

Demonstration and Transfer of Selected New Technologies for Animal Waste Pollution Control

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Conclusions

The *Demonstration and Transfer of Selected New Technologies for Animal Waste Pollution Control* project has successfully completed the evaluation of four dairy waste treatment methodologies, a demonstration utilizing byproduct from one of the treatments, and published educational information for dairy producers in the North Bosque River and surrounding watersheds; providing science-based information to dairy producers considering implementing one of the evaluated methods for removing P from dairy waste.

Findings from these evaluations showed that the physiochemical methods (Geotube[®] and Electrocoagulation) effectively remove 88 percent or more P from dairy waste; however, their costs were such that treatment would only be feasible once every 10 to 15 years. Microbial treatment products failed to perform as well as the other two technologies, but they did show some beneficial reductions in P and other effluent constituents. Lagoon effluent treated with the L4DB[®] system showed TP reductions of 27 and 52 percent from the lagoon profile and lagoon supernatant while effluent treated with the WTS[®] system yielded mixed results. Samples collected from the lagoon and tanks showed TP reductions of 17 and 60 percent respectively while SRP increased over time in both environments. The evaluation of turfgrass grown on soil amended with residual material from the Geotube[®] demonstration proved that this material is an effective soil amendment for stimulating the growth of turfgrass without significant detrimental impacts to ground or surface water quality.

Perhaps the most important findings from this study are that viable means do exist to reduce P in dairy waste by 50 percent or more; however, some claims by solicitors may not be accurate or may even be misleading. Anyone considering implementing a treatment to reduce P in animal waste should be cautious when making their decision. Costs for these treatment methods vary widely and should also be taken into consideration.

Throughout the course of the evaluations, project personnel also learned that specifically evaluating the effects of the microbial treatment methods is difficult in both lagoon and tank environments. Weather and variable manure loading impacts play an important role in the actual make-up of effluent held within lagoons and have the potential to skew the effects of microbial treatment. As a result, extended evaluations covering several years and seasons is a preferred method for more accurately assessing the effectiveness of microbial treatment methods.

Ultimately this project accomplished its goals by providing scientifically proven information on the function and effectiveness of each demonstrated treatment method to area dairy producers. A secondary benefit of this study is that dairy producers have reported fewer solicitations by companies trying to sell their product or service to reduce P in dairy waste.

***Demonstration and Transfer of Selected New Technologies
for Animal Waste Pollution Control***

TSSWCB Project 03-10

Final Report



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Table of Contents

List of Figures.....	3
List of Tables	3
Executive Summary	4
Project Background	5
Project Approach	7
Technology Demonstrations and Methodology	8
Geotube® Dewatering System	8
Electrocoagulation System	9
L4DB® Microbial Treatment System	10
Wastewater Treatment Solution (WTS®) System	12
Sample and Sample Analysis.....	14
Demonstration Results	15
Geotube® Dewatering System	15
Electrocoagulation System	15
L4DB® Microbial Treatment System	15
Wastewater Treatment Solution (WTS®) System	15
Technology Costs	17
Geotube® Dewatering System	17
Electrocoagulation System	17
L4DB® Microbial Treatment System	17
Wastewater Treatment Solution (WTS®) System	17
Geotube® Residual Material Demonstration	19
Project Approach and Sampling	19
Results	20
Conclusions.....	21
Appendix A(<i>Geotube® Dewatering System</i>).....	A-1
Appendix B(<i>Electrocoagulation System</i>).....	B-1
Appendix C(<i>L4DB® Microbial Treatment System</i>).....	C-1
Appendix D(<i>Wastewater Treatment Solution (WTS®) System</i>).....	D-1
Appendix E(<i>Geotube® Residual Material Demonstration</i>).....	E-1

List of Figures

Figure 1. Geotube [®] dewatering system prior to treatment	8
Figure 2. Mixing tank in the Electrocoagulation System	10
Figure 3. Tank sampling during L4DB [®] Microbial Treatment System demonstration	11
Figure 4. Lagoon sampling during the Wastewater Treatment Solution (WTS [®]) System demonstration	12
Figure 5. Efficacy of technologies on the reduction of Total Solids (TS), Total phosphorus (TP), and Soluble Reactive Phosphorus (SRP) from dairy lagoon effluent	16
Figure 6. Estimated per cow, per year cost for treating dairy lagoon effluent using different technologies	18
Figure 7. Turfgrass response to Geotube [®] residual material demonstration sample design	19

List of Tables

Table 1. TIAER laboratory methods and equipment used for sample analysis	14
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Executive Summary

The *Demonstration and Transfer of Selected New Technologies for Animal Waste Pollution Control* project was conducted by the Texas AgriLife Extension Service and Texas Water Resources Institute and was designed as a means for evaluating animal waste treatment methods and their ability to remove phosphorus (P) from dairy waste. A variety of factors present in the North Bosque River watershed have led to the excessive loading of P and subsequent algal growth in the water body. As a result, the Texas Commission on Environmental Quality developed two Total Maximum Daily Loads (TMDLs) for the North Bosque River mandating that P loading to the water body be reduced by at least 50 percent.

Upper portions of the North Bosque River watershed are home to numerous dairy operations that can be a source of manageable P and other nutrients to the watershed. Prior to the development of this project, dairy producers in the area were approached by different companies soliciting their respective products that ‘guaranteed’ P removal from their dairy waste and/or lagoons; however, the dairy producers were not presented with scientific evidence to support these claims and were skeptical about actual results. This project was designed in response to the need for scientific evidence and evaluated the ability of four products/technologies to remove P from liquid dairy manure prior to its application on nearby fields.

The program was set up so that an unbiased, third party laboratory analyzed samples collected from dairy waste prior, during, and after treatment by each respective product or technology to provide scientifically sound information to dairy producers so they can make an informed decision about implementing a specific treatment to reduce P from their dairies. Each technology provider utilized a different approach for applying or implementing their respective treatments; the providers were allowed to demonstrate their technology without any modifications recommended by Texas AgriLife Extension Service. Specific sampling procedures and locations were not consistent between each evaluation due to the nature of the technologies; two physiochemical methods treated the waste stream to separate solids and nutrients from liquid manure while two biological treatment methods utilized microbes to treat the entire lagoon. Though each technology resulted in improvements of lagoon characteristics, only the physiochemical treatments effectively removed more than 50 percent of P present in the dairy waste.

As an addendum to the project, a demonstration was conducted to evaluate the feasibility of growing turfgrass on soils amended with byproduct from one of the physiochemical treatment evaluations. The large volume of solids remaining after treatment raised the question of how to effectively dispose of the solids in a beneficial way. The demonstration assessed the response of turfgrass growth and leachate/runoff water quality from small cylinders containing soils amended with the particular byproduct. Results showed that turf production increased as a result of the amendment and water quality was not drastically compromised.

This report summarizes the results of each demonstrated product or technology and the turfgrass growth demonstration. It highlights both positive and negative aspects of each treatment methodology so producers who consider implementing one of the technologies may have science-based findings predicting respective performance.

Project Background

In 1998, the North Bosque River segment 1226 and the Upper North Bosque River segment 1255 were deemed "impaired segments" on the *Texas Water Quality Inventory and 303(d) List*. Recent studies conducted or sponsored by the Texas Commission on Environmental Quality (TCEQ), the Texas State Soil and Water Conservation Board (TSSWCB), the Texas Institute for Applied Environmental Research (TIAER), the Texas Water Resources Institute (TWRI), and others demonstrated that high levels of phosphorus (P) and other nutrients from point and nonpoint sources degraded the water quality in the North Bosque River. Nonpoint sources such as dairy waste application fields (WAFs), and point sources such as municipal wastewater treatment plants, were identified as the major controllable sources of P in the watershed.

These findings led to the U.S. Environmental Protection Agency's (USEPA) approval of two Total Maximum Daily Loads (TMDLs) for P in the North Bosque River. In December 2002, TCEQ approved the implementation plan for the two TMDLs, and TSSWCB approved them in January 2003. The goal of these TMDLs was to achieve a reduction of total annual loading and annual average concentrations of soluble reactive P (SRP) by approximately 50 percent. It is anticipated that SRP reductions of this magnitude will reduce the potential for problematic algal growth in the North Bosque River and Lake Waco.

When this project began in 2003, there were roughly 41,000 dairy cows in the North Bosque River watershed. Runoff from production areas such as feedlots and feed lanes is regulated as point source while runoff from waste applications fields (WAFs) is not regulated, and is therefore treated as a nonpoint source. It is anticipated that the measures to control SRP loading from WAFs may include a combination of dairy regulations for land application of manure and wastewater as well as voluntary land management and stewardship programs. Several permitted dairies in the watershed use best management practices (BMPs) that reduce the nutrient content in the effluent applied to WAFs. In most cases, these include the separation of solids from liquid manure by either gravitational (settling basins) or mechanical (screen separators) methods that may remove as much as 40 percent of solids from liquid dairy manure. While separating solids does actually reduce total P (TP), as much as 90 percent of the SRP remains in the effluent to be stored in a basin or lagoon and eventually land applied to WAFs. Low-cost, highly efficient, and easy-to-adopt technologies or BMPs that will reduce TP and SRP from dairy effluent applied to WAFs will contribute significantly to the overall goal of a 50 percent reduction in annual SRP loading in the North Bosque River.

The North Bosque River watershed contains areas that have concentrated numbers of dairy operations. Dairy lagoons are designed and built to catch, contain, and process water as well as certain amounts of rainwater; however, lagoons must be periodically dewatered to maintain adequate storage capacity. As a result, WAFs typically receive repeated application of effluent causing P levels to increase over time. Another factor causing repeated application of effluent to WAFs is the proximity to the lagoons. Minimizing costs is critical to the profitability of a dairy operation and as a result, application of lagoon effluent to the closest fields is preferred and expedites excessive P build-up on these fields. This practice elicits the need for practices or technologies that can reduce the level of P in lagoon effluent prior to its application to WAFs.

To address this need, the *Demonstration and Transfer of Selected New Technologies for Animal Waste Pollution Control* project (TSSWCB #03-10) was developed to evaluate the ability of selected technologies or treatment methods to remove P from dairy waste streams prior to its application to WAFs. Through this project, four technologies were evaluated and one field demonstration was conducted to evaluate the potential impacts of using residual material from one technology for beneficial on-farm uses.

The final project report briefly summarizes results of each technology demonstration and the field demonstration. Detailed information about the performance of each technology can be found in the final reports for each project. The following reports are listed in their respected appendices and links to each report are provided below.

Appendix A

Geotube[®] Dewatering System

<http://twri.tamu.edu/reports/2009/tr345.pdf>

Appendix B

Electrocoagulation System

<http://twri.tamu.edu/reports/2009/tr346.pdf>

Appendix C

LADB[®] Microbial Treatment System

<http://twri.tamu.edu/reports/2009/tr344.pdf>

Appendix D

Wastewater Treatment Solution (WTS[®]) System

<http://twri.tamu.edu/reports/2009/tr342.pdf>

Appendix E

Geotube[®] Residual Material Demonstration

<http://twri.tamu.edu/reports/2009/tr343.pdf>

Project Approach

This project was developed as a methodology to provide a third party assessment of each technology demonstrated. To accomplish this goal, a Technical Advisory Committee was established to provide guidance for the project by selecting specific demonstrations to evaluate; selecting cooperating dairy facilities where technologies were demonstrated; aiding in developing protocols and procedures used in the evaluation of each technology; and assisting with the development and delivery of publications, field demonstrations, and other project outputs.

Each technology was evaluated for its efficacy to reduce total P, SRP, other nutrients, and metals by sampling and analyzing the raw and treated effluent. Cost effectiveness, treatment efficiency, and the ease of adoption for each BMP were evaluated and are presented in this report as well as each individual report. Each technology was demonstrated for a period of at least three months. A third-party analytical analysis was conducted by the lab at the Texas Institute of Applied Environmental Research (TIAER) at Tarleton State University in Stephenville, Texas. Individual sampling schemes were developed for each technology demonstrated as each treatment scenario approached the issues in differing manners. Two of demonstrations diverted the lagoon influent stream through respective treatment systems prior to entering the lagoon while two other demonstrations treated the lagoon as a whole. As such, analyzed samples were collected from the treatment system for two of the demonstrations and samples were collected directly from the lagoon during the other demonstrations.

Extensive detail about sampling methodology, the samples analyzed, results, and treatment methods are reported in each individual demonstration final report. These reports are available on-line under the “Final Reports” heading at: <http://twri.tamu.edu/project-info/NewTechnologies/>.

Technology Demonstrations and Methodology

Implementation of this project consists of the evaluation of four technologies demonstrated on cooperators' dairy farms by the technology providers. The four technologies demonstrated were a geotextile solids separation system, an electrocoagulation system, a microbial treatment system, and an oxygenated microbial treatment methodology.

Geotube[®] Dewatering System

The Geotube[®] dewatering system (Figure 1) was demonstrated by the Miratech Division of Ten Cate Nicolon and General Chemical Corporation. The system used a chemical pre-treatment to coagulate the solids from the lagoon effluent. The mixture was pumped into two large geotextile filtration tubes, known as Geotubes[®]. These tubes were placed on 6 millimeter impervious polyethylene sheeting. On the down slope end of each tube, a synthetic felt-like fabric was installed to prevent potential soil erosion from water leaving the tube. The synthetic fabric of the Geotubes[®] acted as a filter that trapped solids and nutrients inside of the tubes while allowing the liquid to exit the tube and return to the lagoon. A high percentage of the solids were retained as the liquid seeped from the pores in the fabric (Worley 2004). The tubes were filled to a height of approximately 5' with the mixture and were left to dewater for six months. After dewatering, the residuals were disposed of off-site. The dewatering system comprised of two 14' x 50' tubes and was set-up to treat the 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 then conveyed to a secondary lagoon where it was recycled and used for flushing the parlor and irrigating hay and cropland at the dairy operation.



Figure 1. Geotube[®] dewatering system prior to treatment

For the purposes of this demonstration, effluent was pumped from the lagoon following agitation, just as it would have been if the effluent was applied to nearby WAFs for irrigation purposes. Effluent was pumped at a rate of approximately 400 gpm through a 6" pipe and mixed with alum and a synthetic polymer as it entered into the Geotubes[®]. This mixture was added to the effluent to promote precipitation and flocculation of P from the waste stream.

Effluent was first pumped into the Geotubes[®] on March 30, 2005, and additional lagoon effluent was pumped into the Geotubes[®] on April 6, 2005 as well. Sampling on each date consisted of 10 sets of 15 (250 mL) grab samples that were taken during each of the sampling events. At the time of the second sampling event, there was only enough effluent seeping from one of the tubes to take 2 instead of 3 sets of effluent samples. Each set of 15 grab samples were mixed in the TIAER laboratory and analyzed as one composite sample. To assess the efficacy of the Geotubes[®] ability to remove P from the waste stream, samples were collected from a variety of locations. Samples were collected from the raw lagoon effluent, lagoon effluent mixed with the chemical treatment (alum and polymer), and effluent weeping from the Geotubes[®]. After six months of dewatering, the Geotubes[®] were opened and the material retained inside was sampled.

Publications describing the application and performance of this specific technology demonstration include:

Mukhtar, S., L. A. Lazenby, and S. Rahman. 2007. Evaluation of a Synthetic Tube Dewatering System For Animal Waste Pollution Control. *Applied Engineering in Agriculture* 23 (5): 669–75.

Mukhtar, S., K. Wagner, and L. Gregory. 2007. *Technologies for reducing nutrients in dairy effluent*. Texas Cooperative Extension Publication B-6196. College Station.

Mukhtar, S., K. Wagner, and L. Gregory. 2009. *Field Demonstration of the Performance of a Geotube[®] Dewatering System to Reduce Phosphorus and Other Substances from Dairy Lagoon Effluent*. TWRI Report No. TR-345. College Station: Texas Water Resources Institute, Texas A&M System.

Electrocoagulation System

The electrocoagulation (EC) system was demonstrated by Ecoloclean Industries, Inc. and consisted of numerous components including two mixing tanks (Figure 2), a dissolved air flotation unit, a sludge tank, the Electrocoagulation unit, a reaction tank with a mixer, two feed tanks equipped with mixers, and a final filter.

A centrifuge was added into the second system and set up to aid in removing solids from the lagoon effluent prior to it going through the EC unit. The system utilized chemical pre-treatment of alum, lime and a proprietary polymer to coagulate and separate suspended solids in the slurry 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. The configuration of the system and its components varied from event to event as a result of efforts to optimize the system. To accommodate these changes, the points at which samples were taken varied as well.

At all sampling events, samples were taken from the lagoon effluent, the lagoon effluent after the addition of the chemical pre-treatments, the effluent from the EC system, and the residual solids. Samples were also taken where the mixture exited the centrifuge after its addition to the system.



Figure 2. Mixing tank in the Electrocoagulation System

The EC system was set-up to treat 40 gpm of 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 near the dairy. In total, seven sampling events were conducted during the EC demonstration between June 8, 2005 and August 2, 2005. During each sampling event except for the first one, 10 sets of 15 (250 mL) grab samples were collected and delivered to the lab at TIAER for analysis.

Publications describing the application and performance of this specific technology demonstration include:

Mukhtar, S., K. Wagner, and L. Gregory. 2007. *Technologies for reducing nutrients in dairy effluent*. Texas Cooperative Extension Publication B-6196. College Station.

Mukhtar, S., K. Wagner, and L. Gregory. 2009. *Field Demonstration of the Performance of and Electrocoagulation System to Reduce Phosphorus and Other Substances from Dairy Lagoon Effluent*. TWRI Technical No. TR-346. College Station: Texas Water Resources Institute, Texas A&M System.

L4DB[®] Microbial Treatment System

The L4DB[®] microbial treatment system demonstrated by Envirolink[®] LLC from Greeley, Kansas consisted of a liquid-borne microbial solution derived from milk and containing *Lactobacillus acidophilus* and *Lactobacillus gasseri* as the active cultures. The treatment was applied by spraying a predetermined volume of the microbial solution around the perimeter of the lagoon

while simultaneously agitating the lagoon with a pump and sprinkler that sprayed effluent back into the lagoon. The volume of microbial solution applied was applied based on the lagoon size, depth of water and solids in the effluent, and was adjusted as ambient temperatures and precipitation varied. When colder ambient temperatures prevailed, the lagoon received higher treatment doses due to decreased bacterial activity; months with higher precipitation totals received a smaller dose as a result of increased dissolved oxygen levels in the lagoon. Additionally, two tanks (Figure 3) were filled with lagoon effluent and treated separately in an effort to evaluate the performance of the microbial treatment under controlled conditions. One tank was used as a control and was not treated while the other was treated according to the specifications of the technology provider.

This demonstration was conducted in the Bosque River watershed on a 300-head lactating cow, free-stall dairy with a single cell anaerobic lagoon. The free stall alleys were flushed four times weekly and scraped on the remaining three days of the week. Each flush utilized 10,000 to 12,000 gallons of water that flowed directly into the lagoon. In order to manage lagoon depth as needed, nearby hay fields and cropland were irrigated using a big gun irrigation system. Sampling was conducted from the lagoon, the irrigation pipeline prior to field application, and the two controlled tanks. Irrigation samples collected during each sampling event were taken from a spigot in the irrigation pipeline every three minutes for three hours yielding 60 samples. Two sets of tank and lagoon samples were collected during each sampling event.



Figure 3. Tank sampling during the L4DB[®] Microbial Treatment System demonstration

The first set was collected from the supernatant (the upper 2 ft of the lagoon or 1 ft of the tank) while the second set was collected from the entire profile of the lagoon and tanks. Ten sets of these samples were collected from the lagoon; nine in fixed locations and the remaining one from the irrigation pump. Two sets of samples were collected from each tank. Depth measurements were also taken to record the thickness of the dense sludge level at the bottoms of the lagoon and tanks. All samples were delivered to the TIAER laboratory for analyses.

Publications describing the application and performance of this specific technology demonstration include:

Rahman, S. and S. Mukhtar. 2008. Efficacy of Microbial Treatment to Reduce Phosphorus and other Substances from Dairy Lagoon Effluent. *Applied Engineering in Agriculture* 24 (6): 809–19.

Mukhtar, S., S. Rahman, and L. Gregory. 2009. *Field Demonstration of the Performance of the L4DB[®] Microbial Treatment System to Reduce Phosphorus and Other Substances from Dairy Lagoon Effluent*. TWRI Report No. TR-344. College Station: Texas Water Resources Institute, Texas A&M System.

Wastewater Treatment Solution (WTS[®]) System

The WTS[®] system was demonstrated by Ozona Environmental[®] LLC from Ozona, Texas. The system is a two part solution treatment that contains a microbial stimulant (WTS[®]) and an oxygenating additive (O2T). According to the technology provider, the system introduces and stimulates indigenous populations of microorganisms, ultimately resulting in reduced organic matter and nutrients in the wastewater. The WTS[®] system was initially applied directly to the lagoon (Figure 4) at a rate of 1 gal/head; thereafter, it was applied at a rate of 0.5 gal/100 head-day (3gal/day for the 600 head dairy). O2T was simultaneously applied to the lagoon at a rate of 0.1 gal/100 head-day or 0.6 gal/day. These application rates were constantly maintained using Viking injectors (Viking injector, Kyjac Inc., Nesquehoning, Pa.).

This system was demonstrated on a 600 head free-stall dairy in the Bosque River watershed that flushed and scraped its free-stall alleys. The dairy has a two lagoon system that allows for extended effluent detention time prior to the system being pumped out of the second lagoon and used as irrigation water for nearby cropland. Sampling for this demonstration was conducted in the primary lagoon at ten set locations; nine in the body of the lagoon and one at the lagoon inlet.



Figure 4. Lagoon sampling during the Wastewater Treatment Solution (WTS[®]) System demonstration

Two plastic tanks were also used to evaluate the treatment system under controlled circumstances. Nine sampling locations were used in each tank; including samples taken from the lagoon profile (entire depth), lagoon supernatant (upper 2 ft), tank profile, and tank supernatant (upper 1 ft). Samples collected during this demonstration were also delivered to TIAER for laboratory analysis.

Publications describing the application and performance of this specific technology demonstration include:

Mukhtar, S., S. Rahman, and L. Gregory. 2009. *Field Demonstration of the Performance of Wastewater Treatment Solution (WTS[®]) to Reduce Phosphorous and other Substances from Dairy Lagoon Effluent*. TWRI Report No. TR-342. College Station: Texas Water Resources Institute, Texas A&M System.

Sampling and Sample Analysis

Sampling procedures utilized to collect samples from each demonstration were consistent throughout the duration of the project. The standard method was to collect 250 mL samples from lagoon effluent prior to treatment, during, and after treatment by the respective technologies. The media sampled and its locations varied significantly between technologies due to the nature of each individual demonstration. In all four demonstrations, samples collected from individual sites were mixed to form composite samples; thus reducing the overall number of samples analyzed.

Sample analysis was conducted by the TIAER laboratory in Stephenville, Texas. This lab was chosen due to its analysis capabilities and proximity to sampling sites. Extensive analysis was conducted on each sample to evaluate the sample's pH and levels of nutrients, metals, and solids. Table 1 provides detail on individual parameters evaluated, analysis methods used, and the equipment for testing. As a result of high sample costs and limited resources, individual samples from each collection site were combined into composite samples; thus decreasing the overall number of samples analyzed, yet yielding a fair view of effluent's spatial and temporal variability.

Table 1. TIAER laboratory methods and equipment used for sample analysis

Parameter	Method	Equipment Used
Nitrite + +Nitrate Nitrogen	EPA 353.2 and SSSA 38-1148	Perstorp [®] or Lachat [®] QuickChem Autoanalyzer
Total Kjeldahl Nitrogen (TKN)	EPA 353.2, modified	Perstorp [®] or Lachat [®] QuickChem Autoanalyzer
Potassium	EPA 200.7	Spectro [®] ICP
Calcium	EPA 200.7	Spectro [®] ICP
Magnesium	EPA 200.7	Spectro [®] ICP
Sodium	EPA 200.7	Spectro [®] ICP
Manganese	EPA 200.7	Spectro [®] ICP
Iron	EPA 200.7	Spectro [®] ICP
Copper	EPA 200.7	Spectro [®] ICP
Orthophosphate Phosphorus	EPA 365.2	Beckman [®] DU 640 Spectrophotometer
Total Phosphorus	EPA 365.4, modified	Perstorp [®] or Lachat [®] QuickChem Autoanalyzer
Total Suspended Solids	EPA 160.2	Sartorius [®] AC210P or Mettler [®] AT261 analytical balance, oven
Total Solids	SM 2540C	Sartorius [®] AC210P or Mettler [®] AT261 analytical balance, oven
Total Volatile Solids	SM 2450G	Sartorius [®] AC210P or Mettler [®] AT261 analytical balance, oven, muffle furnace
Total Volatile Solids	EPA 160.4	Sartorius [®] AC210P or Mettler [®] AT261 analytical balance, oven, muffle furnace
Potential Hydrogen	EPA 150.1 and EPA 9045A	Accument [®] AB15 Plus pH meter
Conductivity	EPA 120.1 and EPA 9050A	YSI [®] 3200 conductivity meter
Aluminum	EPA 200.7	Spectro [®] ICP

Demonstration Results

A general overview of performance results from each demonstration is presented and summarized in figure 5. Greater detail about individual technology performance can be found in the final reports for each demonstration (pg. 3).

