1	3/30/2005	**2.33**	**0.05**	**8.46**	**306**	**450**	**3420**	**700**	**2720**	**2970**	**7.2**
EF2T1	3/30/2005	**4.46**	**<0.04**	**6.67**	**304**	**80**	**3270**	**531**	**2740**	**3190**	**7.18**
EF3T1	3/30/2005	**4.6**	**0.055**	**9.24**	**315**	**208**	**3130**	**718**	**2410**	**2920**	**7.16**
EF1T2	3/30/2005	**1.84**	**<0.04**	**4.62**	**281**	**184**	**3740**	**618**	**3120**	**3560**	**6.87**
EF1T2	3/30/2005	**5.71**	**0.084**	**17.5**	**329**	**1520**	**4490**	**1340**	**3150**	**2960**	**7.27**
EF3T2	3/30/2005	**7.31**	**0.081**	**13.5**	**310**	**427**	**3310**	**783**	**2530**	**2880**	**7.42**

Table C-2. Conductivity and concentrations of metals for the sampling event on 3/30/05.

Site ID	Date	Spec. Cond Umoh/cm	K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Mn mg/L	Fe mg/L	Cu mg/L
EF1T1	3/30/2005	**5280**	**292**	**est 284**	**133**	**est 130**	**1.38**	**1.09**	**<0.003**
EF2T1	3/30/2005	**5510**	**295**	**est 298**	**132**	**est 141**	**1.42**	**0.617**	**<0.003**
EF3T1	3/30/2005	**5250**	**302**	**est 238**	**130**	**est 148**	**1.01**	**0.73**	**<0.003**
EF1T2	3/30/2005	**5540**	**279**	**est 357**	**138**	**est 136**	**1.83**	**1.34**	**<0.003**
EF1T2	3/30/2005	**5280**	**289**	**est 378**	**134**	**est 144**	**1.87**	**5**	**0.141**
EF3T2	3/30/2005	**5220**	**301**	**est 272**	**129**	**est 149**	**1.1**	**1.26**	**<0.003**

Table C-3. Concentrations of nutrients, solids, and pH for the sampling event on 4/6/05.

Site ID	Date	OPO4P mg/L	NO23N mg/L	TP mg/L	TKN mg/L	TSS mg/L	Total Solids mg/L	Total Vol. Solids mg/L	mg/L Fixed Solids	TDS mg/L	pH
EF1T1	4/6/2005	**5.3**	**0.126**	**9.34**	**328**	**217**	**4230**	**882**	**3350**	**4010**	**7.12**
EF2T1	4/6/2005	**6.44**	**0.875**	**10.9**	**346**	**88**	**5950**	**1260**	**4690**	**5860**	**7.42**
EF3T1	4/6/2005	**7.14**	**0.517**	**11.5**	**335**	**60**	**4970**	**1050**	**3920**	**4910**	**7.52**
EF1T2	4/6/2005	**12**	**0.116**	**20.4**	**341**	**314**	**3620**	**1000**	**2610**	**3310**	**7.43**
EF2T2	4/6/2005	**11.1**	**0.065**	**19.5**	**337**	**202**	**3490**	**931**	**2560**	**3290**	**7.48**

Table C-4. Conductivity and concentrations of metals for the sampling event on 4/6/05.

Site ID	Date	Spec. Cond Umoh/cm	K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Mn mg/L	Fe mg/L	Cu mg/L
EF1T1	4/6/2005	**6070**	**378**	**est 287**	**185**	**est 203**	**1.34**	**0.721**	**<0.003**
EF2T1	4/6/2005	**7420**	**469**	**est 306**	**est 257**	**est ~300**	**0.966**	**0.51**	**<0.003**
EF3T1	4/6/2005	**6830**	**420**	**est 292**	**218**	**est 249**	**0.941**	**0.353**	**<0.003**
EF1T2	4/6/2005	**5620**	**318**	**est 223**	**143**	**est 172**	**0.797**	**0.948**	**0.023**
EF2T2	4/6/2005	**5560**	**326**	**est 301**	**150**	**est 184**	**0.912**	**0.76**	**<0.003**

Residual solids

Table C-5. Concentrations of nutrients, solids, and pH for the sampling event on 10/3/05.