Geotube[®] Dewatering System

Results from the three sampling events conducted during the demonstration of the Geotube[®] Dewatering System indicated that the system effectively removed 88 percent of SRP and 97 percent of TP. These removal rates far exceeded the 50 percent reduction goal. Additionally, the technology also removed 95 percent of the total solids from the effluent pumped through the system and was effective in removing all metals, nutrients, and solids.

Electrocoagulation System

The EC system also proved to be effective in removing TP and SRP, yielding 96 and 99.6 percent reductions respectively from the lagoon effluent. The performance of the entire system with respect to removing metals was sporadic. Only Mg was observed to have consistent reductions from each sampling event. Other metals had a wide range of reductions and increases without any apparent trends from event to event. The inconsistencies in the performance of this system for both the metals and solids is possibly linked to the changes made in the system's configuration and the changes in the chemical pre-treatment from event to event.

L4DB[®] Microbial Treatment System

Overall, the L4DB[®] treatment was somewhat effective in reducing TP, but was not effective in reducing SRP in the lagoon. Recorded levels of TP and SRP in lagoon and irrigation water varied greatly throughout the course of the demonstration and were likely due to environmental conditions and microbial degradation of sludge in the lagoon. During the one-year demonstration, TP reductions averaged 27 percent in samples collected from the lagoon profile and 52 percent from the lagoon supernatant; however, a 28 percent increase was seen in TP levels in irrigation waters. SRP levels behaved similarly showing sporadic increases and decreases in the lagoon and irrigation waters.

The L4DB[®] technology also yielded variable performances for other nutrients evaluated, but generally exhibited considerable reductions in metals and solids. Much of this variability was likely due to overloading of the lagoon as well as varied treatment application rates. The technology provider pre-determined the application rate for this lagoon based on experiences, but not by measuring environmental conditions of the lagoon. A general conclusion made was that most of these solids, nutrients, and metal reductions were likely due to microbial treatment, dilution of lagoon slurry due to excessive rain and runoff water, and settling of dead and degraded bacterial mass accumulated at the bottom of lagoon.

Wastewater Treatment Solution (WTS®) System

The WTS® system showed mixed results for P removal. TP levels recorded in the lagoon did not change significantly throughout the course of the demonstration; instead the values varied significantly between each sampling event. In the separate tank demonstration of the WTS® system yielded a decrease in TP of 17 percent collected from the tank profile. TP levels in tank supernatant also decreased in the treated and untreated tanks at respective rates of 60 and 55 percent. SRP levels in the lagoon and tanks showed an increasing trend over time. Generally speaking, this system was not effective at reducing P or other nutrients from the lagoon or tanks.

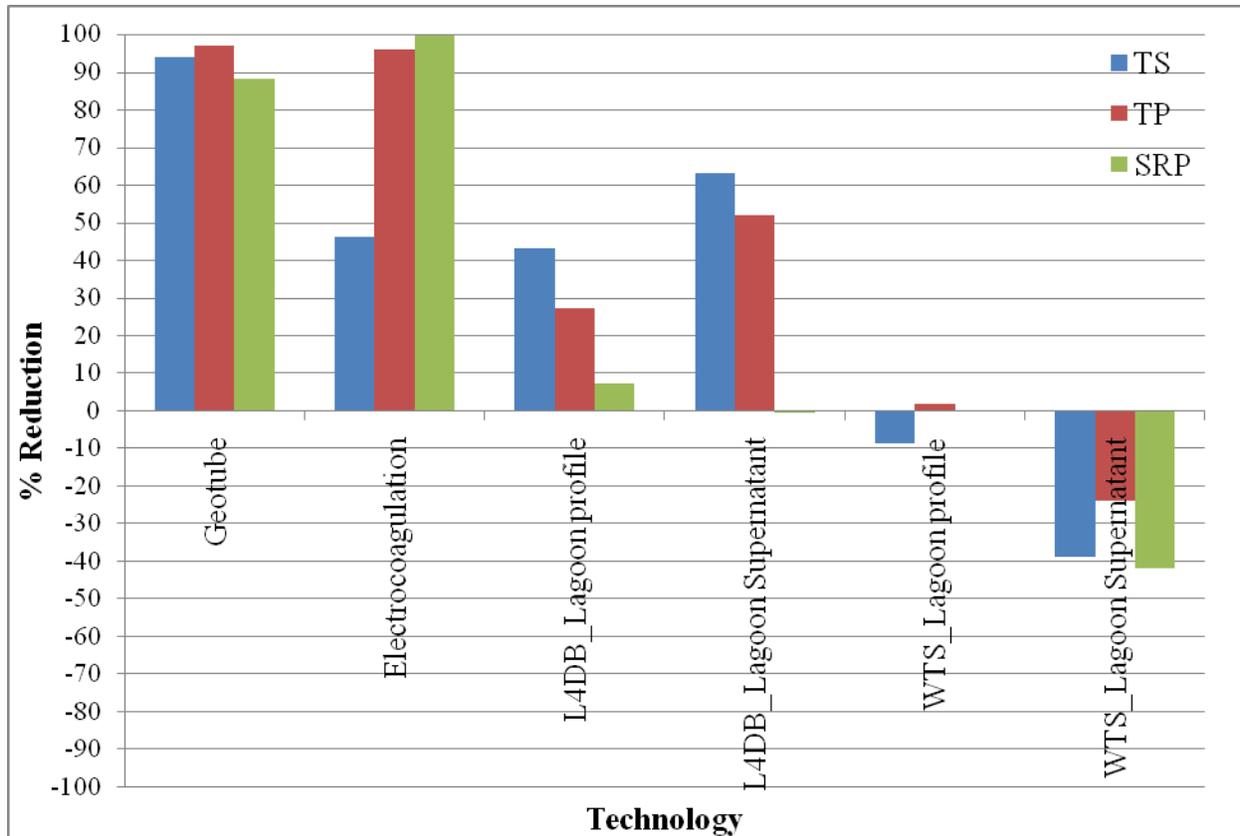


Figure 5. Efficacy of technologies on the reduction of Total Solids (TS), Total phosphorus (TP), and Soluble Reactive Phosphorus (SRP) from dairy lagoon effluent (note: a negative reduction indicates that measured levels increased during the demonstration)

Technology Costs

Costs to implement the four demonstrated technologies varied widely depending upon the method used (Figure 6). Similarly, the technology providers were unable to provide consistent cost per unit information among the technologies. The two mechanical technologies are reported in a cost per gallon and the microbial technologies are reported on a cost per head basis. All costs were converted to a cost per head per year basis to attempt to yield some level of consistency.

Geotube[®] Dewatering System

Treatment costs for the Geotube[®] Dewatering System were furnished by the technology provider as a one-time cost of \$90,000 to treat 1.9 million gallons of effluent (\$0.047 per gallon). Assuming this treatment would only be used once in 15 years to remove nutrient and sludge accumulations in the lagoon of a 2,000 head dairy operation, this cost equates to \$3 per head per year.

Electrocoagulation System

The cost estimate for the EC system was provided by the technology provider as an average of \$0.12 per gallon to treat a lagoon. This cost would be incurred to hire Ecoloclean Industries to perform the task. Assuming a similar 2,000 head dairy was treated once in 15 years, the treatment of 1.9 million gallons of lagoon effluent would cost \$228,000 or \$7.60 per head per year.

L4DB[®] Microbial Treatment System

Treatment cost information from the technology provider for the L4DB[®] system varied depending on a variety of dairy specific factors for which the technology provider considers when dosing the lagoon. The provider estimated that to treat the lagoon, dairies smaller than 1,000 head would cost \$12 per head per year, dairies 1,001 to 7,000 head would cost between \$7.20 to \$10.80 per head per year, and dairies greater than 7,001 head would cost from \$3.60 to \$7.20 per head per year. This demonstration was conducted by treating the lagoon; therefore, a cost per gallon cannot be determined for this treatment method.

Wastewater Treatment Solution (WTS[®]) System

Cost information provided for the WTS[®] system indicates that treatment costs for this technology vary depending on the specific conditions at each dairy. The technology provider did indicate that costs are typically \$6 per cow per year. This method was applied to a lagoon with an un-metered amount of daily inflow; therefore, a cost per gallon could not be determined.

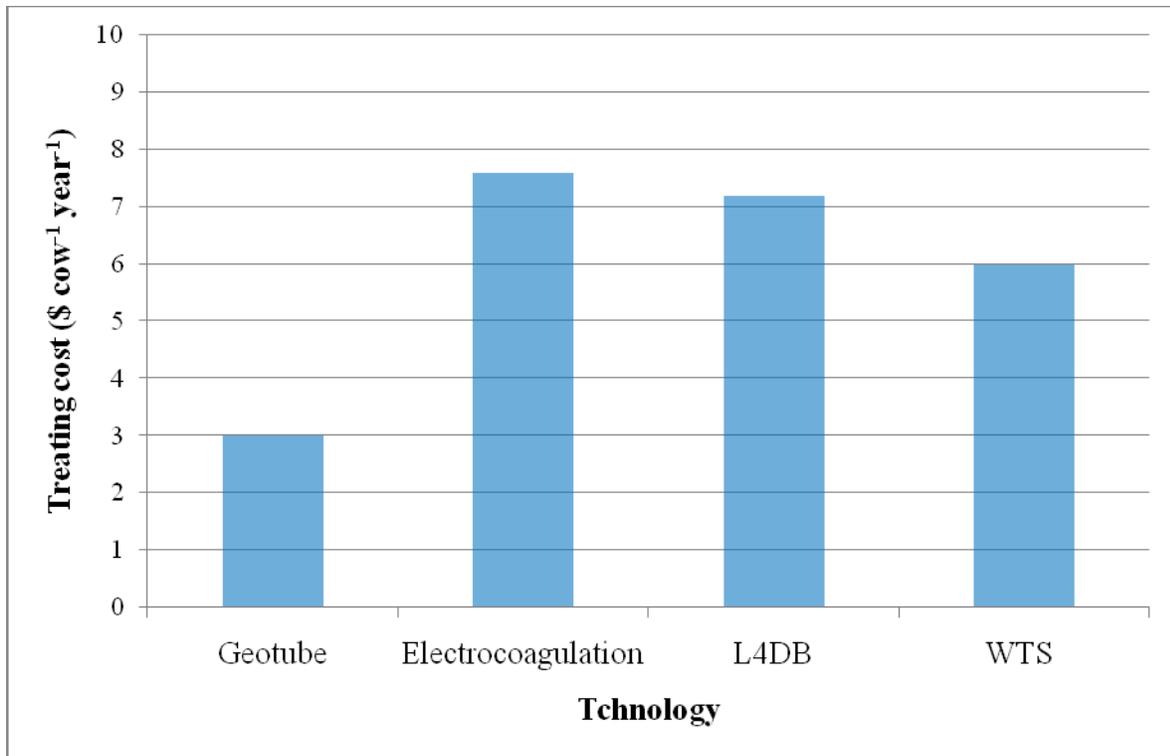


Figure 6. Estimated per cow, per year cost for treating dairy lagoon effluent using different technologies.

Geotube[®] Residual Material Demonstration

As an addendum to the project, a demonstration, “Cycling of Geotube[®] Solids from Dairy Lagoons through Turfgrass Sod,” was conducted to illustrate the benefits of producing a marketable crop using residual material retained by the Geotube[®] Dewatering System. After treatment of the lagoon using this system, geotextiles tubes measuring 14 ft x 50 ft retain the bulk of solid material, nutrients, and metals that were removed from the dairy’s lagoon. Disposing of this residual material is an economical hindrance for implementing this technology.

Through this project, faculty in the Soil and Crop Sciences and Biological and Agricultural Engineering Departments at Texas A&M University utilized this resource as a soil amendment to produce turfgrass. The goal of this project was to evaluate the sustainability of systems for cycling Geotube[®] solids through turfgrass production for value-added export with sod. The first objective was to evaluate turfgrass establishment using physical, chemical, and biological properties of contrasting soil textures with and without incorporation of increasing rates of Geotube[®] solids. The second objective was to evaluate leaching losses of nutrients from contrasting soil textures with and without incorporation of Geotube[®] solids during turfgrass establishment.

Project Approach and Sampling

In order to effectively conduct this demonstration, an experiment was designed to test four replications of three Geotube[®] solids application rates on two soil types by packing the soils into 0.25ft x 1ft polyvinyl chloride (PVC) pipe cylinders (figure 7) and amending the soils with 0, 12.5, and 25 percent Geotube[®] solids by volume and then sprigging with Tifway Bermudagrass. Water was initially applied to the columns from the bottom up and on the surface thereafter. On days 45 and 90 of the experiment the cylinders were irrigated so that one pore volume of water was collected as leachate to determine the impacts of Geotube[®] solids incorporation. Turfgrass growth was monitored and recorded prior to the harvesting of grass stems and leaves. These clippings were analyzed for nitrogen and phosphorus content by the Texas AgriLife Extension Service’s Soil, Water and Forages Testing Laboratory in College Station.



Figure 7. Turfgrass response to Geotube[®] residual material demonstration sample design

Results

The results of this experiment indicated that under these laboratory conditions, incorporating Geotube[®] solids into soils used to produce turfgrass had no detrimental effects on production or major impacts on leachate collected from the cylinders. In this demonstration, turfgrass production increased as Geotube[®] solids application rates increased in both evaluated soils. Results also showed that alum and polymers in the Geotube[®] solids did not negatively affect turf production.

Analysis of the soils amended with 0, 12.5, and 25 percent Geotube[®] solids showed decreasing trends in bulk density and gravimetric water content (likely due to increased organic matter from the Geotube[®] residuals and biomass production, respectively) while total organic carbon, total nitrogen, and total phosphorus increased as Geotube[®] solids levels increased.

Leachate analysis indicated that both nitrogen and phosphorus levels increased as Geotube[®] solids application rates increased; however, these increases provided nutrients needed to establish and produce quality turfgrass sod. Nitrate levels in the leachate did reach problematic proportions and may pose water quality threats to shallow groundwater during turfgrass establishment when nitrogen uptake is at its lowest levels.

Observed improvements in turfgrass productivity and soil properties combined with low leaching losses of SRP at high soil pH were indicative of the potential benefits of Geotube[®] solids incorporation in soils used to produce turfgrasses. Increases in Tifway bermudagrass clipping yields during establishment and maintenance provided evidence that incorporated, volume-based rates of Geotube[®] solids were an excellent source of inorganic and organic sources of P and N. In addition, the organic carbon incorporated through volume-based rates of solids reduced soil bulk density. Despite benefits to turfgrass and soil properties, the rates of Geotube[®] solids need to be managed to prevent detrimental effects on groundwater quality. High nitrate concentrations in the volume-based rates applied in the present study exceeded Tifway bermudagrass requirements during establishment, which contributed to high nitrate concentrations in soil and leachate. In contrast, leaching loss of dissolved reactive P from soil amended with the Geotube[®] solids was low even though volume-based rates increased total, soil-test, and water-extractable P to concentrations above plant requirements. Under the high soil pH conditions in the present study, the alum and/or polymers added during solids separation in the Geotube[®] could have limited solubility of reactive inorganic P forms even after the solids were incorporated in soil. Although leaching loss of soluble reactive P from volume-based rates of Geotube[®] solids was not problematic, observed leaching losses of inorganic N and organic P forms indicated rates less than 12.5 percent by volume may be necessary during turfgrass establishment.

Overall, the Geotube[®] demonstration proved the feasibility and highlighted the benefits of utilizing this residual material to produce value-added crops.

Appendix A

Agriculture is Life!

**Field Demonstration of the Performance
of an Electrocoagulation System
to Reduce Phosphorus and Other Substances
from Dairy Lagoon Effluent**

**Final Report
July 2006**

By:

**S. Mukhtar, Texas AgriLife Research
K. Wagner, Texas Water Resources Institute
L. Gregory, Texas Water Resources Institute**

**Funded by the Texas State Soil and Water Conservation Board
under CWA Section 319, EPA TSSWCB Project # 03-10**

**Partners: Texas AgriLife Extension Service (formerly Texas Cooperative Extension)
Texas Water Resources Institute
Ecoloclean Industries, Inc.**

**Texas Water Resources Institute Technical Report
January 2009**

Field Demonstration of the Performance of an Electrocoagulation System to Reduce Phosphorus and Other Substances from Dairy Lagoon Effluent



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Table of Contents

Executive Summary	1
Introduction	2
The Ecoloclean System	3
Sampling Methods	8
Results and Discussion	14
Total Solids	16
Total Volatile Solids	17
Total Fixed Solids	18
Total Suspended Solids	19
pH	20
Conductivity	21
Nitrate-Nitrite Nitrogen	22
Total Kjeldahl Nitrogen	24
Total Phosphorus	25
Soluble Phosphorus	26
Potassium	27
Calcium	28
Magnesium	29
Sodium	30
Manganese	31
Iron	32
Copper	33
Aluminum	34
Economics	35
Conclusion	35
References	36
Acknowledgements	36
Appendix I	37

Executive Summary

Two upper North Bosque River segments were designated as impaired in 1998 due to point source and 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 (SRP) concentrations by an average of 50%. This demonstration was conducted to evaluate the efficacy of a prospective new technology, an Electrocoagulation (EC) system, to potentially aid the dairy farmers in meeting the goals set by the TMDLs.

This EC system used chemical pre-treatment to coagulate and separate solids in slurry 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. The configuration of the system and its components varied from event to event. To accommodate these changes, the points at which samples were taken varied as well. At all sampling events, samples were taken from the lagoon effluent, the lagoon effluent after the addition of the chemical pre-treatments, the effluent from the EC system and the residual solids. Samples were also taken where the mixture exited the centrifuge after it was added to aid in removing solids. These samples were sent to the lab where they were analyzed for solids, nutrients, metals, pH, and conductivity.

In order for the EC unit to function properly, the technology provider removed large amounts of solids from the raw lagoon effluent even though its solid concentration was a low 0.6 mg/L. By the time the treated effluent reached the EC unit, concentrations of many analytes were so low it is hard to conclude whether or not it is an effective component for treating dairy lagoon effluent. Samples of effluent from the centrifuge indicated that it was the most efficient component in the system as it removed larger amounts of solids, as well as more of the nutrients and metals than any other component in the system. Overall, the performance of the system was sporadic from event to event, which may be attributed to the changes in the system that occurred. However, it was consistently effective in reducing total phosphorus (TP) and SRP, on average reducing these constituents by 96% and 99.6% respectively from the dairy lagoon effluent. Some uncertainty surrounds the efficacy of this system to reduce both TP and SRP so efficiently because both these and other nutrients are not stable and do change form.

Economic data shows that costs to treat dairy lagoon effluent were \$0.12 per gallon (\$120 per 1,000 gallons). This cost did not include removal of residual material from the farm and will vary depending on the number of cows and volume of process generated influent entering the lagoon. This price per gallon is considerably higher than traditional methods of sludge treatment that range from \$5 to \$32 per 1,000 gallons of treated effluent.

Introduction

Water quality degradation due to phosphorus (P) contribution as a nonpoint source of pollution from effluent and manure applied to waste application fields (WAFs) is a major concern in the Bosque River watershed. Point sources of pollution have also been identified as contributors to the problem in the Bosque River. 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 Texas Commission on Environmental Quality (TCEQ) to apply TMDLs for P to the designated segments. In December 2002, the TCEQ approved the implementation plan of these two TMDLs, and they were approved by the Texas State Soil and Water Conservation Board (TSSWCB) in January 2003. These TMDLs call for a reduction of the annual loading and annual average SRP concentrations by an average of 50%.

The TCEQ 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 WAFs is vital to protecting these water bodies.

Runoff from WAFs is not strictly regulated because it is regarded as a nonpoint source. Currently, a number of dairy operations in the 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 more efficient BMPs will need to be adopted by the dairies. One prospective BMP is the use of an EC system to remove pollutants from the effluent being stored and treated in dairy lagoons.

This report outlines the performance of an EC system that was introduced for evaluation by Ecoloclean Industries, Inc. This EC system used chemical pre-treatment to coagulate and separate solids in slurry 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. The configuration of the system and its components varied from event to event. To accommodate these changes, the points at which samples were taken varied as well. At all sampling events, samples were taken from the lagoon effluent, the lagoon effluent after the addition of the chemical pre-treatments, the effluent from the EC system and the residual solids. Samples were also taken where the mixture exited the centrifuge after its addition to the system to aid in solids removal. The system was set-up to treat the effluent from a 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 Electrocoagulation System

For the first sampling event on June 8, 2005 the system was configured as follows (Fig. 1):

- Effluent from the lagoon was pumped at about 40 gallons per minute into a large mixing tank (Fig. 3).
- Unknown quantities of Alum ($AlSO_4$), lime ($CaOH$), and a proprietary anionic emulsion polymer were pumped into the large mixing tank from separate smaller mixing tanks (Fig. 3).
- Unknown quantity of a proprietary “mud mixture” was mixed in the Tri-Flow tank (Fig. 4) 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 (in the DAF, small air bubbles are introduced in to the liquid. Solid flocculants adhere to the surface of the bubbles as they float to the top of the DAF tank. These solids are then removed by scraping them off the top of the liquid).
- The liquid exiting the DAF (Fig. 5) was then sent to the EC unit (Fig. 6).
- The effluent from the EC was pumped into a series of sequential tanks:
 - Reaction tank with a mixer (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),
 - Poly feed tank with a mixer (here 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),
 - Clarifier Tank A (in this tank the up-flow rate of the water is less than the settling rate of the coagulated solids to allow 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 (Fig. 6).

For the sampling event on June 27, 2005, the configuration was altered. The changes to Fig. 1 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 clarifier tank C.
- The effluent then drained into the final filter it was sampled.

For the following weeks, refer to Fig. 2:

On the next sampling conducted July 7, 2005 the DAF was returned to its original location in the system's components configuration, and the reaction tank was removed. A centrifuge (Fig. 8) was placed after the large mixing tank. The liquid exiting the centrifuge tank then proceeded onto 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.

For the sampling event 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 on July 26, 2005 and August 8, 2005, the configuration remained the same as that for the July 7, 2005 sampling.

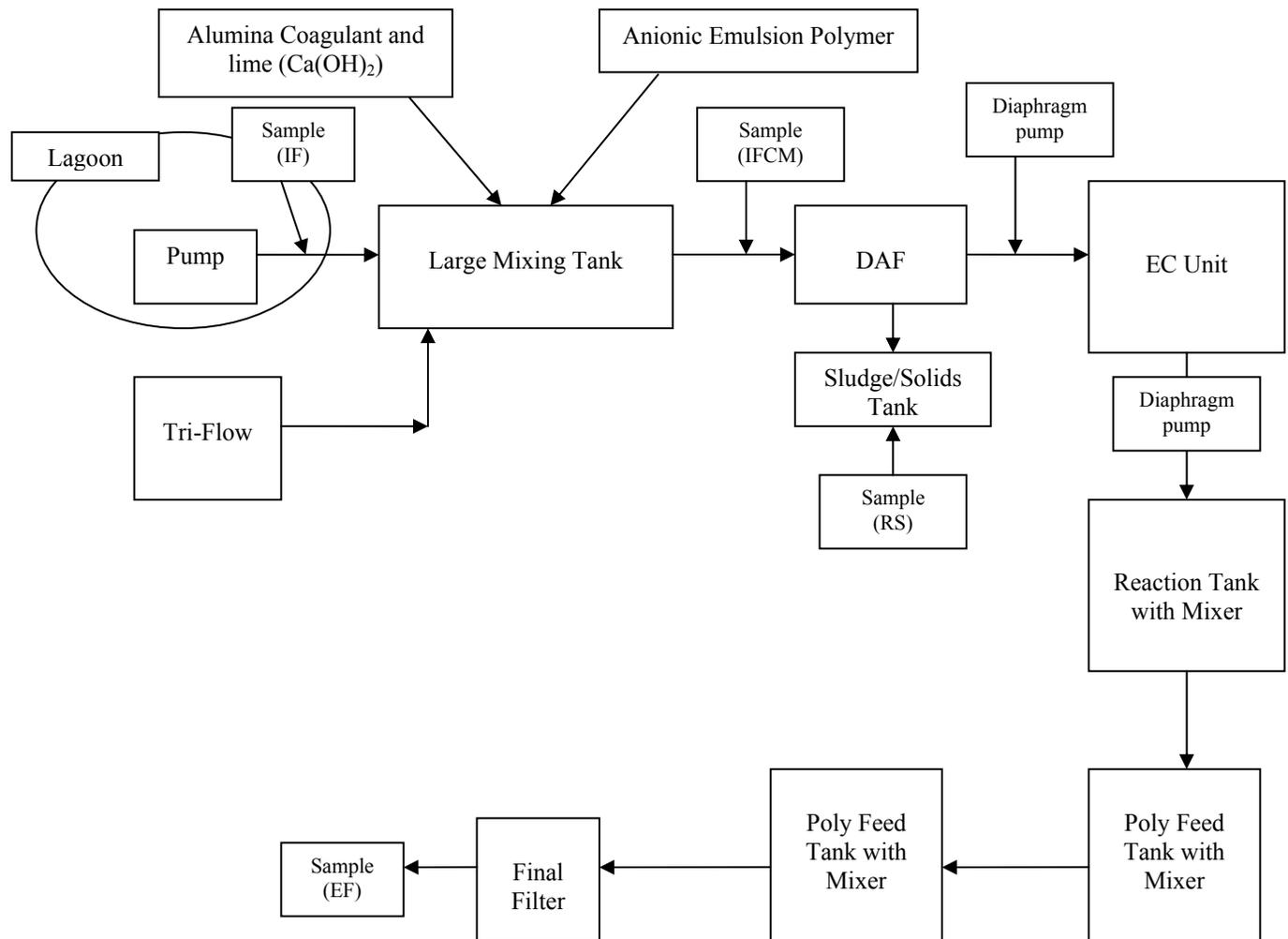


Fig. 1: Schematic of EC System's Components Configuration for the Weeks of June 8, 2005 and June 27, 2005

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
Collection/Equilization 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 are placed parallel to one another in the system.
The small mixing tanks and the Tri-Flow both feed into the large mixing tank, but do not interact with each other.

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
Collection/Equilization 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 are placed parallel to one another in the system.

The small mixing tanks and the Tri-Flow both feed into the large mixing tank, but do not interact with each other.

Sampling Method

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

Sampling event 1:

- Three sample sets were taken from the influent (IF) (lagoon effluent entering the system).
- One set of seven bottles were taken at the effluent outlet (EF). (Only seven bottles could be taken because the system could not be run for long enough to fill more than seven bottles.)
- 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.) (Fig. 1)

Sampling event 2:

- Two sample sets were taken from the lagoon effluent entering the system (IF). (Fig. 1)
- Two sets were taken from the mixture exiting the large mixing tank (IFCM). (Fig. 1)
- Three sample sets were taken at the effluent outlet (EF). (Fig. 1)
- Three samples of solids (RS) from the system were taken. (Solid samples were taken from the sludge tank. Fig. 1)

Sampling events 3 – 7:

- Two sample sets were taken from the lagoon effluent (IF) entering the system.
- Two sets were taken from the mixture exiting the large mixing tank (IFCM).
- Two sets were taken from the liquid exiting the centrifuge (PCF).
- Two samples of solids (RS) exiting the centrifuge were taken by fully filling a quart size freezer bag for each sample (Fig. 2).
- Two sets were taken at the effluent outlet (EF) (Fig. 2).

Samples were put on ice and transported to the laboratory within a few hours of each sampling event for analysis of the following analytes: Total Solids (TS), Total Volatile Solids (TVS), Total Fixed Solids (TFS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Soluble Phosphorus (SRP), Total Phosphorus (TP), Nitrate/Nitrite-Nitrogen (NNN), Total Kjeldahl Nitrogen (TKN), Potassium (K), Aluminum (Al) Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn), Iron (Fe), and Copper (Cu). These analytes were analyzed according to the methods in Table 2.

Table 2: Laboratory Analytical Methods*

Parameter	Method	Equipment Used
Nitrite+Nitrate Nitrogen	EPA 351.2	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Kjeldahl Nitrogen	EPA 353.2	Perstorp® or Lachat® QuickChem Autoanalyzer
Potassium	EPA 200.7	Spectro ® ICP
Calcium	EPA 200.7	Spectro ® ICP
Magnesium	EPA 200.7	Spectro ® ICP
Sodium	EPA 200.7	Spectro ® ICP
Manganese	EPA 200.7	Spectro ® ICP
Iron	EPA 200.7	Spectro ® ICP
Copper	EPA 200.7	Spectro ® ICP
Orthophosphate Phosphorus	EPA 365.2	Beckman® DU 640 Spectrophotometer
Total Phosphorus	EPA 365.2,4	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Suspended Solids	EPA 160.2	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Total Solids	SM 2540C	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Volatile Solids	EPA 160.4	Sartorius® AC210P or Mettler® AT261 analytical balance, oven, muffle furnace
Potential Hydrogen	EPA 150.1	Accument® AB15 Plus pH meter
Conductivity	EPA 120.1	YSI® 3200 conductivity meter
Aluminum	EPA 200.7	Spectro ® ICP

* Concentrations of Total Dissolved Solids were found by subtracting the concentrations of Total Suspended Solids from Total Solids.



Fig. 3. Large Tank (Top) to Mix Added Alum, lime, and a Polymer (Bottom) for Chemical Pretreatment of Lagoon Effluent



Fig. 4. The Tri-Flow “Mud Mixer”



Fig. 5. The Dissolved Air Flotation (DAF) Unit



Fig. 6. The EC Unit with Iron Electrodes, Built on a Filter Press Frame



Fig. 7. The Final Filter and Port for Effluent Sampling



Fig. 8. Sample Being Taken from the Centrifuge

Results and Discussion

In the following section, results for each analyte are reported using the following abbreviations (Figs. 1 and 2 for locations where the samples were taken):

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

Generally, concentrations of all physicochemical constituents analyzed from the lagoon effluent (influent pumped to the EC system) varied among sampling events. This may be attributed to the inlet location and depth in the lagoon that may have varied from week to week during these sampling events. Changing inlet locations are typical of dairy lagoons and were utilized to represent a field scenario for testing this technology. Pumps used to irrigate fields are situated on floating platforms that can move around in the lagoon; depth also changes quite often due to pumping, influent entering the lagoon, and rainfall events.

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

Project limitations prohibited sample collection from occurring after each component in the system; however, this did not defeat the goal of measuring the overall effectiveness of the system to remove P from lagoon effluent. During the last five sampling events, the system setup (Fig. 1) allowed us to single out the large mixing tank (IF to IFCM) and the centrifuge (IFCM to PCF) and evaluate their individual effectiveness. During those weeks, those two components were responsible for removing the bulk of TP and SRP (see Table 11a and 12a). Other system components could not be individually sampled. Overall, the system removed at least 90% of TP and SRP in all sampling events.

Effluent samples from the centrifuge (PCF) indicated that it was the most efficient component in the system as it removed larger amounts of solids, nutrients, and metals than any other component in the system. In Fig. 9, the analytes are grouped according to the stage in the system (i.e. IF to IFCM or PCF to EF) which was most effective in reducing its concentration. Fig. 9 shows that the centrifuge was by far the most efficient component for the most analytes and that chemical pre-treatment was the second most efficient within the system.

The main reductions in Na (although there was an overall increase in Na concentrations), K, and conductivity occurred between the sampling point after the centrifuge (PCF) and the final filter (EF). It is not clear why these reductions occurred. The EC unit may not

have caused these reductions since Na and K are positively charged metals and would not be affected by the positive iron ions being given off by the electrodes. These analytes are also highly soluble and would most likely not settle out in the series of tanks in between the two sampling points. In order for the EC unit to function properly, the technology provider removed large amounts of solids from the raw lagoon effluent even though its solid concentration was only about 0.6 mg/L. By the time the treated effluent reached the EC unit, concentrations of many analytes were so low it is hard to conclude whether or not it is an effective component for treating dairy lagoon effluent.

With the exception of Nitrate-Nitrite Nitrogen, there was no relationship between the concentration of any analyte and its overall percent reduction by the system from one sampling event to the other. For many of the analytes, either increase or reduction of their concentrations by different components in the system was variable among all sampling events. Concentrations of all analytes in residual solids (solids separated by the centrifuge) were substantially greater than those sampled from any other location in the system.

Because it was not possible to take a full set of samples on the June 8, 2005 event, and because of inconsistencies in the system's components configuration for this event, the data from this sampling was not used in the comparisons for this report

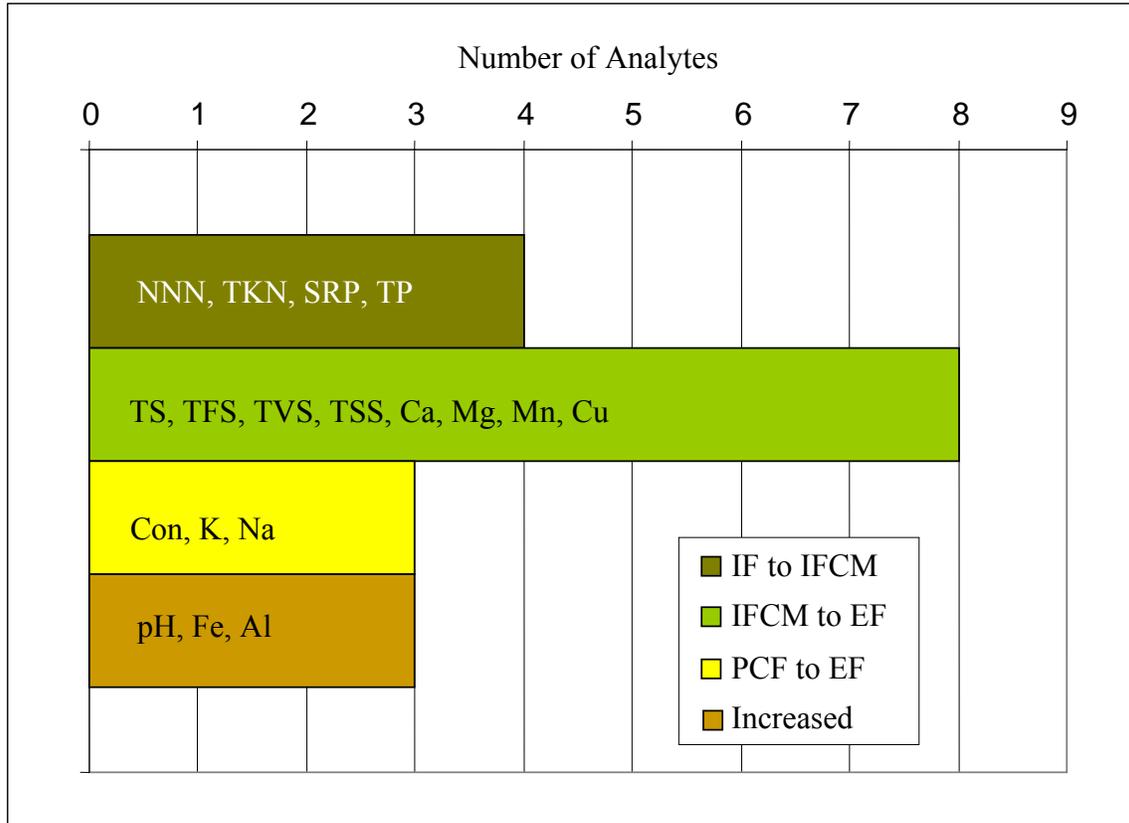


Fig. 9. Analytes Grouped According to the Stage in the System which was the most Efficient in Reducing its Concentration

Total Solids (TS)

(Refer to Tables 3.a and 3.b)

There was a small but consistent drop in the concentration of influent TS over all six sampling events. The expected increase in concentration of TS from the influent to IFCM is apparent; however, the amount of increase varied from event to event. PCF values of TS were somewhat similar for most sampling events, but reduction of TS by the centrifuge (between IFCM and PCF) varied from event to event. Generally, the largest reduction of TS resulted in the liquid samples collected post centrifuge (IFCM) indicating the key mechanism for removing TS was the centrifuge. Conversely, a small reduction in TS concentrations from PCF to EF suggested that the EC unit was less effective in the removal of TS. The percent change from IF to EF of the lagoon effluent TS in the system was highly variable among all sampling events.

Table 3.a. Average and Standard Deviations of TS Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 3.b. 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	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	-0.47					
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
IF to EF	-0.41	-0.21	-0.24	-0.24	-0.16	-0.36
% Change (IF to EF)	-63	-35	-40	-41	-29	-65

Total Volatile Solids (TVS)

(Refer to Tables 4.a and 4.b)

The concentration of TVS in the influent was nearly 45% of TS over all six sampling events. Influent TVS concentrations after the chemical pretreatment varied somewhat and generally increased compared to those for the IF because of the addition of chemicals and other solids during pretreatment of IF. Both concentrations of TVS after the centrifuge (PCF) and effluent (EF) showed little variability among all sampling events. The largest reduction of TVS in the system occurred between IFCM and PCF, indicating the centrifuge was the predominant mechanism for removing TVS. The percent change from IF to EF of TVS was inconsistent from event to event.

Table 4.a. Average and Standard Deviations of TVS Concentrations for each Sampling Point in the System*

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (s.d.)	0.26 ± 0.002	0.27 ± 0.004	0.27 ± 0.004	0.25 ± 0.002	0.24 ± 0.004	0.23 ± 0.004
IFCM (s.d.)	0.20 ± 0.16	0.37 ± 0.04	0.30 ± 0.19	0.39 ± 0.02	0.34 ± 0.09	0.27 ± 0.07
PCF (s.d.)		0.13 ± 0.008	0.15 ± 0.016	0.11 ± 0.020	0.13 ± 0.042	0.12 ± 0.008
EF (s.d.)	0.05 ± 0.002	0.09 ± 0.002	0.10 ± 0.001	0.10 ± 0.003	0.10 ± 0.002	0.05 ± 0.009
RS (s.d.)	8 ± 0.25	7 ± 0.03	4 ± 0.35	5 ± 2.1	5 ± 0.15	4 ± 0.21

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 4.b. 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	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	-0.15					
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
IF to EF	-0.22	-0.17	-0.16	-0.16	-0.14	-0.18

% Change (IF to EF)	-83	-66	-61	-62	-59	-78
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Total Fixed Solids (TFS)

(Refer to Tables 5.a and 5.b)

The TFS concentration in the influent was fairly consistent with small decreases on the second and third event. The concentration of TFS after the chemical pretreatment was highly variable. Concentrations of TFS after the centrifuge and in the effluent were fairly consistent for all six sampling events. The largest drop in TFS concentrations in the system was seen between the point where the chemical pretreatment was added (IFCM) and after it exited the centrifuge (PCF). This indicated that the key mechanism for removing TFS from lagoon effluent was the centrifuge. The percent change from IF to EF for TFS was highly variable for all six sampling events.

Table 5.a. Average and Standard Deviations of TFS Concentrations for each Sampling Point in the System*

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (s.d.)	0.39 ± 0.001	0.35 ± 0.0	0.32 ± 0.03	0.32 ± 0.004	0.32 ± 0.004	0.32 ± 0.008
IFCM (s.d.)	0.52 ± 0.33	0.75 ± 0.08	0.74 ± 0.39	0.97 ± 0.08	0.95 ± 0.30	0.78 ± 0.23
PCF (s.d.)		0.35 ± 0.02	0.34 ± 0.09	0.28 ± 0.02	0.34 ± 0.10	0.30 ± 0.03
EF (s.d.)	0.20 ± 0.008	0.31 ± 0.004	0.25 ± 0.003	0.25 ± 0.03	0.29 ± 0.004	0.14 ± 0.001
RS (s.d.)	24 ± 1.99	20 ± 0.44	13 ± 2.0	15 ± 6	19 ± 1.6	18 ± 0.60

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 5.b. 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	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	-0.32					
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
IF to EF	-0.19	-0.04	-0.07	-0.08	-0.02	-0.18

% Change (IF to EF)	-49	-12	-23	-24	-7	-56
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Total Suspended Solids (TSS)

(Refer to Tables 6.a and 6.b)

The TSS concentration in the influent shows a small but consistent drop with each consecutive sampling event. TSS concentrations of IFCM are fairly inconsistent from event to event and, as expected, showed a marked increase from the TSS concentrations in the influent due to addition of chemicals and the proprietary ‘mud mix’. Concentrations of TSS after the centrifuge were similar from event to event with the exception of a much higher value on July 26. The centrifuge removed most TSS from the lagoon effluent being treated by the system. The percent change from IF to EF was highly variable ranging from a 46% increase to a 99% decrease over the six sampling events. In fact, on two of the six sampling events (July 7 and July 26), there was an overall increase in the TSS.

Table 6.a. Average and Standard Deviations of TSS Concentrations for each Sampling Point in the System*

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (s.d.)	0.09 ± 0.03	0.07 ± 0.07	0.05 ± 0.05	0.06 ± 0.06	0.06 ± 0.06	0.04 ± 0.04
IFCM (s.d.)			0.65 ± 0.65	1.06 ± 1.06	1.01 ± 1.01	0.84 ± 0.08
PCF (s.d.)		0.03 ± 0.03	0.02 ± 0.02	0.06 ± 0.06	0.27 ± 0.27	0.08 ± 0.08
EF (s.d.)	0.01 ± 0.004	0.09 ± 0.09	0.03 ± 0.03	0.04 ± 0.04	0.09 ± 0.09	0.02 ± 0.02

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 6.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM			0.60	1.00	0.96	0.80
IF to PCF		-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
IF to EF	-0.08	0.02	-0.01	-0.02	0.03	-0.01

% Change (IF to EF)	92	-18	31	32	-46	40
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pH

(Refer to Tables 7.a and 7.b)

The pH of the influent had only slight variability in the samples for each event. The small increase in pH observed may have resulted from addition of lime in the pretreatment. There was also a consistent decrease in pH after the treated lagoon effluent passed through the centrifuge (with the exception of July 19 when there was an increase), and a consistent increase after the slurry passed through the EC unit. Overall, there was a small increase in pH with the exception of the sampling event on July 26.

Table 7.a. Average and Standard Deviations of pH for each Sampling Point in the System*

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

*All values are on an as is basis.

Table 7.b. 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	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	-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
IF to EF	0.5	0.2	0.3	0.1	0.0	0.2
% Change (IF to EF)	7	2	3	2	0	2

Conductivity (Cond)

(Refer to Tables 8.a and 8.b)

There was a small but steady drop in the influent conductivity over the six events that correspond to the pattern of declining concentration seen in the solids. There were slight increases and decreases in conductivity among sampling points in the system. These changes were not uniform from event to event. Percent change from IF to EF varied 35% over the six sampling events. These reductions were due to the removal of sodium and other conductive substances in the lagoon effluent treated by the system.

Table 8.a. Average and Standard Deviations of Conductivity for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in µS/cm

Table 8.b. Change in Conductivity between Each Sampling Point in the System as well as the Over All Percent Change of Conductivity in the System (IF to EF)

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM			-775	-160	-665	-570
IF to PCF		-130				
IFCM to PCF			740	-470	525	355
PCF to EF		-1355	-1820	-985	-795	-3035
IF to EF	-2431.7	-1485	-1855	-1615	-935	-3250
% Change (IF to EF)	32	21	28	24	14	49

Calcium (Ca)

(Refer to Tables 14.a and 14.b)

As with the influent TS concentrations, there was a small but steady drop in the concentration of Ca in the influent over the six sampling events. The variations in the concentrations of the samples for each event were small as well. There was a large increase in the concentration from IF to IFCM due to the lime (CaOH_2) added during the chemical pretreatment. The largest reduction of Ca from the lagoon effluent occurred between IFCM and PCF, indicating that the centrifuge was responsible for removing the majority of Ca. The amount of Ca removed by the EC unit was small in comparison to the reduction by the centrifuge. The percent change from IF to EF ranged nearly 72% over the six sampling events.

Table 14.a. Average and Standard Deviations of Ca Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 14.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	405	1118	1784	1303	1458	710
IFCM to EF	-668					
IFCM to PCF		-1177	-1865	-1383	-1451	-754
PCF to EF		-54	-88	-51	-47	-106
IF to EF	-263	-112	-169	-131	-40	-150
% Change (IF to EF)	-89	-42	-66	-55	-17	-66

Regression Plot of NNN IF Concentration vs. Overall Percent Reduction

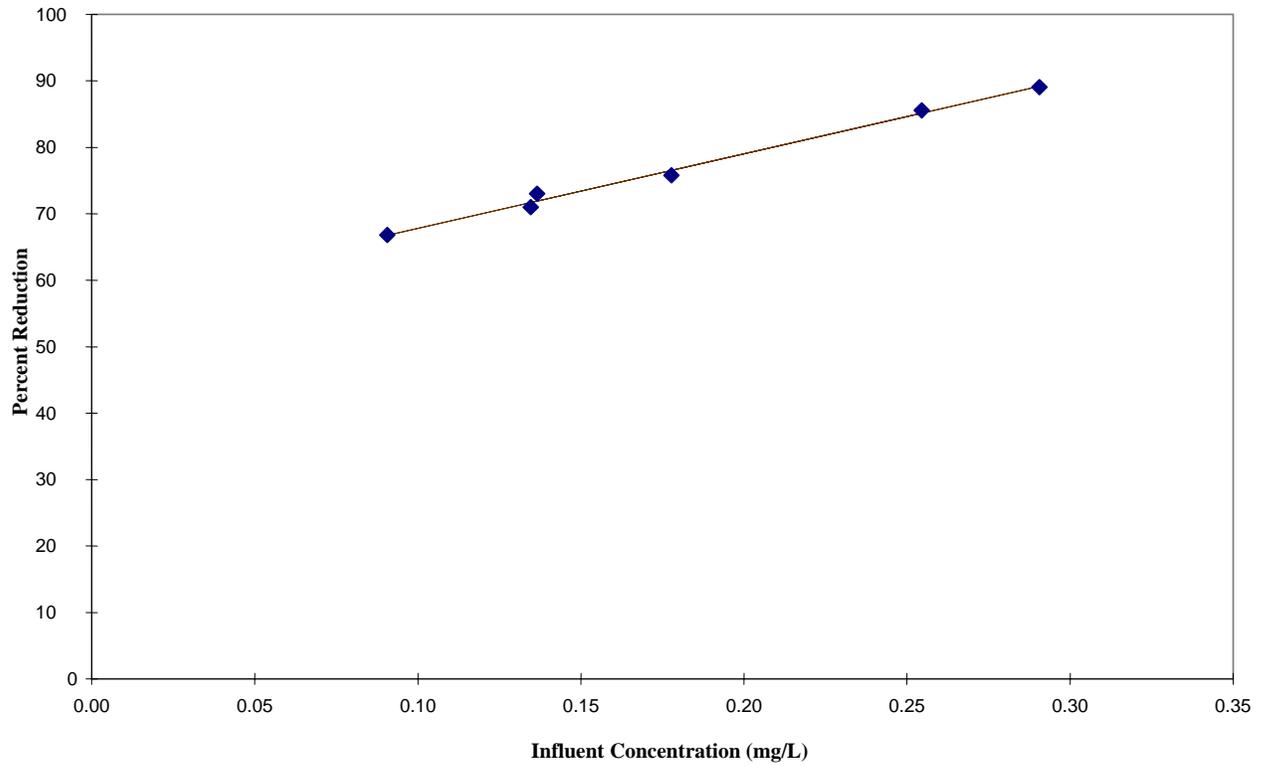


Fig. 10. Plot of NNN IF Concentration and Overall Percent Reduction along with the Line of Best Fit

Total Kjeldahl Nitrogen (TKN)

(Refer to Tables 10.a and 10.b)

The concentration of TKN in the influent was fairly consistent from event to event. The amount of TKN removed by the chemical pretreatment (IF to IFCM) was inconsistent as was the amount removed by the solids separation in the centrifuge and the amount removed by the EC unit. As a result of this inconsistency, it did not appear that any one mechanism in the system was key to removing TKN from lagoon effluent. The percent change from IF to EF of TKN by the entire system was variable and ranged from as low as nearly 37% to as high as 72%, over the six sampling events.

Table 10.a. Average and Standard Deviations of TKN Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 10.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	-507	-3	-105	-76	-167	-99
IFCM to EF	184					
IFCM to PCF		-212	-86	-116	-16	-70
PCF to EF		11	-99	-48	-106	-206
IF to EF	-323	-204	-290	-239	-289	-376
% Change (IF to EF)	-51	-37	-49	-46	-52	-72

Total Phosphorus (TP)

(Refer to Tables 11.a and 11.b)

The concentration of TP in the influent was fairly consistent over most sampling events, with the exception of highly variable values on the first sampling event. Concentrations of TP after chemical pretreatment (IFCM) varied highly from week to week. There was also some variability in the TP concentrations in samples collected after the centrifuge (PCF) and in the final effluent. For some sampling events the largest reduction occurs between IF and IFCM and on other events it occurs between IFCM and PCF. On average, the system effectively removed more than 90% of TP from raw lagoon influent.

Table 11.a. Average and Standard Deviations of TP Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 11.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	-27	-10	-52	-10	-34	-13
IFCM to EF	-9					
IFCM to PCF		-41	-1	-40	-10	-35
PCF to EF		3	-0.6	-3	-6	-6
IF to EF	-36	-48	-54	-54	-50	-53
% Change (IF to EF)	-98	-93	-98	-98	-92	-98

Soluble Phosphorus (SRP)

(Refer to Tables 12.a and 12.b)

The concentration of SRP in the influent varied slightly over all of the six sampling events. Table 3.a shows that the largest reduction in SRP concentration occurred between IF and IFCM. This indicates that the chemical pretreatment was the key mechanism for reducing SRP in this system. The percent change from IF to EF for the entire system was consistently higher than 99%; however, the increment in percent reduction from IFCM to EF was very small. This indicates the EC unit played a very small role in the removal of SRP from the lagoon effluent treated by the system.