Sample ID	Site	Extractable NO2+3N SSSA 38-1148	Soluble Phosphorus SSSA 32-891	Total Phosphorus EPA 365.4 mod	Total Kjeldahl Nitrogen EPA 351.2 mod	Total Volatile Solids (%) SM2540E	Total Fixed Solids (%) SM2540E	Percent Solids SM2540B	pH EPA 9045C
RS1T1	10/3/2005	729	18.0	4660	18900	11.6	14.0	25.6	7.12
RS2T1	10/3/2005	426	17.1	4520	20200	11.3	13.7	25.0	7.91
RS3T1	10/3/2005	717	10.6	4750	19300	11.4	14.6	26.0	7.24
RS4T1	10/3/2005	1620	14.7	5000	18800	11.1	14.7	25.8	7.13
RS1T2	10/3/2005	716	15.5	5190	20000	12.9	15.9	28.8	7.01
RS2T2	10/3/2005	977	8.64	4830	20300	11.6	14.9	26.5	7.12
RS3T2	10/3/2005	679	19.4	4720	19900	12.4	16.2	28.6	7.13
RS4T2	10/3/2005	537	19.2	4650	19400	12.0	15.2	27.2	7.63

Table C-6. Concentrations of metals for the sampling event on 10/3/05.

Sample ID	Site	Potassium EPA200.7 6010B	Calcium EPA200.7 6010B	Magnesium EPA200.7 6010B	Sodium EPA200.7 6010B	Manganese EPA200.7 6010B	Iron EPA200.7 6010B	Copper EPA200.7 6010B	Aluminum EPA200.7 6010B
RS1T1	10/3/2005	4390	56500	4720	1040	317	4260	126	6500
RS2T1	10/3/2005	4620	54700	4840	1190	291	3940	117	5870
RS3T1	10/3/2005	4300	59400	4640	1030	309	4100	126	6470
RS4T1	10/3/2005	3970	76900	5490	977	249	3650	109	5810
RS1T2	10/3/2005	4880	59700	5110	1130	320	4520	125	7860
RS2T2	10/3/2005	4960	61900	5130	1220	302	4490	132	8330
RS3T2	10/3/2005	4780	62800	5290	1150	298	4320	127	6720
RS4T2	10/3/2005	4580	63600	5090	1180	328	4170	131	5590

Table C-7. Concentrations of P, N, and solids in the IF and IFCM samples

Site ID	Date	Ext P mg/Kg dry	Ext NO3N mg/Kg dry	TP mg/Kg dry	TKN mg/Kg dry	% solids	% Volatile Solids	% Fixed Solids
IF1	3/30/2005	742	7.42	5540	33800	6.03	3.3	2.73
IF2	3/30/2005	246	3.95	5530	30400	6.65	3.46	3.19
IF1	3/30/2005	647	7.08	5690	33800	5.99	3.29	2.69
IF2	3/30/2005	285	4.83	4780	30600	7.08	3.6	3.49
IF1T1	4/6/2005	754	12.6	5300	31100	6.11	3.27	2.85
IF2T1	4/6/2005	58.6	2.06	5130	30800	6.19	3.23	2.96
IF1T2	4/6/2005	676	12.9	5660	34500	6.04	3.18	2.86
IF2T2	4/6/2005	704	6.34	5200	31100	6.08	3.22	2.86

Table C-8. Concentrations of pH, K, and Metals in the IF and IFCM samples

Site ID	Date	pH	K mg/Kg dry	Ca mg/Kg dry	Mg mg/Kg dry	Na mg/Kg dry	Mn mg/Kg dry	Fe mg/Kg dry	Cu mg/Kg dry
IF1	3/30/2005	7.75	8930	est st 55100	6280	est 3280	348	2950	98.8
IF2	3/30/2005	7.62	9080	est 55400	6500	est 2840	335	3890	89.3
IF1	3/30/2005	7.94	9720	est 53400	6490	est 3360	338	3170	102
IF2	3/30/2005	7.68	8190	est 54000	6050	est 2890	321	3290	93.7
IF1T1	4/6/2005	7.53	9840	est 56900	6730	est 3350	354	3660	92.7
IF2T1	4/6/2005	7.16	9250	est 54600	6320	est 3350	335	2980	90.4
IF1T2	4/6/2005	7.51	10000	est 57200	6780	est 3580	362	3480	96
IF2T2	4/6/2005	7.59	8890	est 53100	6140	est 3360	325	2850	86.1

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