Table 12.a. Average and Standard Deviations of SRP Concentrations for each Sampling Point in the System*

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (s.d.)	4.1 ± 0.13	4.6 ± 0.10	4.6 ± 0.11	5.7 ± 0.07	4.1 ± 0.02	5.3 ± 1.4
IFCM (s.d.)	0.50 ± 0.35	0.05 ± 0.009	0.05 ± 0.04	0.07 ± 0.002	0.12 ± 0.06	0.15 ± 0.11
PCF (s.d.)		0.05 ± 0.004	0.01 ± 0.002	0.11 ± 0.067	0.22 ± 0.012	0.11 ± 0.095
EF (s.d.)	0.064 ± 0.046	0.015 ± 0.007	0.006 ± 0.001	0.006 ± 0	0.010 ± 0.004	0.007 ± 0
RS (s.d.)	6.8 ± 1.4	0.25 ± 0.06	0.20 ± 0.12	1.7 ± 0.77	0.28 ± 0.03	2.4 ± 0.3

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 12.b. Change in Concentration (mg/L) of SRP between each Sampling Point in the System as well as the Over All Percent Change of SRP in the System (IF to EF)

Date	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	-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
IF to EF	-4.0	-4.6	-4.6	-5.7	-4.1	-5.3
% Change (IF to EF)	-98	-99.7	-99.9	-99.9	-99.8	-99.9

Potassium (K)

(Refer to Tables 13.a and 13.b)

The concentration of K in the influent decreased steadily for the first four sampling events then increased for the last two. This did not correspond to any pattern seen in the other analytes. The largest reductions of K occurred with the centrifuge but reductions in lagoon effluent K were generally small and inconsistent at different treatment points in the system on each sampling event. The percent change from IF to EF varied widely; ranging nearly 45% over the six sampling events.

Table 13.a. Average and Standard Deviations of K Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 13.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	-146	-201	-64	39	-61	-61
IFCM to EF	-203					
IFCM to PCF		90	-74	-120	-42	-70
PCF to EF		2	-153	-400	-51	-353
IF to EF	-349	-109	-290	-480	-153	-484
% Change (IF to EF)	-38	-13	-34	-65	-20	-62

Calcium (Ca)

(Refer to Tables 14.a and 14.b)

As with the influent TS concentrations, there was a small but steady drop in the concentration of Ca in the influent over the six sampling events. The variations in the concentrations of the samples for each event were small as well. There was a large increase in the concentration from IF to IFCM due to the lime (CaOH_2) added during the chemical pretreatment. The largest reduction of Ca from the lagoon effluent occurred between IFCM and PCF, indicating that the centrifuge was responsible for removing the majority of Ca. The amount of Ca removed by the EC unit was small in comparison to the reduction by the centrifuge. The percent change from IF to EF ranged nearly 72% over the six sampling events.

Table 14.a. Average and Standard Deviations of Ca Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 14.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	405	1118	1784	1303	1458	710
IFCM to EF	-668					
IFCM to PCF		-1177	-1865	-1383	-1451	-754
PCF to EF		-54	-88	-51	-47	-106
IF to EF	-263	-112	-169	-131	-40	-150
% Change (IF to EF)	-89	-42	-66	-55	-17	-66

Magnesium (Mg)

(Refer to Tables 15.a and 15.b)

Concentration of Mg in the influent consistently decreased a small amount over all sampling events. This trend was similar to TS concentrations in the influent. The change in concentration from IF to IFCM was inconsistent which may be due to the changes in chemical pretreatment from event to event. The reduction in Mg concentration between the different sampling points was inconsistent from event to event but the centrifuge removed the most Mg from the lagoon effluent treated by the system. The percent change from IF to EF varied slightly and ranged about 20% over the six sampling events.

Table 15.a. Average and Standard Deviations of Mg Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 15.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	-89	-43	-46	11	36	-2
IFCM to EF	-51					
IFCM to PCF		-57	-92	-89	-88	-54
PCF to EF		-14	-6	-27	-26	-59
IF to EF	-140	-114	-143	-105	-78	-115
% Change (IF to EF)	-59	-52	-66	-57	-43	-63

Sodium (Na)

(Refer to Tables 16.a and 16.b)

Similar to TS and some other metals, the concentration of Na in the influent consistently decreased over all of the sampling events. The increases and decreases in Na concentration of the lagoon effluent being treated varied inconsistently from event to event making it unclear if there was any one mechanism contributing to the removal of Na. The percent change from IF to EF varied widely, ranging from a 7% increase to a 36% decrease.

Table 16.a. Average and Standard Deviations of Na Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 16.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	-19	-81	21	54	29	43
IFCM to EF	-80					
IFCM to PCF		93	-24	-63	-36	-46
PCF to EF		7	-70	-26	-2	-71
IF to EF	-99	19	-73	-35	-9	-74
% Change (IF to EF)	-31	7	-27	-16	-4	-36

Manganese (Mn)

(Refer to Tables 17.a and 17.b)

The concentration of Mn in the influent varied inconsistently from event to event; however, these variations were only a fraction of a mg/L for each event. There was a consistent decrease in Mn concentration between IFCM and PCF for all sampling events, showing that the centrifuge was effective in removing Mn from the lagoon effluent. From PCF to EF, there is a proportionally substantial increase in Mn concentration, ranging from a 5600% increase to a 170% increase over the five events employing the centrifuge. This many-fold increase may have been the addition of proprietary ‘mud mix,’ ahead of the centrifuge to the lagoon effluent. The percent change from IF to EF was highly variable, ranging from a 24% increase to an 80% decrease over the six sampling events.

Table 17.a. Average and Standard Deviations of Mn Concentrations for each Sampling Point in the System*

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (s.d.)	1.2 ± 0.02	1.1 ± 0.04	1.2 ± 0.02	0.8 ± 0.13	0.99 ± 0.01	1.1 ± 0.005
IFCM (s.d.)	0.8 ± 0.86	1.3 ± 0.22	1.1 ± 0.33	1.2 ± 0.41	1.9 ± 0.23	1.2 ± 0.19
PCF (s.d.)		0.04 ± 0.002	0.02 ± 0.02	0.06 ± 0.06	0.28 ± 0.23	0.16 ± 0.06
EF (s.d.)	0.2 ± 0.02	1.3 ± 0.02	1.2 ± 0.19	0.4 ± 0.63	1.2 ± 0.24	0.4 ± 0.08
RS (s.d.)	59 ± 1.9	37 ± 4.0	15 ± 4.1	23 ± 18	26 ± 1.9	27 ± 0.392

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 17.b. 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	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	-0.6					
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
IF to EF	-1.0	0.2	-0.04	-0.4	0.2	-0.6
% Change (IF to EF)	-83	20	-3	-45	24	-60

Iron (Fe)

(Refer to Tables 18.a and 18.b)

Influent Fe concentrations fluctuated slightly and generally decreased from event to event. There was a substantial increase in Fe concentration from IF to IFCM for all of the six sampling events. This increase was due to the chemical pretreatment of the lagoon effluent. The amount with which the Fe concentration increased was variable from event to event. A substantial decrease was seen from IFCM to PCF, indicating that the centrifuge was effective in reducing the concentration of Fe after the chemical pretreatment. Due to the ions given off by the iron electrodes in the EC unit, there was a very large increase in the effluent leaving the EC unit. Overall, there was a very large, but variable percent increase for all of the six sampling events ranging from a 28% increase to a 2600% increase.

Table 18.a. Average and Standard Deviations of Fe Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 18.b. 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	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	-3.6					
IFCM to PCF		-15	-9	-15	-25	-14
PCF to EF		82	94	70	83	20
IF to EF	1.2	78	90	67	82	18
% Change (IF to EF)	28	2052	2627	1798	2270	552

Copper (Cu)

(Refer to Tables 19.a and 19.b)

Cu concentrations in the influent were fairly consistent, varying only slightly from event to event. The change in Cu concentration from IF to IFCM was inconsistent. For all sampling events regardless of the increase or decrease due to the chemical pretreatment, there was a considerable decrease in Cu concentration from IFCM to PCF. This indicated that the centrifuge was effective in removing Cu from the influent. The amount of the decrease from IFCM to PCF became smaller each event. The change in concentration was highly variable from PCF to EF ranging from a 700% increase to a 50% decrease. Therefore, it appeared that the EC unit does not effectively remove Cu from the lagoon effluent. With the exception of the event on July 19, there was a substantial percent change from IF to EF of Cu mainly due to the centrifuge effectively removing solids from the lagoon effluent being treated by the system.

Table 19.a. Average and Standard Deviations of Cu Concentrations for each Sampling Point in the System*

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

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 19.b. 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	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	-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
IF to EF	-1.12	-1.04	-1.11	0.13	-0.77	-0.87
% Change (IF to EF)	-92	-90	-96	14	-84	-81

Aluminum (Al)

(Refer to Tables 20.a and 20.b)

Concentration of Al in the influent was fairly consistent, varying slightly from event to event. There was a many fold increase in Al concentration from IF to IFCM due to the addition of alum (Al_2SO_4) in the pretreatment. The largest reduction of Al in the system occurred between IFCM and PCF, indicating that the centrifuge was the key mechanism for removing Al. There was a reduction of Al concentration by the EC unit, with the exception of the event on July 7 where there was a substantial increase between PCF and EF of 390%. The percent change from IF to EF ranged from an 1180% increase to a 4% decrease over the six sampling events.

Table 20.a. Average and Standard Deviations of Al Concentrations for each Sampling Point in the System*

Date	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF (s.d.)	2 ± 0.3	2 ± 0.1	2 ± 0.3	2 ± 0.0	2 ± 0.1	1 ± 0.1
IFCM (s.d.)	75 ± 67	300 ± 43	274 ± 172	242 ± 69	160 ± 1	115 ± 24
PCF (s.d.)		5 ± 0.3	8 ± 0.4	11 ± 6	32 ± 36	13 ± 15
EF (s.d.)	2 ± 1.3	23 ± 3.8	3 ± 0.8	10 ± 7.6	16 ± 0.1	2 ± 2.8
RS (s.d.)	4451 ± 353	7158 ± 2654	3537 ± 1939	9615 ± 4045	4732 ± 360	4064 ± 582

*All values are on an as is basis. IF, IFCM, PCF and EF are in mg/L, RS is in mg/Kg.

Table 20.b. 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	27-Jun	7-Jul	12-Jul	19-Jul	26-Jul	2-Aug
IF to IFCM	73	298	272	240	157	114
IFCM to EF	-73					
IFCM to PCF		-295	-266	-231	-127	-102
PCF to EF		18	-5	-1.3	-17	-11
IF to EF	-0.09	21	1.4	8	13	1.2
% Change (IF to EF)	-4	1185	84	456	538	89

Economics

Economic information for the EC system was provided by Mr. Royis Ward from Ecoloclean Industries. Their estimate shows that the cost for the EC system to treat effluent from the dairy lagoon during this test was approximately \$0.12 per gallon (\$120 per 1,000 gallons) of treated effluent. This estimate does not include the costs to remove residual materials from the dairy. Costs will vary depending on the number of cows at each dairy and the volume of process generated influent entering the lagoon.

Compared to conventional methods; the EC system costs substantially more per 1,000 gallons of treated effluent. In 2000, the Environmental Review Commission of the North Carolina General Assembly estimated that using conventional technologies costs between \$5 and \$32 per 1,000 gallons of treated effluent depending on the type of treatment process employed.

Conclusion

Due to the designation of the two upper North Bosque River segments as impaired from point source and nonpoint source pollution of P 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 produce the needed reductions; therefore, many prospective new technologies are being researched.

The results for this EC system from six sampling events showed that the system removed TP and SRP on average by 96% and 99.6% respectively from the dairy lagoon effluent. The performance of the entire system with respect to removing metals was sporadic, only Mg was observed to have consistent reductions from each sampling event. The rest of the metals had a wide range of reductions and increases without any apparent trends from event to event. The inconsistencies in the performance of this system for both the metals and solids is very possibly linked to the changes made in the system's configuration and the changes in the chemical pre-treatment from event to event.

This system was effective in reducing both TP and SRP from lagoon effluent and exceeded the TMDL goal of 50% P removal. Costs for installing and operating this system could be an issue; but dairy producers will make the final decision whether or not to implement this technology. Findings from this study will be summarized in a fact sheet and distributed to dairymen, County Extension agents, the advisory committee, and other interested parties allowing them to make informed decisions about this technology.

References

Texas Natural Resource Conservation Commission (TNRCC) (Now TCEQ). 2001. Two Total Maximum Daily Loads for Phosphorus in the North Bosque River. The Strategic Assessment Division, TNRCC.

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Appendix A-I

Raw Data: Concentrations of analytes for samples treated as liquid

Table A.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 A.2. Conductivity and Metals (mg/L) Concentrations 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 A.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 A.4. Conductivity and Metals (mg/L) Concentrations 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 A.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 A.6. Conductivity and Metals (mg/L) Concentrations 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 A.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 A.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 B

Agriculture is Life!

**Field Demonstration of the Performance of a
Geotube® Dewatering System to Reduce
Phosphorus and Other Substances from
Dairy Lagoon Effluent**

**Final Report
July 2006**

By:

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**Funded by the Texas State Soil and Water Conservation Board
under CWA Section 319, EPA TSSWCB Project # 03-10**

**Partners: Texas AgriLife Extension Service (formerly Texas Cooperative Extension)
Texas Water Resources Institute
Ten Cate Nicolon – Miratech Division**

**Texas Water Resources Institute Technical Report
January 2009**

*Field Demonstration of the Performance of a
Geotube® Dewatering System to Reduce
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Table of Contents

Executive Summary	1
Introduction	2
Geotube® Dewatering System	3
Methods	6
Sampling	6
Calculations	8
Results	10
Solids and pH	10
Nutrients	11
Metals	11
Conductivity	11
Mass Balance	12
Economics	17
Conclusion	17
References	19
Acknowledgements	19
Appendix I	20
Appendix II	22

Executive Summary

Two upper North Bosque River segments were designated as impaired in 1998 due to point source and 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 (SRP) concentrations by about 50%. This demonstration was conducted to evaluate the efficacy of a prospective new technology, the Geotube® dewatering system that may aid dairy farmers in reducing P from lagoon effluent to be applied to waste application fields and thus reducing NPS pollution.

In this Geotube® dewatering system, effluent is pumped from the dairy lagoon using a PTO-driven chopper pump into a PVC pipe with a series of elbows that facilitate thorough mixing of the chemical pretreatment. Alum and a polymer are added to the effluent agglomerate solids and precipitate P as it flows through the elbows to the Geotubes®. Two 14' x 50' geotextile fabric tubes were installed on a 6 millimeter impermeable polyethylene sheet next to a primarily dairy lagoon that received flushed manure. After the tubes were filled, they were allowed to dewater for a period of 6 months. Rainwater typically sheds off of the tubes and does not soak into the tubes. At the first two sampling events in March and April 2005, samples of the dairy lagoon effluent, the lagoon effluent after the addition of the chemical pre-treatment, and the effluent dewatering from the tubes were taken and flow rates into the tube were measured. At the last sampling event in October 2005, samples of residuals and depth of the dewatered residuals were taken from both tubes. Samples from the three events were analyzed for concentration of solids, nutrients, metals and pH.

Results showed that the Geotube® dewatering 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 SRP for the two events was very high at 85%. It should be noted that these findings were limited to the sampling of the tubes in March and April and the tubes continued to dewater for several months. Therefore, any changes in the concentration of the dewatering effluent, volatilizing solids and precipitating substances after the sampling events could not be accounted for.

A brief economic analysis of this dewatering system was furnished by the technology provider. Cost estimates for a long-term dewatering system were \$90,000 to treat 1.9 million gallons of dairy lagoon effluent containing 15+ years worth of nutrients and solids that settled to the bottom of the lagoon at a 2000 head lactating cow open-lot dairy. This estimate includes all capital and operating costs except removal of residual solids. Costs will vary depending on the size of the dairy and the length of time between lagoon treatments using Geotubes®.

Introduction

Water quality degradation due to phosphorus (P) contribution as a nonpoint source pollutant from effluent and manure applied to waste application fields (WAFs) is a major concern in the Bosque River watershed. Point source pollutants have also been identified as contributors to the problem in the Bosque River. 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 Texas Commission on Environmental Quality (TCEQ) to apply TMDLs for P to the designated segments. In December of 2002, the Texas Commission on Environmental Quality approved the implementation plan of these two TMDLs, and these plans were approved as well by the Texas State Soil and Water Conservation Board (TSSWCB) in January, 2003. These TMDLs call for a reduction of the annual loading and annual average SRP concentrations by about 50%.

The TCEQ 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 WAFs is vital to protecting these water bodies.

Runoff from WAFs is not strictly regulated because they are regarded as a nonpoint source. Currently, a number of dairy operations in the 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 more efficient BMPs will need to be adopted by the dairies. One prospective BMP is the use of a Geotube[®] dewatering system, to remove P and other constituents from the effluent being stored and treated in dairy lagoons.

This report outlines the performance of a Geotube[®] dewatering system which 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 the solids from the lagoon effluent. The mixture is then pumped into two large geotextile filtration tubes situated on 6 millimeter impervious polyethylene sheeting. On the down slope end of each tube, a synthetic felt-like fabric was installed to prevent potential soil erosion from water leaving the tube. The synthetic fabric of the geotextile tube acts as a filter as the liquid is pumped into the tube and a high percentage of the solids are retained as the liquid weeps from the pores in the fabric (Worley, 2004). After the tubes are filled to a height of approximately 5' with the mixture (Fig. 2.b), the pumping of effluent ceases and they are left to dewater for 6 months. After dewatering, the residuals are disposed of off-site. The dewatering system comprised of two 14' X 50' tubes was set-up to treat the 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.

Geotube[®] Dewatering System

For the sampling events on March 30, 2005 and April 6, 2005 the system's configuration was as follows (Figs. 1, 2.a, and 3):

- 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 (Fig 3).
- 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 polymer were injected as a chemical pre-treatment into the pipe as the liquid flowed through a series of 90° elbows which served to mix the liquid with the pre-treatment (Fig 2a).
- 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.

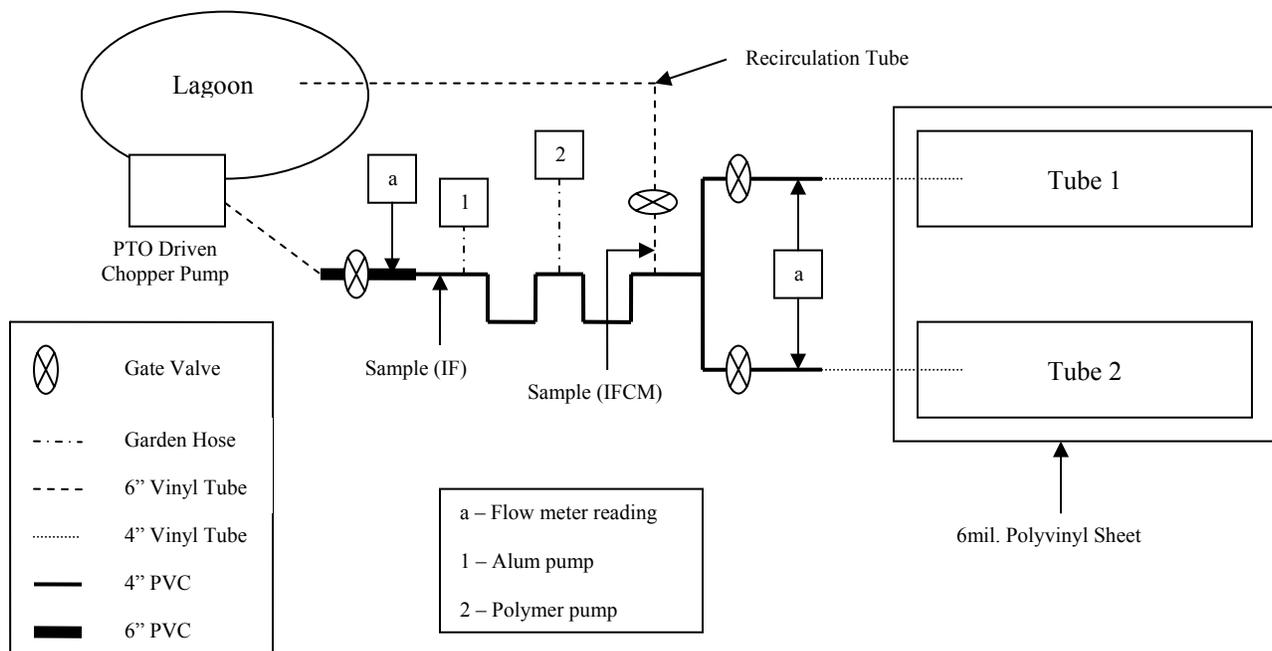


Fig. 1. Schematic of the Geotube[®] Dewatering System Components (not to scale)



Fig. 2.a. Geotube® System Configuration



Fig. 2.b. Geotubes® Filled to Approximately 5' in Height



Fig. 3. PTO Driven Chopper Pump in the Primary Lagoon

Methods

Sampling

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 (Figs. 4, 7, & 8). 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). (Fig. 1 & 5)
- 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). (Fig. 1)
- 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 (Fig. 6)
- 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 (Fig. 4). 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 laboratory within a few hours of each sampling event for analysis of the following analytes: Total Solids (TS), Total Volatile Solids (TVS), Total Fixed Solids (TFS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Soluble Reactive Phosphorus (SRP), Total Phosphorus (TP), Nitrate/Nitrite-Nitrogen (NNN), Total Kjeldahl Nitrogen (TKN), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn), Iron (Fe), and Copper (Cu). (Table 1)
- 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 (Fig. 1)

Table 1: Laboratory Analytical Methods

Parameter	Method	Equipment Used
Nitrite+Nitrate Nitrogen (NNN)	EPA 351.2	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Kjeldahl Nitrogen (TKN)	EPA 353.2	Perstorp® or Lachat® QuickChem Autoanalyzer
Potassium (K)	EPA 200.7	Spectro ® ICP
Calcium (Ca)	EPA 200.7	Spectro ® ICP
Magnesium (Mg)	EPA 200.7	Spectro ® ICP
Sodium (Na)	EPA 200.7	Spectro ® ICP
Manganese (Mn)	EPA 200.7	Spectro ® ICP
Iron (Fe)	EPA 200.7	Spectro ® ICP
Copper (Cu)	EPA 200.7	Spectro ® ICP
Orthophosphate Phosphorus (SRP)	EPA 365.2	Beckman® DU 640 Spectrophotometer
Total Phosphorus (TP)	EPA 365.2,4	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Suspended Solids (TSS)	EPA 160.2	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Total Solids (TS)	SM 2540C	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Volatile Solids (VS)	EPA 160.4	Sartorius® AC210P or Mettler® AT261 analytical balance, oven, muffle furnace
Potential Hydrogen (pH)	EPA 150.1	Accument® AB15 Plus pH meter
Conductivity (Cond.)	EPA 120.1	YSI® 3200 conductivity meter
Aluminum (Al)	EPA 200.7	Spectro ® ICP

* Concentrations of Total Dissolved Solids were found by subtracting the concentrations of Total Suspended Solids from Total Solids.

Calculations

- Once the raw data was 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.
- Residual samples taken on October 3, were used to calculate pooled averages and standard deviations using concentrations from both tubes.
- Percent reductions for each week were calculated using the following equation:
 - $\{(IF_{avg}-EF_{avg})/(IF_{avg})\} * 100$

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.

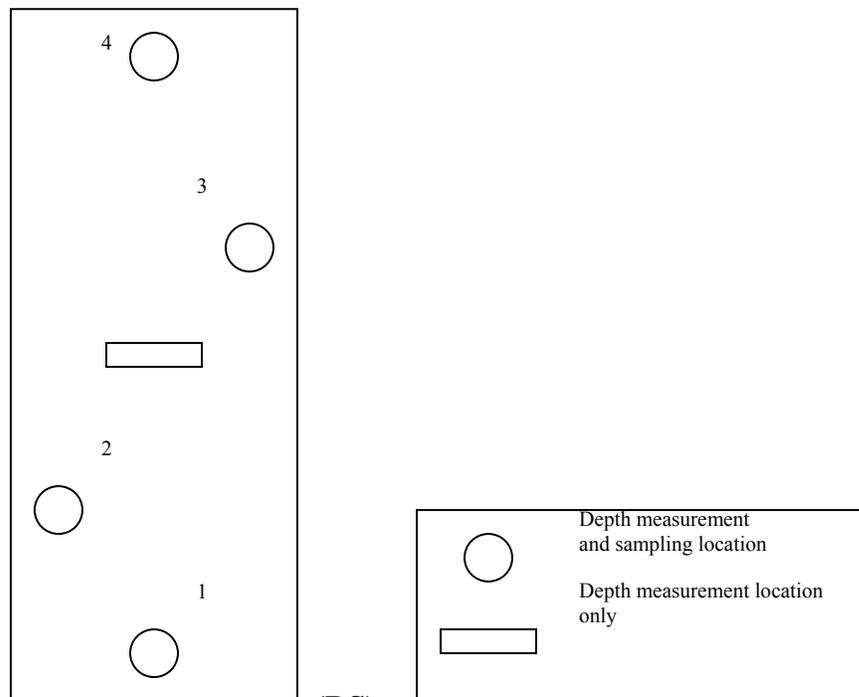


Fig. 4. Location of Residual Samples (RS) and Depth Measurements for Tubes 1 and 2



Fig. 5. Influent Being Sampled



Fig. 6. Effluent Being Sampled from a Dewatering Geotube®

Results

Tables 2, 3, and 4 show average concentrations and percent reductions (%RD) of solids, nutrients, and metals, respectively for data collected from the sampling events of March 30, April 6 and October 3, 2005. Concentrations of all analytes in the influent (IF) were similar for the two sampling events of March 30 and April 6 with small variations between 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 6. Hence, the results should be considered a snapshot of the performance of this system at the time of the sampling events.

Despite the fact that average concentrations of analytes were not corrected for their respective amounts in IF, EF or RS (Tables 2-4), it was observed that all of the analytes, with the exception of SRP and sodium, had large increases in concentration from the levels in IF to the levels in RS. This indicates the Geotubes[®] were effectively functioning as filters, retaining much of the solids, nutrients, and metals as the liquid dewatered from the tubes.

The data in Tables 2-4 show concentrations of analytes averaged across samples collected and composited from both Geotubes[®].

Solids and pH

As shown in Table 2, TFS and TVS generally comprised the majority of the solids in IF. The IF had a TS content of about 6% for both tubes at either sampling event. The TVS concentrations in IF and IFCM contributed more than 50% of total solids but only a fraction of TVS was found in the dewatered liquid from both tubes. After 6 months of dewatering, TVS concentrations in the residual solids were lower than TFS. This was due to the loss of volatile solids in EF or emission of TVS as gas 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 concentration of TVS did not increase after the addition of the pre-treatment because none of the solids being added from alum and polymer were volatile. The high percent reduction for all solids on both sampling events (March 30 and April 6) and large percent increases in all residual solids (October 3) indicated that Geotubes[®] were effective as filters for the dairy lagoon effluent (IF). TVS had the highest percent reductions of all solids.

Overall, there was a slight change in the pH of lagoon effluent treated with alum and a polymer and pumped into the tubes. The lagoon effluent became slightly more neutral

from IF to EF and a decrease in pH was seen from IF to RS. These reductions in the pH were due to addition of alum (acidic) to the IF. Additionally, lower TS content in EF samples may have provided more accurate (less buffering) pH probe readings as compared to IF and RS samples with much higher TS.

Nutrients

SRP in IF was less than 15% of TP from both sampling events. Total P and K concentrations in IF were substantially lower than the TKN concentrations for both sampling events. The reduction of SRP from IF to IFCM as well as its reduced concentration from IF to RS was attributed to the addition of the positively charged aluminum in alum (added in the chemical pre-treatment) binding to the negatively charged OPO₄-P (SRP) rendering most of it insoluble. Table 3 shows that the system effectively removed very high percentages of SRP, TP, and TKN; however, K being highly soluble, remained in the tubes and less than 50% was removed in IF on both sampling events. The high percent reductions indicated that this system was effective in reducing SRP, TP, and TKN from the dairy lagoon effluent.

Metals

Although concentrations of Ca in the influent appear to be very large in comparison with the other analytes, its concentration is not atypical in the slurry of an average dairy lagoon (Barker et al. 2001). Very high percent reductions were seen for Ca, Mn, Fe, and Cu. For some of the EF samples, concentrations of Cu in the effluent were below the laboratory instrumentation detection limits. It is apparent from the low percent reductions that this system was not effective in reducing Na from the dairy lagoon effluent (IF). For all other metals, the Geotubes[®] functioned as an effective filter.

Conductivity

Average values of conductivity found in EF of both tubes were 5347 $\mu\text{S}/\text{cm}$ (± 140) and 6300 $\mu\text{S}/\text{cm}$ (± 806) for March 30 and April 6 sampling events, respectively. According to Barker et al. (2001), the average conductivity for anaerobic dairy lagoon liquid (supernatant) in North Carolina was 3738 $\mu\text{S}/\text{cm}$ (± 939). Dairy lagoon slurry samples (composite samples from top of the liquid level to top of the dense sludge at the bottom) in Texas by Mukhtar et al. (2004) showed that average conductivity was 7324 $\mu\text{S}/\text{cm}$ (± 2931). The EF concentrations of most metals (minerals) from both tubes were lower than IF or RS concentrations resulting in lower conductivity than the average from lagoon supernatant (Barker et al., 2001) or slurry (Mukhtar et al., 2004).

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 (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 October 3 sampling event (Fig 4). 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 6). Separation efficiencies (eq. 1), mass balance (eq. 2) and mass balance error (eq. 3) were then calculated (Table 6):

$$\text{Eq. 1: } S.E. = [(IF_m - EF_m) / IF_m] * 100$$

$$\text{Eq. 2: } M.B. = IF_m - EF_m - RS_m$$

$$\text{Eq. 3: } M.B.E. = (M.B. / IF) * 100$$

$$\text{Where } IF_m = (IF_{m \text{ t1+t2, March 30}} + IF_{m \text{ t1+t2, April 6}})$$

$$EF_m = (EF_{m \text{ t1+t2, March 30}} + EF_{m \text{ t1+t2, April 6}})$$

$$RS_m = (RST1_m + RST2_m, \text{October 3})$$

The data for average mass of all solids, nutrients and metals in IF, EF, and RS of Tubes 1 and 2 and S.E., M.B., and M.B.E are presented in Table 6.

Table 2: Average Concentration (s.d.) and Percent Reductions (% Rd) of Solids and pH

	30-Mar (mg/L)				6-Apr (mg/L)				3-Oct (mg/kg as-is)			
	TS	TVS	TFS	pH	TS	TVS	TFS	pH	TS	TVS	TFS	pH
IF (s.d.)	6.01 ± 0.03	3.45 ± 0.21	2.71 ± 0.03	7.85 ± 0.13	6.08 ± 0.05	3.23 ± 0.06	2.86 ± 0.01	7.52 ± 0.01				
IFCM (s.d.)	6.87 ± 0.30	3.38 ± 0.12	3.34 ± 0.21	7.65 ± 0.04	6.64 ± 0.63	3.23 ± 0.01	2.91 ± 0.07	7.38 ± 0.30				
EF (s.d.)	0.36 ± 0.36	0.08 ± 0.08	0.28 ± 0.28	7.18 ± 0.18	0.45 ± 0.10	0.10 ± 0.02	0.34 ± 0.09	7.39 ± 0.17				
RS (s.d.)									26.7 ± 1.4	11.8 ± 0.6	14.9 ± 0.9	7.3 ± 0.3
% Rd	94	98	90	8	93	97	88	2				

Table 3: Average Concentrations and Percent Reductions (% Rd) of Nutrients

	30-Mar (mg/L as-is)				6-Apr (mg/L as-is)				3-Oct (mg/kg as-is)			
	SRP	TP	TKN	K	SRP	TP	TKN	K	SRP	TP	TKN	K
IF (s.d.)	41.7 ± 4.2	337 ± 4.8	2031 ± 9.6	560 ± 31	43.4 ± 3.7	333 ± 13	1992 ± 130	603 ± 2.0				
IFCM (s.d.)	18.3 ± 2.7	326 ± 11	2094 ± 102	592 ± 17	23.2 ± 27.7	317 ± 0.98	1899 ± 11	557 ± 23				
EF (s.d.)	4.9 ± 1.6	10 ± 4.7	308 ± 16	295 ± 5.6	8.4 ± 3.0	14 ± 5.0	337 ± 7.8	372 ± 64				
RS (s.d.)									4.1 ± 1.1	2469 ± 109	5232 ± 356	1219 ± 135
% Rd	88	97	85	47	81	96	83	38				

Table 4: Average Concentrations and Percent Reduction (% Rd) of Metals

30-Mar (mg/L as-is)

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

6-Apr (mg/L as-is)

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

3-Oct (mg/kg as-is)

	Ca	Mg	Na	Mn	Fe	Cu
RS (s.d.)	16532 ± 1986	1346 ± 123	298 ± 31	81 ± 8.9	1118 ± 122	33 ± 3.1

Table 5: Average Conductivity

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

Table 6: 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		Solids (kg)		Nutrients (kg)			
		TS	TFS	SRP	TP	TKN	K
3-Mar	IF (s.d.)	13737 ± 64	6194 ± 16	9.5 ± 0.96	77.1 ± 1.1	464 ± 2.2	128 ± 7.1
6-Apr	IF (s.d.)	2845 ± 23	1337 ± 3.3	2.03 ± 0.17	15.6 ± 0.6	93 ± 6.1	28.2 ± 0.09
3-Oct	RST1 (s.d.)	5003 ± 82	2784 ± 93	0.075 ± 0.02	23.67 ± 1.3	96.46 ± 2.2	21.58 ± 1.1
3-Oct	RST2 (s.d.)	4870 ± 193	2726 ± 106	0.077 ± 0.03	23.62 ± 1.8	96.90 ± 4.1	23.37 ± 1.2
	EFT1 (s.d.)	475.5 ± 149	379.7 ± 115	0.56 ± 0.23	1.14 ± 0.23	41.64 ± 2.2	42.26 ± 9.96
	EFT2 (s.d.)	399.9 ± 48	302.7 ± 33	0.81 ± 0.44	1.76 ± 0.68	41.52 ± 2.6	39.26 ± 2.1
	S.E. (%)	94.7	90.9	88.2	96.9	85.1	47.8
	M.B.	5833	1338	10.1	42.5	281.1	29.8
	M.B.E.	35.2	17.8	86.9	45.9	50.4	19.1

Table 6: Continued

Parameter		Metals (kg)					
		Ca	Mg	Na	Mn	Fe	Cu
3-Mar	IF (s.d.)	745 ± 20.0	87.7 ± 1.6	45.6 ± 0.56	4.71 ± 0.12	42.0 ± 1.9	1.38 ± 0.02
6-Apr	IF (s.d.)	162 ± 0.71	19.2 ± 0.06	9.9 ± 0.38	1.02 ± 0.01	10.2 ± 0.44	0.27 ± 0.004
3-Oct	RST1 (s.d.)	309.65 ± 53.8	24.61 ± 2.0	5.29 ± 0.4	1.46 ± 0.2	19.94 ± 1.4	0.60 ± 0.04
3-Oct	RST2 (s.d.)	301.80 ± 11.2	25.11 ± 1.3	5.69 ± 0.06	1.52 ± 0.09	21.31 ± 1.2	0.63 ± 0.01
	EFT1 (s.d.)	36.84 ± 3.2	19.51 ± 7.1	21.09 ± 9.1	0.165 ± 0.03	0.10 ± 0.03	0.0004 ± 0.0
	EFT2 (s.d.)	42.98 ± 6.6	18.07 ± 0.85	19.81 ± 2.1	0.20 ± 0.05	0.30 ± 0.19	0.006 ± 0.01
	S.E. (%)	91.2	64.9	26.3	93.7	99.2	99.6
	M.B.	216.3	19.6	3.6	2.4	10.5	0.4
	M.B.E.	23.8	18.4	6.5	41.8	20.2	25.3

Separation efficiencies found for all of the analytes are similar to the values for percent reductions shown in Tables 2-4 and Fig. 9. Separation efficiency for the solids was very high; this in conjunction with the high percent reductions observed for these solids indicates that the Geotube[®] dewatering system was effective in separating solids from the dairy lagoon effluent (IF). Overall, high separation efficiencies indicate that the Geotubes[®] were successful in reducing most nutrients and metals in EF.

The M.B.E.s were generally reasonable considering this system was observed under field conditions. The analytes large M.B.E.s were those which could change form such as SRP (and other nutrients) and TS which includes volatile solids that would be lost between IF and either EF or RS. M.B.E.s were generally lower for stable analytes such as metals and TFS.

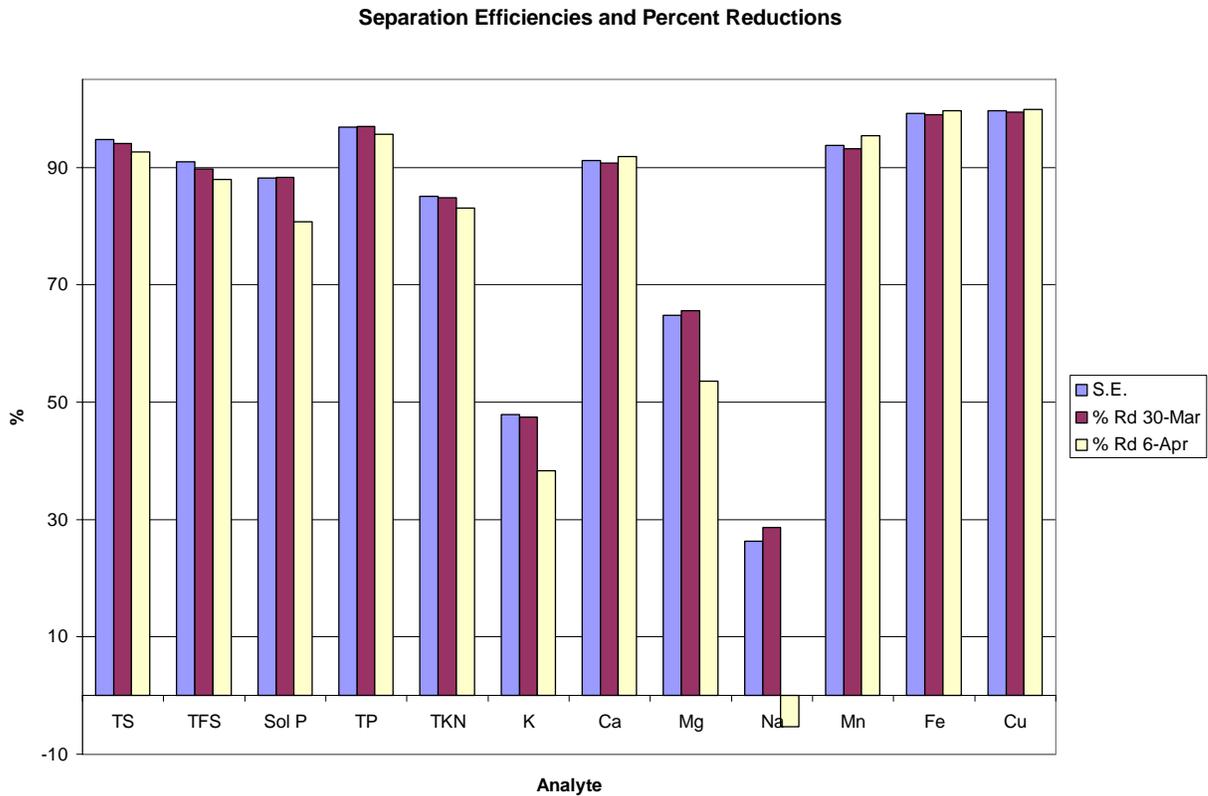


Fig. 9. Comparison of Separation Efficiencies and the Percent Reductions for Each Sampling Event.

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.

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. The size of the system will be dairy specific depending on the number of cows and the average amount of water entering the lagoon. Estimated costs would be about \$90,000 to dewater and contain 15+ year old nutrients in the Geotubes[®] from the retention lagoon. If consideration were allowed for costs per year (cost to remove 15 years worth of sludge and nutrients) for a 2,000 head dairy operation, the real costs amount to about \$6,000 per year, or \$3 per cow per year! When calculated on a cost per gallon basis, the method of treatment was estimated to cost about \$0.047 per gallon (about \$47 per 1,000 of treated effluent).

In comparison with conventional lagoon sludge treatment methods, this technology is slightly higher. In 2000, the Environmental Review Commission of the North Carolina General Assembly estimated that using conventional technologies costs between \$5 and \$32 per 1,000 gallons of treated effluent depending on the type of treatment process employed. Under the same scenario as the Geotube[®] test (2,000 cow dairy and 15 years of nutrients accumulation), conventional treatment would cost between \$0.32 and \$2.03 per cow while the Geotube[®] would cost \$3.

Conclusion

Due to the designation of the two upper North Bosque River segments as impaired from nonpoint source (NPS) pollution of P in the watershed, action must be taken towards the reduction of P from sources such as dairy lagoon effluent applied to the WAFs. The BMPs currently in use are not sufficient to bring about the needed reductions; therefore, many prospective new technologies are being researched. The results from the three sampling events showed that the Geotube[®] dewatering system was highly effective in reducing P from dairy lagoon effluent. The average separation efficiency for SRP and TP were 88% and 97% respectively, which is well above the goal of 50% reduction set by the TMDLs. This system was also successful in filtering TS from the lagoon effluent with 95% separation efficiency.

Considering the effectiveness of P removal by the Geotubes[®], proper application of effluent from the tube should not contribute to increased P runoff from WAFs. Waters must be applied according to permits or water quality management plans in order to

reduce P runoff. If irrigation occurs on un-permitted fields or is applied higher than the recommended rate, increases in P runoff could occur.

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. This system was not considered optimized because 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 opened completely, and then readjusted for the desired flow rate.

This 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. Findings from this study will be condensed into fact sheets that highlight information about how the system operates, installation and operation economics, and its effectiveness to remove P and other materials. The final report and fact sheets will be presented to dairy producers, County Extension agents, the advisory committee, and anyone else interested in the projects in an effort to educate them so they can make an informed decision about using this technology.

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The Miratech Division of Ten Cate Nicolon, Commerce, Georgia is acknowledged for their assistance and support with this demonstration.



Appendix B-I

Raw Data: Concentrations of analytes for samples treated as liquid

Table I.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 I.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 I.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 I.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

Appendix B-II
Raw Data: Residual solids

Table II.1: Concentrations of Nutrients, Solids, and pH for the Sampling Event on 10/3/05

Sample ID	Site	Extractable NO ₂ +3N SSSA 38-1148 mg/L	Soluble Phosphorus SSSA 32-891 mg/L	Total Phosphorus EPA 365.4 mod mg/L	Total Kjeldahl Nitrogen EPA 351.2 mod mg/L	Total Volatile Solids (%) SM2540E mg/L	Total Fixed Solids (%) SM2540E mg/L	Percent Solids SM2540B mg/L	pH EPA 9045C mg/L
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 II.2: Concentrations of Metals for the Sampling Event on 10/3/05

Sample ID	Site	Potassium EPA200.7 6010B mg/L	Calcium EPA200.7 6010B mg/L	Magnesium EPA200.7 6010B mg/L	Sodium EPA200.7 6010B mg/L	Manganese EPA200.7 6010B mg/L	Iron EPA200.7 6010B mg/L	Copper EPA200.7 6010B mg/L	Aluminum EPA200.7 6010B mg/L
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



Appendix C

Agriculture is Life!

**Field Demonstration of the Performance of the L4DB®
Microbial Treatment System to Reduce Phosphorus and
Other Substances from Dairy Lagoon Effluent**

**Final Report
April 2008**

By:

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**Partners: Texas AgriLife Extension Service
Texas Water Resources Institute
Envirolink® LLC, Greeley, Kansas**

**Texas Water Resources Institute Technical Report
January 2009**

Table of Contents

Executive Summary	3
Introduction.....	6
L4DB® treatment system	7
Methods.....	9
Layout of sampling scheme	9
Sludge depth (SD) measurement	13
Lagoon, tank and irrigation effluent sample collection	13
Sample preparation and analysis	17
Statistical analysis	19
Statistical analysis	19
Results and Discussion.....	19
Environmental conditions	20
Lagoon performance.....	21
Sludge depth	21
Physicochemical characteristics of lagoon.....	24
pH	25
Solids	27
Nutrients	35
Metals	44
Conductivity	48
Treatment Costs	50
Conclusion	50
Challenges.....	52
Acknowledgement	52
References.....	53
Appendix I.....	56

Field Demonstration of the Performance of the L4DB® Microbial Treatment to Reduce Phosphorus and other Substances from Dairy Lagoon Effluent

EXECUTIVE SUMMARY

Two upper North Bosque River segments were designated as impaired in 1998 due to point source and nonpoint source (NPS) pollution of phosphorus (P) to these segments of 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 (SRP) concentrations by about 50%. Under Clean Water Act (Section 319(h)), a new technologies demonstration project was funded by the USEPA Region 6 and administered by the Texas State Soil and Water Conservation Board (TSSWCB) for reducing water pollution associated with dairy animal production systems. As part of this demonstration, the efficacy of a prospective new technology (i.e. L4DB® microbial treatment system) was evaluated, which may aid dairy farmers in reducing P from lagoon effluent. In many cases, this effluent is applied to waste application fields (WAFs) as irrigation water; thus reducing P in the effluent can have a direct impact on NPS pollution in the watershed.

Beginning in May 2006 a dairy's anaerobic lagoon was treated with L4DB® microbes at an average application rate of 65 gallons (246 L) of microbial solution/month for a period of 12 months. Lagoon samples were collected monthly or bi-monthly from two different profiles: lagoon supernatant (LS, sampled from top of the liquid level to 2ft (61 cm) depth) and lagoon profile (LP, sampled from the entire depth of the lagoon) using a sludge judge (a sampling tube with a check valve at the bottom to take lagoon sample at different depths). For

each LP and LS, 30 samples (3 samples per location × 10 locations) were collected during each sampling event. A set of 15 LP and 15 LS samples were mixed separately to get two composites of each for nutrients including P, solids, pH, conductivity and metals. In addition, 60 samples of lagoon effluent (hereafter IR) used to irrigate a nearby pasture were collected bi-monthly from a riser located just upstream from the big gun irrigation unit. Fifteen IR subsamples were grouped together to get four IR composite samples. The IR composite samples were also analyzed for the above mentioned physical and chemical constituents.

L4DB® microbial treatment reduced average sludge depth by 24% as compared to its pre-treatment level (however, this reduction was 16%, when sludge measurement anomaly in August 2006 was excluded). The microbial treatment also reduced averaged total solids (TS) and total suspended solids (TSS) by 43 and 45%, respectively, for the LP, and 60 and 71%, respectively, for LS. Conversely, these values increased by 124% for IR effluent over times.

This microbial treatment system was effective in reducing average total phosphorus (TP) by 27 and 52% for the LP and LS, respectively, but not effective in reducing TP concentration for IR effluent. Overall, no clear soluble reactive phosphorus (SRP) reduction trends were observed for any sampling locations. Similar to the effect on TP, the L4DB® treatment was effective in reducing total Kjeldahl nitrogen (TKN) from the LP (36%) and LS (48%), but not effective in reducing potassium (K) for LP and LS. No clear trend of reducing these nutrients from IR effluent was observed over time.

This microbial treatment system was effective in reducing metals concentration as well. The average concentration reductions of Al, Ca, Cu, Fe, and Mn for LP were over 50%, while the reduction seen in Mg was only 22%. Similarly, the concentration reductions observed in LS samples were over 60% for the same suite of elements while Mg was reduced

by about 42%. No clear metal concentration reduction trends were observed for IR effluent. As a result, it can be inferred that most of these solids, nutrients, and metal reductions were likely due to microbial treatment, dilution of lagoon slurry by excessive rain and runoff as well as settling of dead and degraded bacterial mass accumulated at the bottom of lagoon. Additional measurements of lagoon sludge accumulation rate and constituents are warranted to assess possible increase in nutrients and solids due to accelerated solids settling and increased accumulation of microbial mass at the lagoon bottom.

INTRODUCTION

The bulk of the manure from animal feeding operations (AFOs) in the USA is applied to crop and pastureland. Although manure is an excellent resource for plant nutrients and soil conditioning, excessive land application rates and improper uses of manure can lead to environmental concerns. Manure phosphorus (P) that is not utilized by plants represents one of these concerns and can significantly impact surface water quality. Water quality degradation due to nonpoint source phosphorus (P) contribution from effluent and manure applied to waste application fields (WAFs) is a major concern in the Bosque River watershed. In 1998 two upper North Bosque River segments (Upper North Bosque River – Segment 1255; North Bosque River – Segment 1226) were designated as impaired segments on the Texas Clean Water Act, Section 303(d) list (TNRCC, 2001). This designation was the result of excessive nutrient loading and aquatic plant growth in those segments. The changes in the status of the Bosque River segments prompted the Texas Commission on Environmental Quality (TCEQ) to develop TMDLs that address P loading to the designated segments. In December of 2002, TCEQ approved the implementation plan for these TMDLs; these plans were also approved by the Texas State Soil and Water Conservation Board (TSSWCB) in January 2003. The TMDLs call for a reduction of the annual loading and annual average soluble reactive P (SRP) concentrations by about 50%.

The TCEQ has cited pollution from nonpoint source agricultural operations (by way of runoff) as the main source of contamination to these segments. As a result, reducing P from dairy effluent applied to WAFs is vital step in protecting the quality of these water bodies. Runoff from WAFs is not currently regulated because it is considered a nonpoint source, but it's impact on water bodies can be minimized by using on farm management practices to

reduce potential pollutants in dairy lagoon effluent applied to WAFs. There are currently a number of dairy operations in the watershed using best management practices (BMPs) to remove P and SRP from the wastewater; however, to meet the goals of the established TMDLs, new, more effective and efficient BMPs are needed. One prospective BMP is the use of L4DB® microbial treatment to remove P and other constituents from the effluent being stored and treated in dairy lagoons.

This report outlines the performance of a patented liquid-borne L4DB® microbial treatment (hereafter L4DB®) introduced by *EnviroLink® LLC*, Greeley, Kansas. The demonstration evaluated under this project was set-up to treat a single cell anaerobic lagoon at a 300-head lactating cow free-stall dairy in the Bosque River watershed. Free-stall alleys were flushed 4 times per week and scraped in the remaining time. During each flushing, 10,000-12,000 gallons (37,854-45,425 L) of effluent was washed into the lagoon. As needed, this effluent was used to irrigate hay and cropland at the dairy using a big gun irrigation system.

L4DB® treatment system

According to EnviroLink®, the patented liquid-borne L4DB® microbial treatment is derived from milk. Some of the physical and chemical properties of the L4DB® are listed in Table 1. Prior to its application to the lagoon, the L4DB® was thoroughly mixed and applied at an average rate of 65 gallons/month (246 L/month), which was predetermined by EnviroLink® based on the lagoon size, depth of water and solids in the effluent; monthly L4DB® inputs are listed in Table 2. The L4DB® treatment was applied by spraying along the perimeter of lagoon while continuously agitating the liquid surface using a water sprinkler and lagoon effluent.

Table. 1 Properties of L4DB® used in this study

Product name	L4DB®
Manufacturer	Envirolink® LLC, KS
Active ingredient	Lactobacillus acidophilus and lactobacillus gasseri
Boiling point	212°F (100°C)
Vapor pressure	Same as water (760 mg Hg at 100°C)
Specific gravity	1 (gravity of H ₂ O = 1 at 4°C)
Evaporation rate	Same as water
Solubility in water	Total soluble
Appearance and odor	Light tan/ slight odor
Flash point	None
Health hazard	None
Toxicity	None

pH 7.0

Source: MSDS, US Department of labor (provided by Envirolink®) and technology provider

Table 2. Lagoon treatment date and L4DB® treatment application rate

Lagoon treatment date	Application rate, gallons(liters)
5/22/06	100 (378)
06/02/06	50 (189)
07/01/06	50 (189)
08/02/06	50 (189)
09/03/06	50 (189)
10/02/06	50 (189)
11/03/06	50 (189)
12/01/06	75 (284)
01/02/07	100 (378)
02/03/07	75 (284)
03/01/07	75 (284)
04/02/07	50 (189)
05/05/07	75 (284)

As shown in Table 2, the L4DB® application rate was adjusted from time to time based on the ambient temperature and amount of precipitation since the last treatment. In colder months application rate was higher than in a warmer month; this is done to offset lower microbial activity during cooler temperatures. Similarly, when monthly precipitation was greater, application rate was reduced slightly due to increased dissolved oxygen in the lagoon from rain water.

Additionally, two large tanks (volume of liquid in T1 and T2 was 539 gal (2,040 L) and 528 gal (1,998 L), respectively) were filled with untreated flushed manure to assess the L4DB® treatment effect on flushed manure from the free-stall (Fig. 1). Tank T1 was used as the control (no treatment was applied) and T2 was treated with L4DB® at a rate of 1 gal/month (3.78 L/month).



Fig.1. Tanks T1 (control) and T2 (treated) used in this study

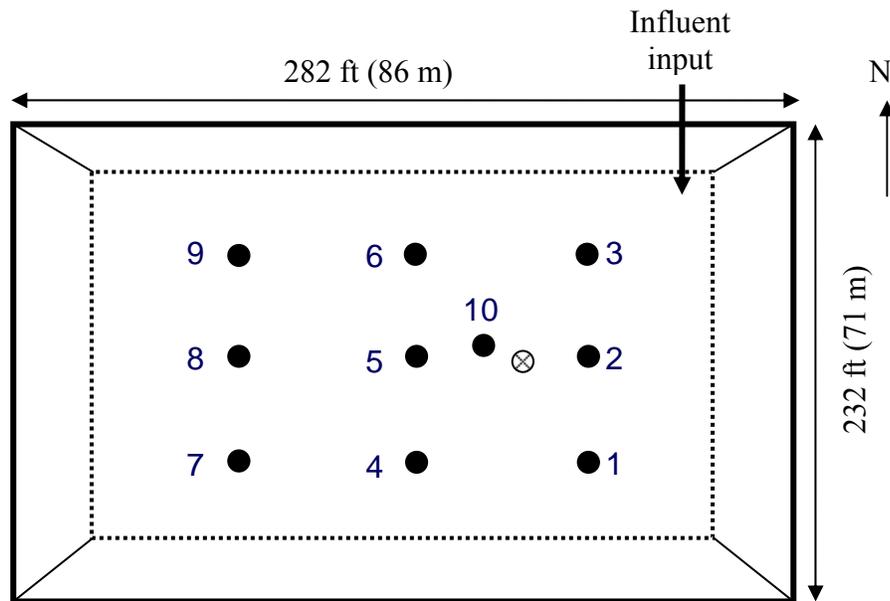
METHODS

Layout of sampling scheme

Prior to sampling, the lagoon was divided into three roughly equal sections by transect lines running the width and length of the lagoon (Figs. 2). The location of each transect was marked permanently using a steel post (Fig. 2a) and each intersection was noted as sampling location 1 through 9 (Fig. 2b). In addition, the 10th sampling location was chosen near the irrigation pump (Fig. 2b).



(a)



(b)

Fig. 2. a) Transect line running the width and length of the lagoon along with sampling location, and b) schematic of lagoon sampling layout. ● Indicates lagoon sampling locations and sludge depth measurement locations; ⊗ indicates irrigation pump locations (not to scale)

At each location three lagoon supernatant (from top of the liquid level to two ft (61 cm) depth, hereafter, LS) and lagoon profile (from the entire depth of the lagoon, hereafter, LP) samples were taken (Fig. 3) for analysis. Summary of sampling events is listed in Table 3.

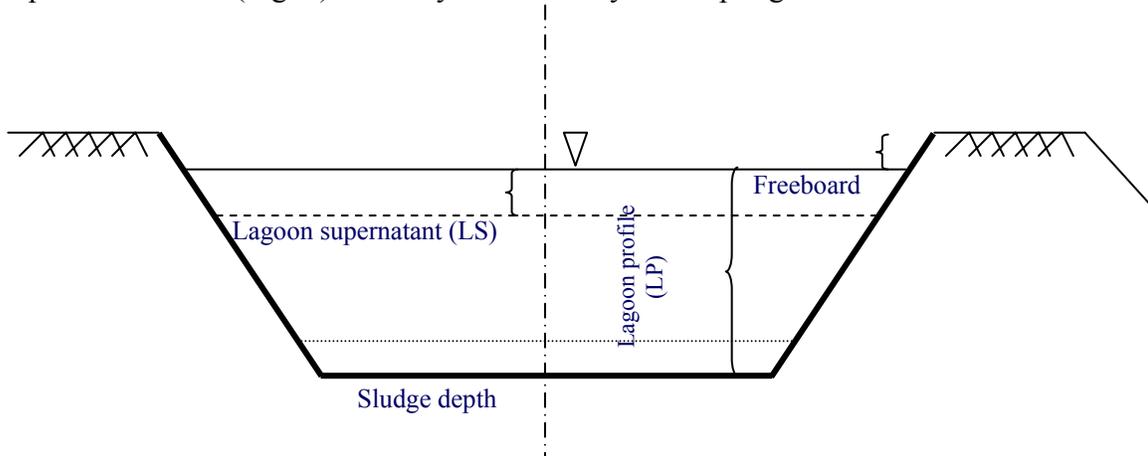


Fig. 3. Schematic of lagoon and sampling profile (not to scale)

Table 3. Sampling events

Component/Date	May, 06	June, 06	July, 06	Aug, 06	Oct, 06	Dec, 06	Feb, 07	Mar, 07	May, 07	June, 07
Irrigation effluent (IR**)	√		√		√	√	√			√
Lagoon profile (LP)	√	√	√	√	√	√	√			√
Lagoon supernatant (LS) Tank	√	√	√	√*	√	√		√*	√	
Tank profile (TP)	√	√	√	√	√	√		√	√	

* Tanks were re-filled and pre-treatment samples were collected

** Irrigation effluent was not sampled during every sampling event due to sampling and analysis cost constraints

Two composite samples each for tank supernatant (from top of the liquid level to 1 ft (30 cm) depth, hereafter, TS) and tank profile (from the entire depth of the tank, hereafter, TP)

samples were taken diagonally from 15 locations, respectively, for each tank during each sampling event (Fig. 4). Due to high evaporation losses from the tanks, they were both emptied and refilled twice with flushed manure during the course of this monitoring study. In phase 1 (hereafter P1), the tanks were filled in May 2006 and sampled in May, June and July 2006. During phase 2 (hereafter P2), both tanks were emptied and refilled in August and sampled in August, October and December 2006. No tank samples were taken in February 2007 due to presence of thick crust on the surface of manure in tanks as well as insufficient tank water depth for TS and TP samples. Low tank volumes were replenished in March 2007 (hereafter, P3) and sampled in March and May 2007. Due to intermittent sampling, tank parameters were evaluated and compared within each phase instead of comparing among phases.

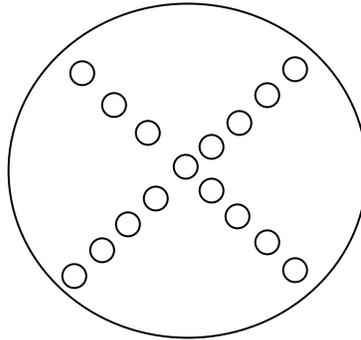


Fig. 4. Approximate tank sampling locations

As listed in Table 2, lagoon effluent (hereafter, IR) irrigated to nearby pasture land (Coastal Bermuda grass) was collected bi-monthly from a riser located just upstream from the big gun irrigation system. The big gun irrigation used a 20 HP centrifugal pump and a 4 inch (10 cm) dia hose for effluent irrigation. Irrigation samples were collected every three minutes for three hours yielding a total of 60 samples. Sample preparation and analysis for IR samples

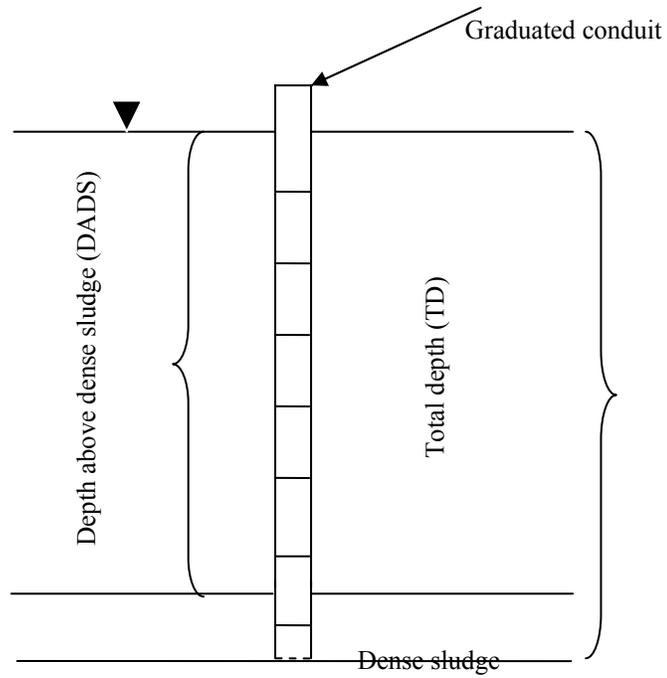
have been discussed in the sample preparation and analysis section. For December 2006 sampling, the irrigation pump was moved from its original location (Fig. 2b) for repairs and installed close to the shore of the lagoon. Once repaired, the pump was moved back to its original location and stayed there for the remainder of the project. During IR sampling, flow rate was monitored using a Greyline PDFM 4 Doppler flow meter (Massena, NY). Flow rates were recorded on three minute intervals and ranged from 136-185 gpm (515-700 lpm) during sampling events. At these rates, a total of 24,391 gallons (92,330 L) to 35,043 gallons (132,651 L) IR effluent was pumped during that time.

Sludge depth (SD) measurement

Typically, reduction of TSS in lagoon supernatant is accompanied by reduction of P, and a potential change in sludge depth. Therefore, accurate tracking of sludge depth is important to evaluate the performance of L4DB® treatment effectively. During each sampling event, total depth (TD) and the depth above dense sludge (DADS) for the lagoon and tanks were measured using a graduated plastic conduit fitted with an end cap (Fig. 5). All depth measurements in the lagoon were taken at the same location as liquid samples were collected. Sludge depth (SD) of lagoon and tanks was estimated by subtracting the DADS from the TD of the lagoon and tanks, respectively.

Lagoon, tank and irrigation effluent sample collection

In order to ensure consistent sampling and monitoring, lagoon sampling locations and the sampling profile were predetermined (Figs. 2 & 3). At each lagoon sampling location, 3 LS and 3 LP samples were taken in 250 ml bottles. Samples were collected using the “Ultra Sludge Judge” (Nasco, Fort Atkinson, WI), which consisted of three 5 ft (1.52 m) sections of 1.25 inch (3 cm) diameter acrylic tube and a ball check valve at the bottom end (Fig. 6).



(a)



(b)

Fig. 5. a) Schematic of lagoon depth measurement, b) actual depth measurement

For LS sampling, the sampler was lowered slowly to the desired depth (2 ft, or 61 cm), while for LP sampling, the sampler was lowered slowly until it rested above the dense sludge at the bottom of lagoon. After lowering the tube at desired depth, it was gently pulled out of the lagoon as straight as possible. A total of 30 LS (3 samples per location \times 10 locations) and 30 LP (3 samples per location \times 10 locations) samples were collected from lagoon during each sampling event. Sample preparation and analysis for LS and LP will be discussed in the following section.



Fig. 6. Lagoon sampling using a sludge judge

Following the same sampling procedures used in the lagoon, 15 TS and 15 TP samples were collected from each tank using a sludge judge (Fig. 7). Thus, total 60 (15 samples per tank \times 2 tanks \times 2 profiles) samples were collected from two tanks during each sampling event.



Fig. 7. Tank supernatant sampling using a sludge judge

In addition, samples of lagoon effluent (IR) used to irrigate a nearby pasture were collected bi-monthly from a riser located between the irrigation pump and a big gun irrigation system (Fig. 8). Samples were collected every three minutes for 3 hours yielding a total of 60 IR samples were collected during each sampling event.



Fig. 8. Sampling of irrigation effluent (IR) from a riser

Within an hour of sampling, bottles kept on ice were transported to the Texas Institute for Applied Environmental Research (TIAER) laboratory, at Tarleton State University in Stephenville, Texas, for physiochemical parameter (i.e., nutrients, solids, metals, pH and conductivity) analysis.

Sample preparation and analysis

After each sampling event, 15 LS samples were mixed together to obtain one LS composite sample. Similarly, 15 LP samples were mixed together to obtain one LP composite sample. In this way, two LS and two LP composite samples (LS1 & LP1 composited samples from locations 1 through 5 and LS2 & LP2 composited samples from locations 6 through 10) were prepared for analysis. Similarly, each set of 15 TS and 15 TP samples were mixed separately to get two TS (T1S and T2S) and two TP (T1P and T2P) composite samples of each for analysis. Also, 15 IR sub-samples were mixed separately to get one IR composite sample. In this way, four IR (hereafter IR1, IR2, IR3, and IR4) samples were prepared for subsequent analysis from each sampling event

Using EPA laboratory procedures (Budde, 1995) and Standard methods (APHA, 2005) (Table 4) all composited samples were analyzed for: Total Solids (TS), Total Volatile Solids (TVS), Total Fixed Solids (TFS), Total Suspended Solids (TSS), Soluble Reactive Phosphorus (SRP), Total Phosphorus (TP), Nitrate/Nitrite-Nitrogen (NNN), Total Kjeldahl Nitrogen (TKN), Potassium (K), Aluminum (Al), Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn), Iron (Fe), and Copper (Cu). Concentrations of Total Dissolved Solids (TDS) were found by subtracting the concentrations of TSS from TS. Also pH and conductivity were measured for each composite sample.

Table 4. Laboratory analytical methods

Parameter	Method	Equipment Used
Nitrite+Nitrate Nitrogen	EPA 353.2 and SSSA 38-1148	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Kjeldahl Nitrogen	EPA 353.2, modified	Perstorp® or Lachat® QuickChem Autoanalyzer
Potassium	EPA 200.7	Spectro ® ICP
Calcium	EPA 200.7	Spectro ® ICP
Magnesium	EPA 200.7	Spectro ® ICP
Sodium	EPA 200.7	Spectro ® ICP
Manganese	EPA 200.7	Spectro ® ICP
Iron	EPA 200.7	Spectro ® ICP
Copper	EPA 200.7	Spectro ® ICP
Orthophosphate	EPA 365.2	Beckman® DU 640 Spectrophotometer
Phosphorus		
Total Phosphorus	EPA 365.4, modified	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Suspended Solids	EPA 160.2	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Total Solids	SM 2540C	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Total Volatile Solids	SM 2450G	Sartorius® AC210P or Mettler® AT261 analytical balance, oven, muffle furnace
Total Volatile Solids	EPA 160.4	Sartorius® AC210P or Mettler® AT261 analytical balance, oven, muffle furnace
Potential Hydrogen	EPA 150.1 and EPA 9045A	Accument® AB15 Plus pH meter
Conductivity	EPA 120.1 and EPA 9050A	YSI® 3200 conductivity meter
Aluminum	EPA 200.7	Spectro ® ICP

EPA = Methods for Chemical Analysis of Water and Wastes, March 1983 and version 2, June 1999.

There is no difference between EPA methods 200.7 and 6010B. Method 200.7 is a newer version and will yield the same results.

Statistical analysis

Analysis of variance (ANOVA) was performed to examine the treatment effects on lagoon slurry and irrigated effluent solids, nutrients and metals at different sampling profiles (LP, LS, and IR) using a general linear model in SAS. The differences among mean groups were compared using the Duncan's multiple range tests (Steel & Torrie, 1997) at a significance level P of 0.05.

RESULTS AND DISCUSSION

Average daily ambient temperature and evapotranspiration (ET) data of the Stephenville area (about 12 miles or 20 km from the dairy) was used to assess environmental conditions during the monitoring period. Total monthly precipitation data for the dairy was provided by the producer.

During the monitoring, period tank evaporation losses were not compensated by addition of lagoon slurry; therefore, it was difficult to maintain a consistent TS and TP sampling depth in tanks between scheduled tank effluent sampling events. As a result, both tanks were re-filled twice during the monitoring period (Table 2); pre-treatment and treated tank slurry samples were taken during each sampling event. Refilling the tanks with flushed manure led to substantial variations in tank constituents; therefore, tank effluent physiochemical characteristics were compared for the period between each tank filling sampling event rather than among refilling of tanks. No clear and consistent trends for solids, nutrients and metals were observed in tank effluent samples. Consequently, tank data and physiochemical characteristics were not a true representation of lagoon environmental

conditions and sampling replication due to extreme outdoor environmental conditions were not included in this report.

Environmental conditions

Monthly precipitation and evapotranspiration (ET) are presented in Fig. 9, and daily ambient temperatures are presented in Fig. 10. It is evident from Figs. 9 and 10 that although there was no precipitation recorded in September 2006, June-August of 2006 were the warmest and driest months. During this period, the study area received low amounts of precipitation and had the greatest ET losses. Conversely, in May 2007, the study area had the highest precipitation with only moderate ET losses. Average ambient temperature for July and August 2006 were 83.2 (± 3.5 °F) and 85.5°F (± 4.2 °F), respectively, while the lowest average temperature occurred in January 2007 and measured 38.6 °F (± 8.67 °F).

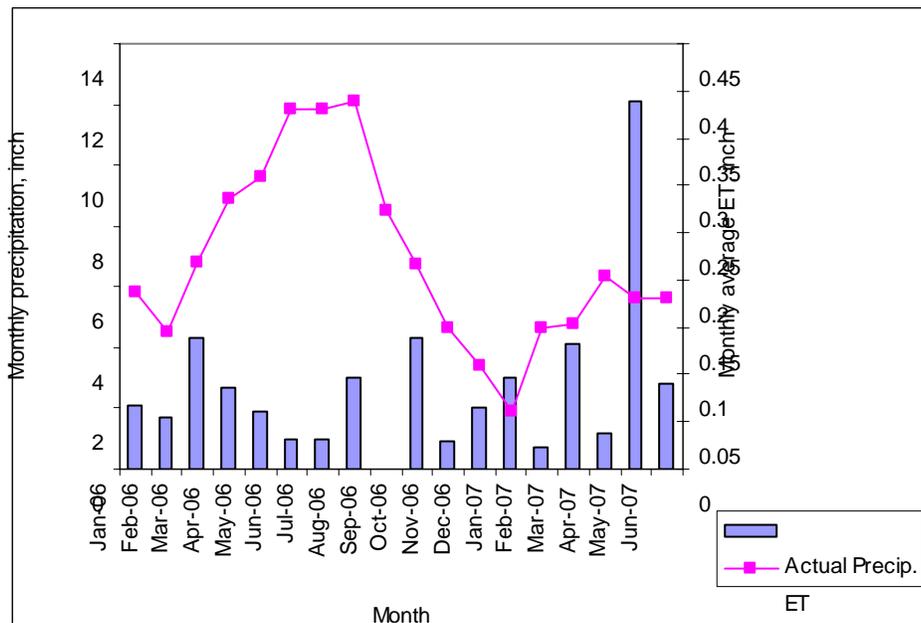


Fig. 9. Precipitation and evapotranspiration (ET) trend in the study area (Note: ET values were taken from the nearest weather station in Stephenville, TX)

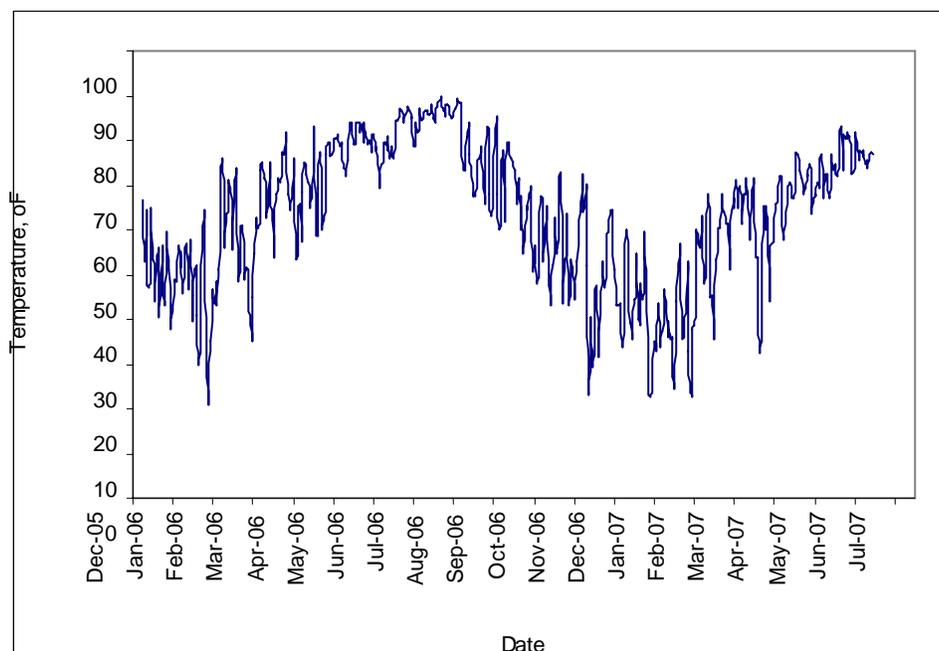


Fig. 10. Daily mean ambient temperature for the study area (Note: ambient temperature was taken from the nearest weather station in Stephenville, TX)

Lagoon Performance

Sludge depth

Average TD and SD in the lagoon during each sampling event are shown in Fig. 11. TD fluctuation was likely due to variations in precipitation, volume of effluent used for irrigation, and ET during monitoring while the variation in DASD was likely due to variation of settling and re-suspension of solids from microbial activities (Fig. 12). Following the first treatment in May 2006, the sludge depth decreased by as much as 21% until July 2006; however, in August 2007, an anomaly was observed (Fig. 11) where the SD decreased sharply by 69%. This drastic decrease in SD was likely due to depth measurement errors. Thereafter, lagoon depths fluctuated at the end of the demonstration, but SD remained lower than the pre-treatment sludge depth (Fig. 11). The likely cause of this reduction is that microbes obtained energy by consuming organic matter, which resulted in reduced solids and eventually reduced

SD. Since sludge accumulation is composed of TFS and slowly degradable volatile solids (Chastain et al., 2001), variations in SD are likely due to variation in these solids for this lagoon. In addition, high variability in sludge depth was also likely due to re-suspension of sludge from microbial activities as well as by wind-driven turbulence and gas lift (Reed et al., 1995), annual cycle of storage, heating and organic matter accumulation (Hamilton et al., 2006; Westerman et al., 2006). Overall, L4DB® treatment was effective in reducing sludge depth by 24% (however, this reduction was 16%, when measurement anomaly in August 2006 was excluded) to its pre-treatment level. This reduction of SD due to microbial treatment is likely to improve lagoon effluent characteristics, increase lagoon capacity and reduce maintenance cost for this lagoon. Average SD for this lagoon was 34% of the TD. Greater sludge depth means higher loading rate which is associated with higher TSS, TVS, TKN, as well as conductivity of the lagoon (Sukias et al., 2001). Overall TD, DADS, and SD for this lagoon during the monitoring period were 10.75 ft (± 1.2), 7.11 ft (± 1.06), and 3.64 ft (± 0.098), respectively.

Further analysis of sampling locations revealed that in a given sampling event no significant differences in TD were observed among locations except for sites L1 and L4 (Fig. 2). Significant differences in DADS and SD measurement were observed among locations, despite measuring these depths at nearly the same locations during all sampling events (Fig. 12). The overall large variation of SD measurement among locations indicates the difficulties in measuring sludge accumulation in the lagoon.

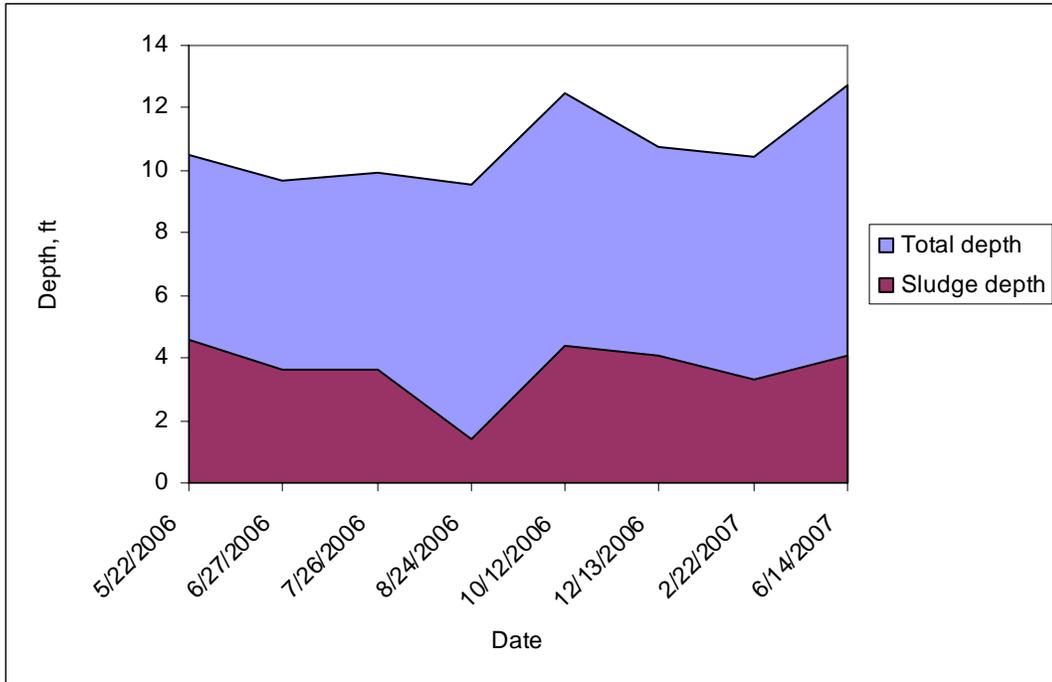


Fig. 11. Total and sludge depths of the lagoon (Note: May 2006 sampling is the pretreatment depth)

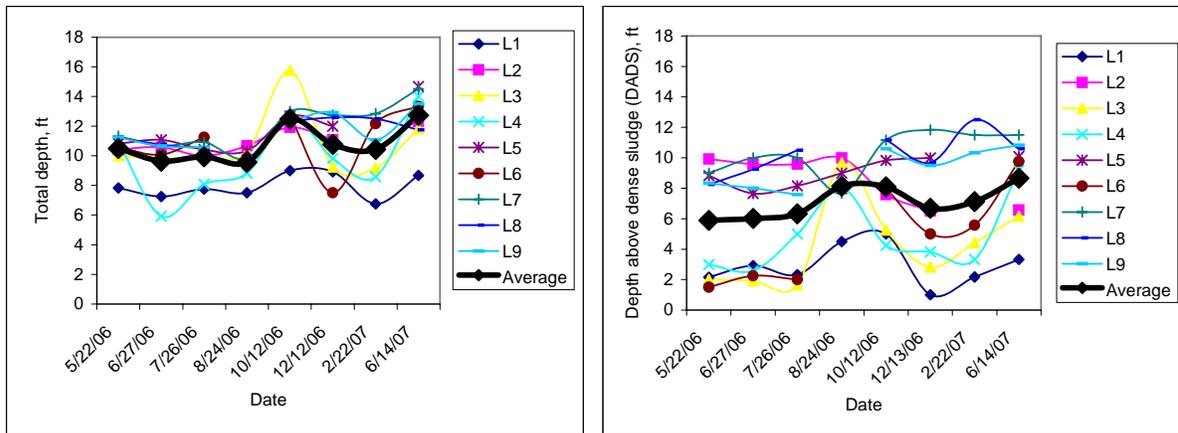


Fig. 12. Total depth (TD) and depth above dense sludge (DADS) at different sampling locations of the lagoon (Note: May 2006 sampling is the pretreatment depth)

Physicochemical characteristics of lagoon

In this section, physicochemical parameters (solids, nutrients and metals) analyzed for LP, LS and IR samples (untreated and treated with bacteria) have been compared among sampling events as well averaged over sampling events. During the monitoring period, lagoon water volume varied considerably (Fig. 13) due to above average natural precipitation, runoff to the lagoon and effluent pumping for irrigation use. To demonstrate the effect of increased lagoon liquid volume due to excessive rains (potentially diluting lagoon slurry), a few results (i.e., TS and TP concentration) are also reported in this section to show treatment and dilution effects.

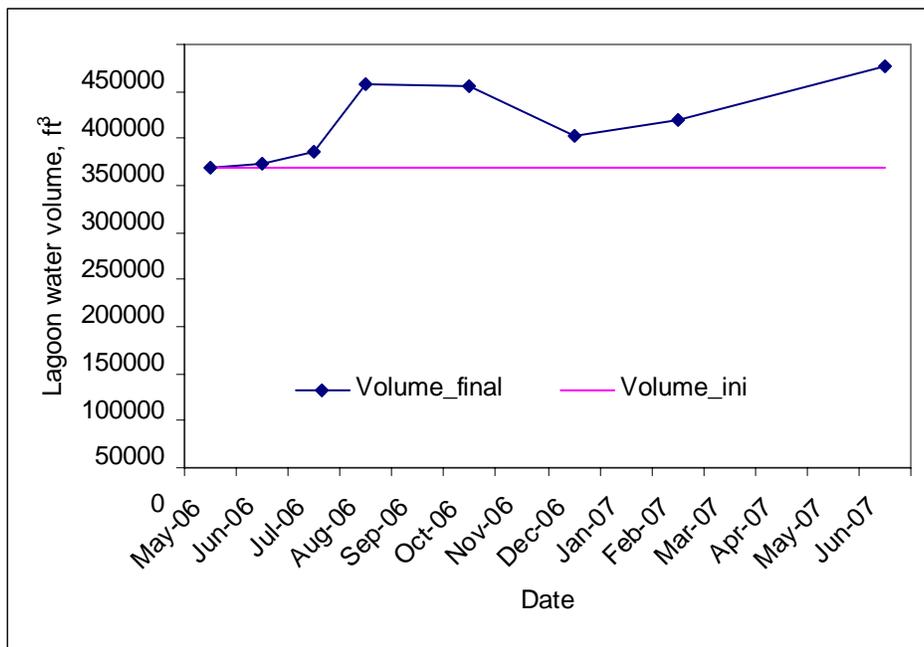


Fig. 13. Lagoon volume changes over time. Volume_ini: Initial volume; Volume_final: Final volume of the lagoon (Note: May 2006 is the initial lagoon depth measurement)

During one of the IR sampling events, four additional irrigation samples (IR_field) were collected using a freezer bag placed inside a coffee can to check whether effluent being

applied to the land had the same chemical make-up as the effluent sampled from the riser. Coffee cans were placed at four random locations within the irrigated area. The IR_field samples were analyzed individually for TS, TSS, TVS, SRP, TP and TKN and were compared with IR samples collected simultaneously for the same sampling event. Results suggested that, except SRP, IR_field showed higher concentrations than all other measured parameters compared to IR effluent samples (Table 5). These differences between IR effluent and IR_field were likely due to foaming that occurred during IR sampling through the riser. As a result, TS, TSS, TVS, SRP, TP and TKN for IR were reported as corrected values whereas the values of other parameters for IR were not corrected since they were not analyzed for IR_field samples.

Table. 5. Comparison of selected parameters in IR effluent, lagoon grab samples at different depths and IR samples collected from the field (IR_field)

Parameter	IR ¹	IR_field ¹
TP (mg/L)	67.6b±4.7	76.3a±0.6
SRP (mg/L)	14.9a±0.7	7.1b±0.6
TS (%)	0.46b±0.005	0.52a±0.004
TSS (%)	0.06b±0.008	0.10a±0.01
TVS (%)	0.19b±0.006	0.23a±0.002
TDS (%)	0.39b±0.005	0.42a±0.006
TFS (%)	0.27b±0.004	0.29a±0.003
TKN (mg/L)	481.5a±22.0	503.0a±14.1

* Averages within a row followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

¹ Both IR and IR_field samples were collected on the same day simultaneously (6/14/07)

pH

Lagoon profile (LP) samples showed significantly lower pH than the IR, whereas no significant differences in pH were observed between LS and IR and LP and LS. IR had

slightly higher pH as compared to LS and LS had slightly higher pH than the LP. Similarly, significant differences in pH were observed among sampling events and pH trends in LP, LS and IR were presented in Fig. 14. Average pH for LP, LS and IR were 7.46 (± 0.14), 7.55 (± 0.17), and 7.57 (± 0.12), respectively, indicating that this microbial treatment slightly increases pH in the LS and IR in this lagoon.

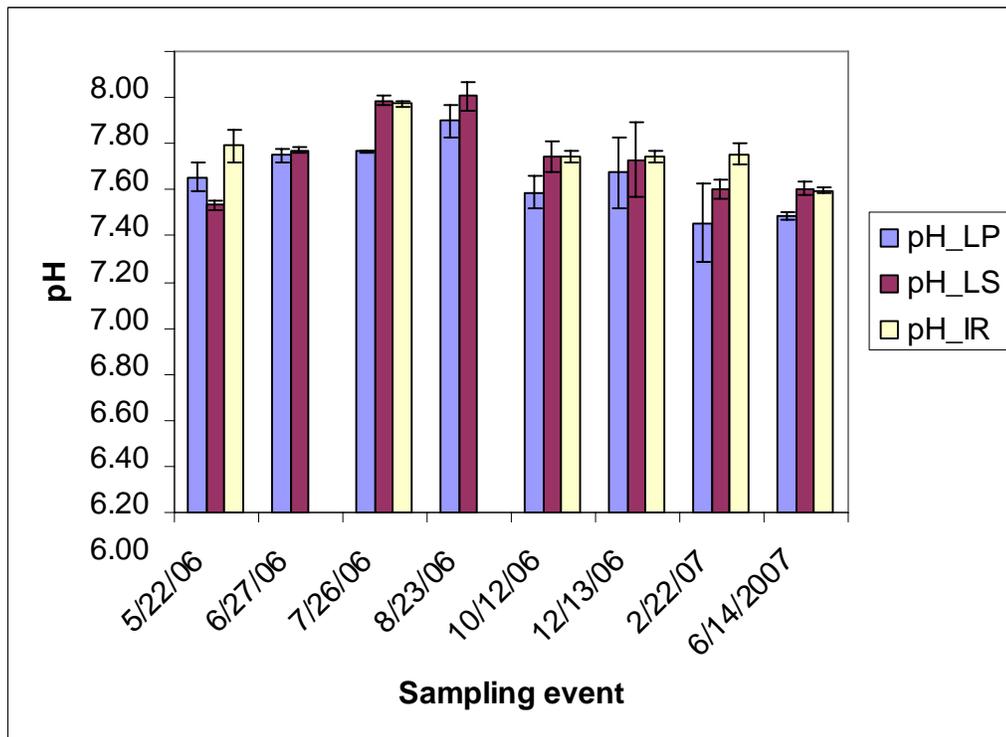


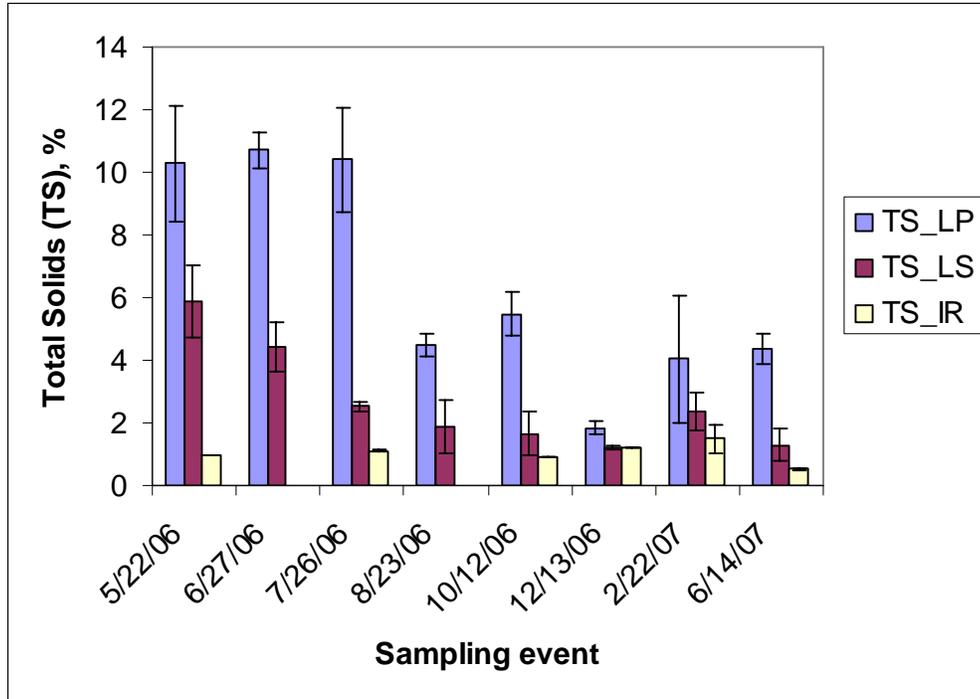
Fig. 14. Average pH trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Although pre-treatment pH for the LP was slightly higher than LS, the pH of LS increased slightly following microbial treatment and remained relatively higher until the end of monitoring. Conversely, pH for IR was slightly higher than that of LP and LS and maintained the same trend until the end of the demonstration. Higher pH for the LS and IR

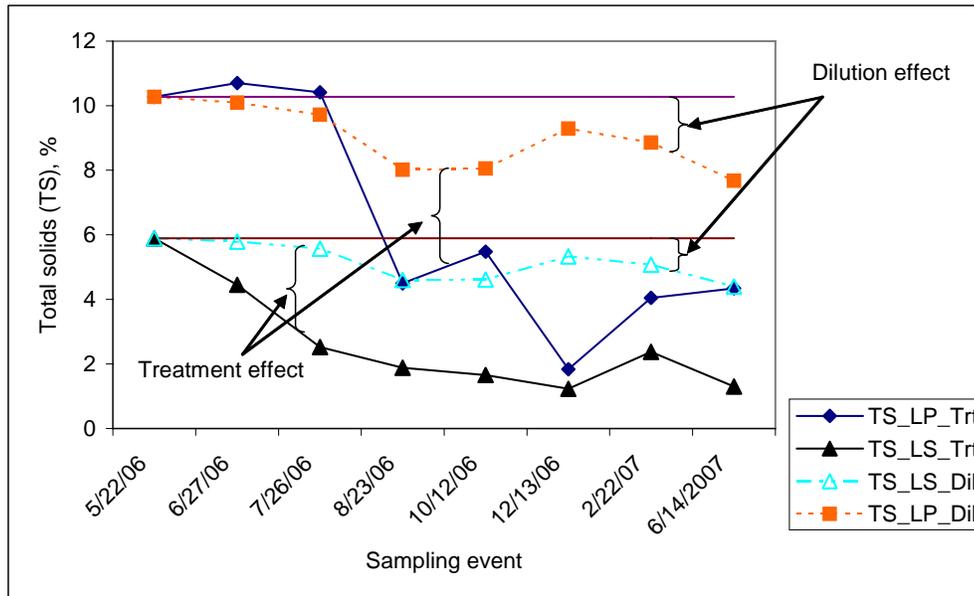
was likely due to lesser amount of organic matter in IR and LS samples as compared to LP. All pH values as received from TIAER are listed in tables I through III in Appendix A.

Solids

Average TS concentrations during each sampling event are shown in Fig. 15a and overall concentration of TS in LP, LS, and IR are listed in Table 6. All solids concentrations as received from TIAER lab are listed in tables IV through VI in Appendix A. TS concentration in LS decreased following first microbial treatment in May 2006 and continued to decrease throughout the monitoring period with a small amount of fluctuation at the end of the demonstration (Fig. 15a). Overall reduction of TS in LS was 60% while the TS concentration for LP did not show significant reduction until August 2006 after the third treatment had been applied; at this point, TS concentration of LP was reduced by 56%. Throughout the course of the demonstration, the overall reduction of TS in the LP was 43%. The higher TS reduction for LP and LS were observed when temperatures were favorable to microbial activities.



(a)



(b)

Fig. 15. L4DB® treatment effects on: a) Total solids (TS) and b) dilution and treatment effect on TS. LP: liquid profile, LS: Liquid supernatant; Trt: Treatment, Dil: Dilution (Note: May 2006 sampling is the pretreatment sampling)

Table 6. Average TS, TSS, TDS, TVS and TFS for lagoon and irrigated effluent samples averaged over sampling events

Parameter ¹	Sampling location		
	LP	LS	IR
Total solids (TS)	6.45a [*] ±3.47	2.66b±1.70	1.04c±0.34
Total suspended solids (TSS)	5.33a±3.64	1.93b±1.77	0.35c±0.42
Total dissolved solids (TDS)	1.30a±1.28	0.85ab±0.38	0.70b±0.17
Total volatile solids (TVS)	3.13a±1.41	1.49b±0.95	0.52c±0.24
Total fixed solids (TFS)	3.32a±2.14	1.16b±0.77	0.49b±0.12

^{*} Averages within a row followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

¹ parameter is in %

The majority of TS concentration reduction in LP and LS samples occurred when temperatures were favorable for microbial activity. As a result, the reduction of TS may be caused by an increase in biological uptake. Conversely, average TS for IR showed a slight increase (21%) as compared to its pre-treatment concentration (Fig. 15a), which could not be explained.

To explore further whether this reduction of solids for LP and LS was likely due to treatment or dilution effect, lagoon water volume changes were taken into account and TS values were adjusted. As seen in Fig. 15b, changes in lagoon water volume can reduce TS concentrations considerably as compared to pretreatment TS concentration due to a dilution effect (TS concentration differences between pretreatment and adjusted for dilution). On the other hand, TS for LP increased slightly following microbial treatment until July 2006 (third treatment) (Fig. 15b). This was likely due to re-suspension of solids resulting from microbial biodegradation of sludge; this phenomenon has also been observed by other researchers (Converse and Karthikeyan, 2004). After July 2006, measured TS levels were always significantly lower than the adjusted TS for dilution. Hence, the differences between the

measured and adjusted for dilution TS concentrations were likely due to microbial digestion of solids, as well as solids settling at the bottom of the lagoon. In addition, volatile losses of solids due to microbial activities might also contribute to reduction of TS from LP as indicated by Zhu et al. (2000).

Overall, average TS for LP, LS and IR (Table 6) were greater than TS concentration observed by Mukhtar et al. (2004), Barker et al. (2001; cited in Mukhtar et al., 2004), and Converse and Karthikeyan (2004). Solids concentration for LS were also higher than the typical 1% found in the supernatant of most anaerobic dairy lagoons suggesting that this lagoon had a much higher solids loading than other lagoons. This could contribute to greater sludge accumulation if this lagoon is not managed properly.

Total suspended solids (TSS) for LP, LS and IR followed a trend similar to TS concentration for these sampling locations. Average TSS concentration for each sampling event and overall concentration averaged for all sampling events are presented in Fig. 16 & Table 6, respectively. The TSS concentration for LP did not show significant reduction following treatment until August 2006 (third treatment) (Fig. 16), when TSS concentration for LP was reduced by 59%. Overall, the reduction of TSS for the LP was 45%. In LS samples, TSS concentration reduced gradually throughout the treatment with the highest reduction occurring in June 2007 (94%); the overall TSS reduction for LS was 71%. TSS concentration for IR increased significantly (123%) as compared to pre-treatment concentration (Fig. 16). For this lagoon, TSS exhibited 83 and 73% of the TS for LP and LS, respectively, while the overall TSS was 63% of TS. Therefore, most TS reductions for LP and LS in this lagoon were apparently reductions of TSS indicating that the treatment system was effective in reducing TSS significantly for LP and LS, but not IR effluent.

As expected, TS and TSS concentrations of LP were significantly greater than those of LS and IR (Table 6). Averaged TSS for the LP was higher than the LS since suspended solids degrade slowly and remain suspended in the entire LP. In addition, accumulated dead and degraded bacterial mass at the bottom of lagoon might also contribute to increased solids content for LP.

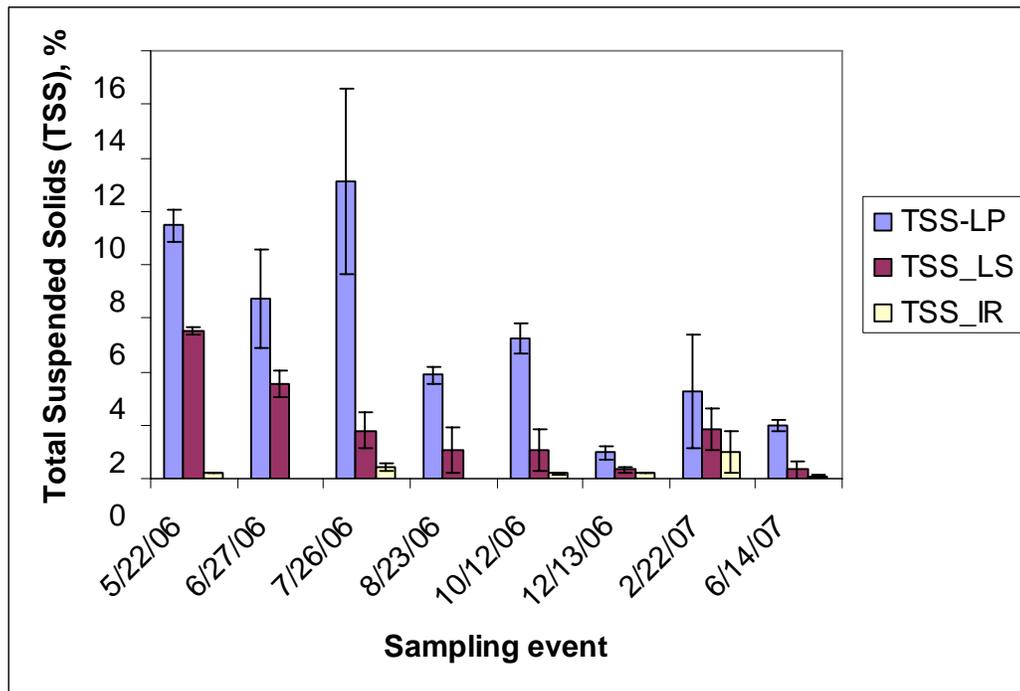


Fig. 16. L4DB® treatment effects on: a) Total suspended solids (TSS). LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Total dissolved solids (TDS) are easily degradable organic matter and a measure of total materials that are dissolved in water. Following microbial treatment of the lagoon, TDS concentration for LS decreased slightly until October 2006 and fluctuated slightly near the end of the demonstration (Fig. 17); overall, TDS in LS samples decreased by 44%. Conversely, following the first treatment TDS for LP increased significantly in June 2006 (280%). This

drastic increase in TDS for the LP was likely due to rapid conversion of suspended solids into dissolved solids by the microbes following the first treatment in the lagoon (Zhu et al., 2000). Thereafter significant TDS reductions were observed in LP until October 2006 (75%), but following October sampling, TDS fluctuated and its concentration increased by 125% in June 2007 from its pre-treatment (Fig. 17). Overall, TDS increased by 28% to its pre-treatment level for LP, however excluding June 2006 and 2007 sampling events TDS decreased by 42% from its pre-treatment in LP profile.

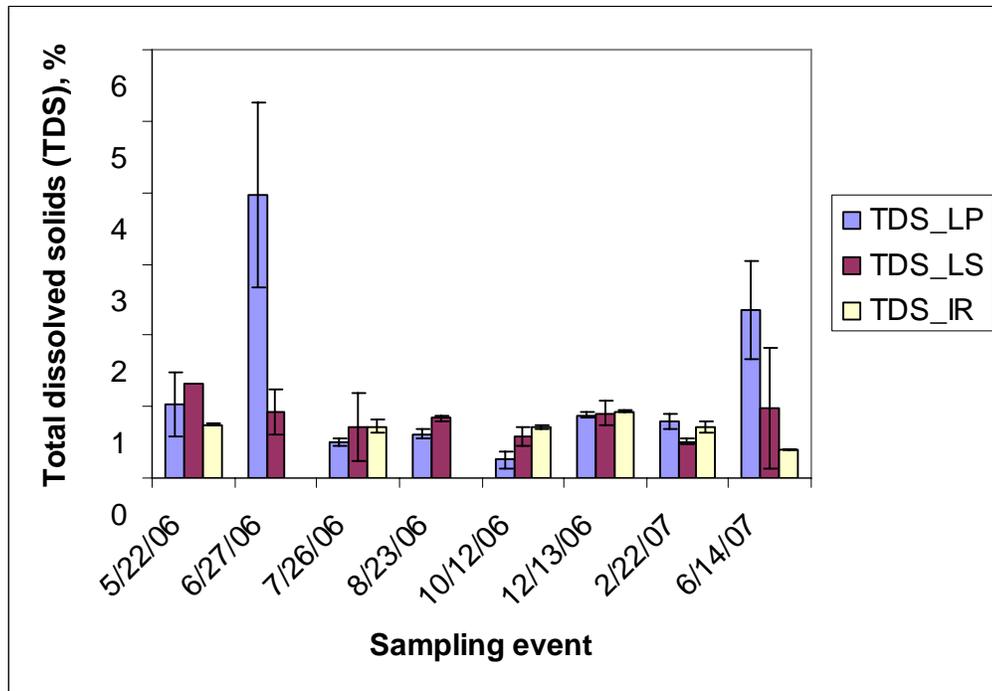


Fig. 17. L4DB® treatment effects on: a) Total dissolved solids (TDS). LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent. (Note: May 2006 sampling is the pretreatment sampling)

Similarly, TDS concentration for IR fluctuated throughout the monitoring period but increased slightly (3%) as compared to the IR pre-treatment concentration. Overall, the ratio of TDS/TS was much higher in IR (0.67) than it was in LS (0.32) and LP (0.20). This implies

that about 67, 32 and 20% of TS in IR, LS and LP were dissolved solids, respectively. Therefore, greater solids for IR are likely due to greater TDS content. This suggests that microbes are more active in the supernatant as compared to the entire profile, where most of the solids reduction was observed.

Total volatile solids (TVS) and TFS are presented in Figs. 18 and 19. Just as TS, TVS did not show significant reduction in LP following treatment until August 2006 (third treatment). After August, TVS concentration in LP decreased by 44% while December 2006 exhibited the highest single TVS reduction (78%). In total, TVS for the LP was 31% and it constituted 48% of the TS. TVS concentration in LS responded similarly and gradually decreased until December 2006; thereafter, values fluctuated slightly. The overall TVS reduction for LS was 58% and TVS represent 56% of TS. IR samples showed no clear TVS trends; overall TVS increased by 37%. This variation in TVS was likely due to variation in the rate and extent of microbial biodegradation of organic compounds and the influence of flushed water added to the lagoon (Wilkie, 2005).

Total fixed solids (TFS) for LP, LS and IR followed a trend similar to TSS (Fig 19). The TFS concentration for LP did not show significant reduction following treatment until August 2006 (third treatment) when TFS concentration for LP decreased by 64%; the overall reduction of TFS in LP was 51%. Total fixed solids (TFS) concentration in LS reduced gradually throughout the monitoring period with the highest reduction occurring in June 2007 (85%) and the overall TFS reduction was 62%. Total fixed solids concentrations for IR fluctuated throughout the monitoring period and showed an overall reduction of 9% (Fig. 19). Typically, TFS is neither chemically reactive nor biologically degradable and theoretically it

should stay unchanged (Zhu et al., 2000). In this case, TFS fluctuated in the lagoon suggesting that variability in sludge depth was partly due to variation in these solids.

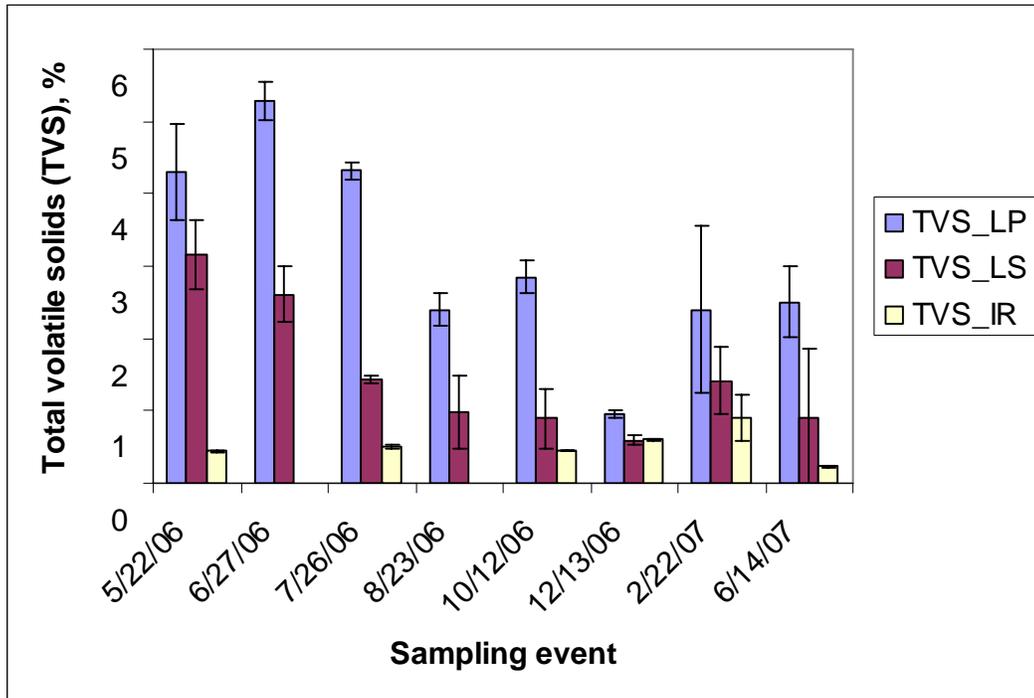


Fig. 18. Total volatile solids (TVS) trend over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Both TDS and TFS for LP were significantly greater than those from LS and IR, while they were statistically similar between LS and IR. Additionally, all other solids for LS were significantly greater than those for IR. The difference in solids concentration between LS and IR was un-expected because the irrigation pump inlet was located at a depth of 15 inches (46 cm), which is within the LS samples collection depth range (0-24 inches).

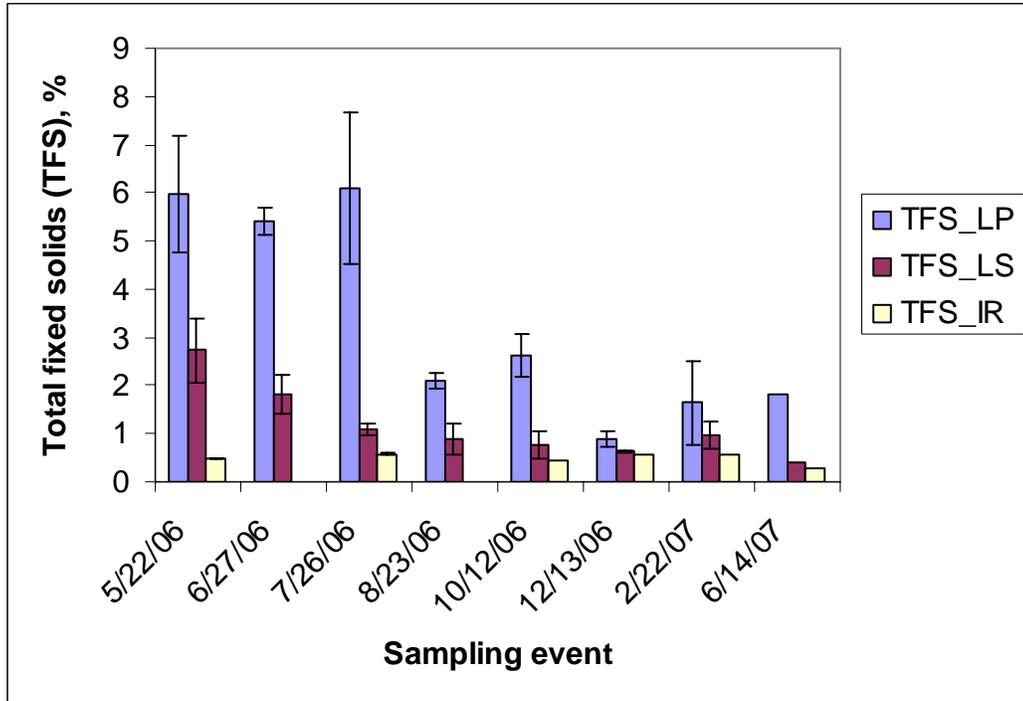
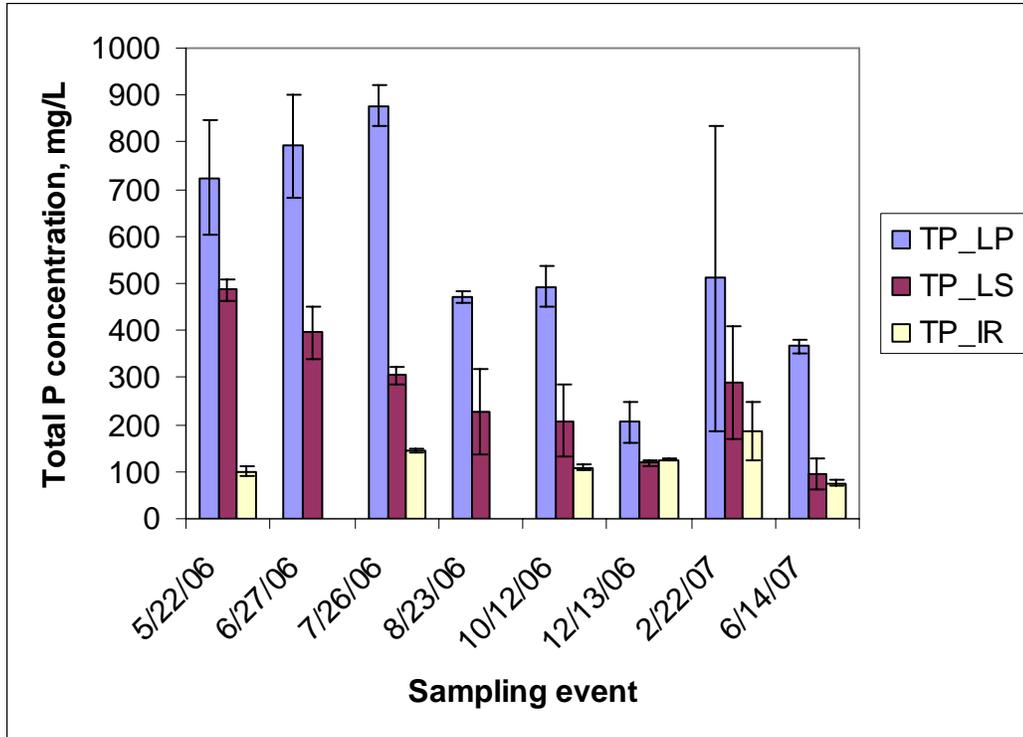


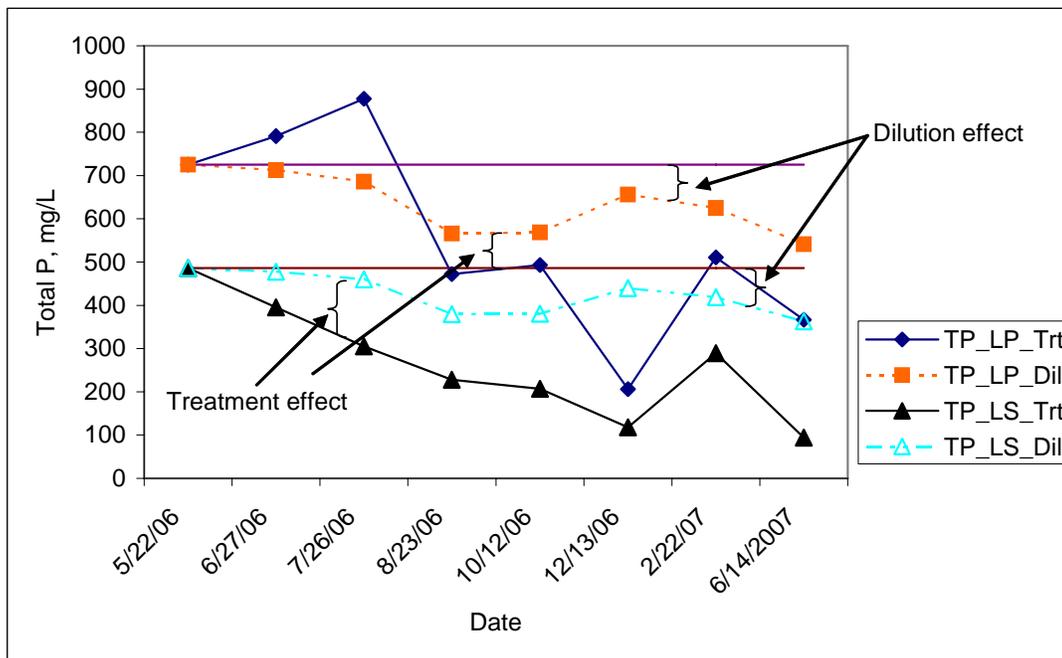
Fig. 19. Total fixed solids (TFS) trend over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Nutrients

Average total P for LP, LS and IR for each sampling event are presented in Fig 20a. Total P concentration in LP increased slightly until July 2006 and was likely due to re-suspension of solids resulting from microbial degradation of sludge (Converse and Karthikeyan, 2004). In December 2006, TP concentrations in the LP were reduced by 72% from its pretreatment concentration; thereafter, TP concentration fluctuated considerably until the end of demonstration (Fig. 20a).



(a)



(b)

Fig. 20. a) Total phosphorus (TP) trend over time for the L4DB® treatment and b) treatment and dilution effect on Total P. LP: liquid profile, LS: Liquid supernatant; Trt: Treatment, Dil: Dilution (Note: May 2006 sampling is the pretreatment sampling)

Microbial consumption of suspended solids is the likely reason for TP reductions; sedimentation of particulate P and degraded microbial cells at the bottom of the lagoon could also influence TP levels in the lagoon. Throughout the course of the demonstration, TP was reduced by an average of 27%.

Total P concentration for LS decreased gradually following microbial treatment until August 2006 when it began to fluctuate somewhat for the remainder of the demonstration (Fig. 20a). The highest single reduction in TP was 81% for LS samples and was observed in June 2007 with the average reduction totaling 52% for the entire demonstration. The high TP reduction in June was likely due to combination of increased microbial activities at a favorable environmental condition, dilution resulting from runoff water contribution, as well as the low evapotranspiration rate during that time (Fig. 20a).

In the case of IR effluent, overall TP concentration increased by 28% compared to its pretreatment concentration and could be the cause of greater dissolved solids in the IR effluent. No clear trend in TP levels was observed in IR samples; however, a weak correlation ($R^2 = 0.20$) was observed between TP and TDS for IR effluent.

A dilution effect could have influenced reductions in TP for LP and LS. To evaluate this theory, lagoon water volume changes were taken into account and TP concentration were adjusted accordingly. As shown in Fig. 20b, dilution itself can reduce TP concentration substantially from its pretreatment concentration as indicated by the dilution effect. After adjusting samples for dilution, it was revealed that differences between treatment and dilution adjusted TP concentrations were likely due to L4DB® microbial treatment (Fig. 20b). No significant reduction in TP concentration was observed for the LP until August 2007, when TP measured was significantly lower than TP adjusted for dilution. Although, measured TP

concentrations varied towards the end of monitoring, but these values were much lower than those adjusted for dilution. Dilution analysis shows that the differences between treatment TP and TP adjusted for dilution were likely due to treatment effects. Overall, significant differences in TP concentration were observed among LP, LS and IR effluent (Table 7).

Table 7. Average TP, SRP, TKN, NNN and K concentration (mg/L) for lagoon and irrigated effluent samples averaged over all sampling events

Parameter ¹	Sampling location		
	LP	LS	IR
Total phosphorus (TP)	555a*±239	265b±137	124c±43
Soluble reactive phosphorus (SRP)	9.24a±3.79	9.28a±3.89	4.28b±1.83
Total Kjeldahl nitrogen (TKN)	2023a±801	1288b±586	775c±223
Nitrate-Nitrite Nitrogen (NNN)	0.22a±0.10	0.23a±0.10	0.20a±0.06
Potassium (K)	1228a±294	1129ab±289	992b±312

* Averages within a row followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

¹ parameter is in mg/L

As expected, higher TP concentration for LP was likely due to higher TS and TSS as compared to LS and IR (Table 6). In addition, degraded microbial cells accumulate at the bottom of the lagoon and runoff water added might also contribute to increased TP concentration for LP. In this study no quantitative or qualitative assessment of runoff water added to the lagoon was conducted, therefore we can not quantify the effects of runoff on the lagoon. TP was also strongly tied to TS ($R^2 = 0.91$) and TSS ($R^2 = 0.87$) (Fig. 21). A similar correlation for TP versus TS and TSS was also reported by McFarland et al. (2003). A stronger relationship was observed in LS samples between TSS and TP ($R^2=0.92$) as compared to TS and TP ($R^2= 0.90$). This suggests that most of the TP in LS is adsorbed to

suspended materials (i.e., TSS), while it is adsorbed to larger particulate matter for the LP. Therefore, without measuring the sludge's P content, the reduction of P from the entire profile due to treatment can not be unequivocally determined.

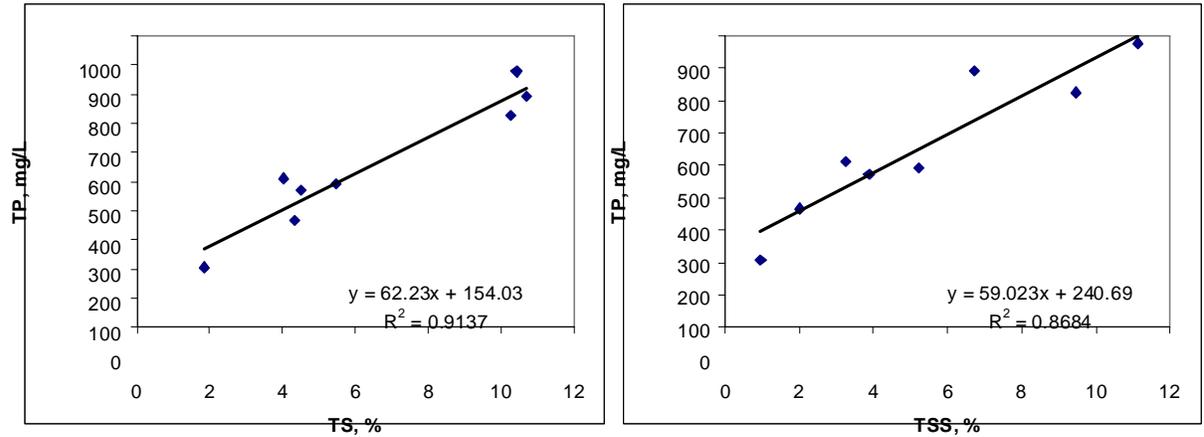


Fig. 21. Relationship between TP vs. TS and TP vs. TSS for LP

Conversely, TP for IR effluent increased by 28% from its pre-treatment concentration, which was likely due to loosening of sludge and dead microbial cells from the bottom of the lagoon to the upper profile as well as mixing of slurry due to impeller action at pumping depth. This loosening of sludge phenomena is also observed by other researchers (Converse and Karthikeyan, 2004), indicating that loosening of the settled solids from the lagoon bottom caused them to rise to the upper profile, carrying the P associated with them.

Average SRP for LP, LS and IR during each sampling event is presented in Fig. 22. Following the first microbial treatment, SRP concentration for these sampling locations reduced gradually until August 2006; thereafter its concentration fluctuated considerably, especially at the end of sampling (June 2007) when SRP concentration increased significantly as compared to pre-treatment concentrations (Fig. 22). This increased SRP concentration was

likely due to excessive runoff water contribution to the lagoon. Average SRP for IR was significantly lower than in LP and LS; however, it was statistically similar to LP and LS (Table 7). Overall, no clear SRP reduction trends were noticed for any of these locations.

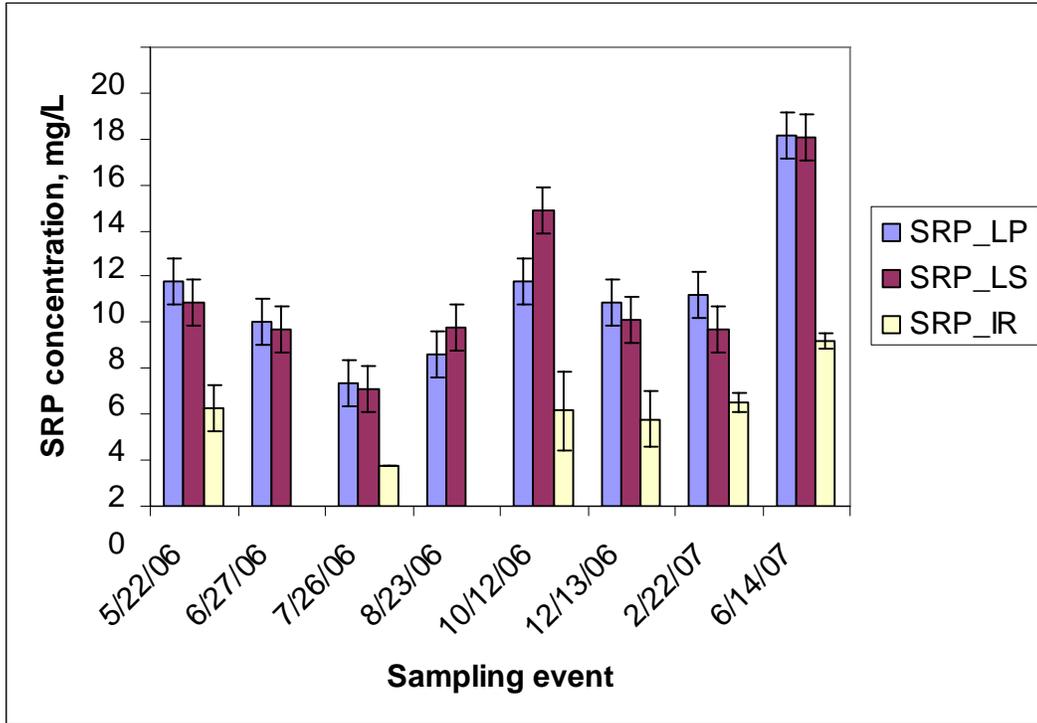


Fig. 22. Orthophosphate phosphorus (SRP) concentration trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Total Kjeldahl nitrogen (TKN) in LP, LS and IR samples followed a trend similar to TP concentration. No significant changes in TKN concentration were observed in LP until August 2006; thereafter, little variation of TKN was observed (Fig. 23). The highest TKN reduction for LP occurred in December 2006 (67%) and the overall reduction was 36%. The highest TKN reduction in LS samples was observed in June 2007 (74%) and the overall reduction was 48%. Total Kjeldahl nitrogen fluctuated in IR (Fig. 23) and over time, TKN concentration in IR increased slightly (6%). The highest TKN concentration for LP was likely

due to higher TSS in the LP, since TKN is strongly correlated with TSS in LP ($R^2 = 0.78$) and LS ($R^2 = 0.89$). This is comparable to the findings of McFarland et al. (2003), where they reported a correlation coefficient of 0.85 between TSS and TKN.

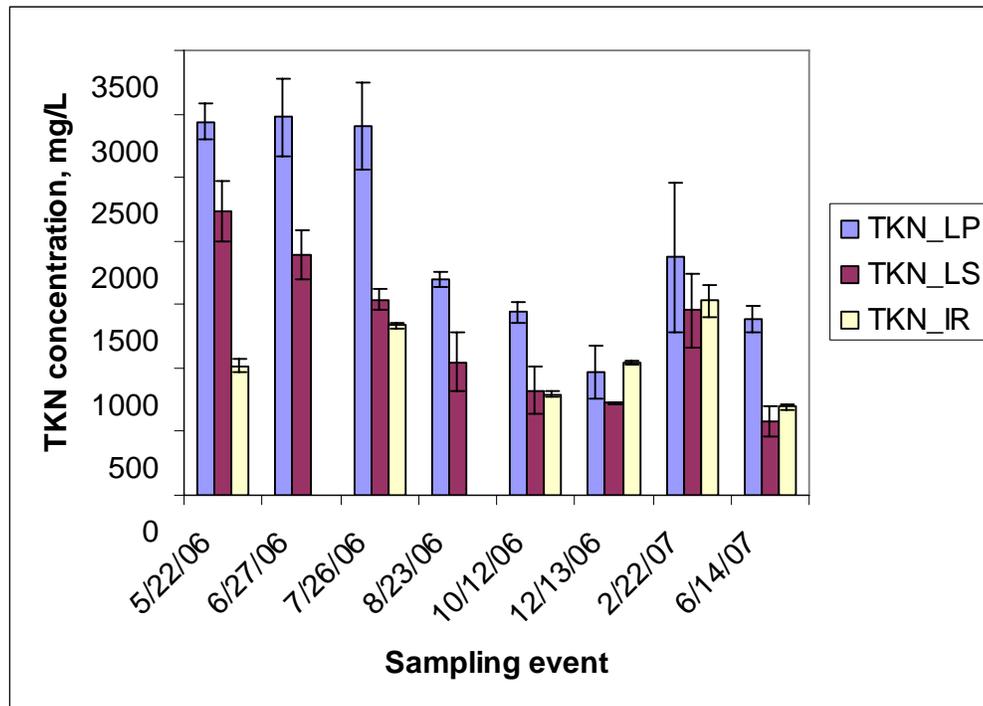


Fig. 23. Total Kjeldahl nitrogen (TKN) concentration trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Significant differences in TKN concentration were observed among LP, LS and IR (Table 7) as well as among sampling events for LP, LS and IR (Fig. 23). The reduction of TKN concentration for LP and LS were likely due to a combination of treatment effects, added flush water and ammonia volatilization. Higgins et al. (2004) reported that reductions in TKN concentration are also likely due to ammonia volatilization caused by higher lagoon temperature and wind velocity. Scotford et al. (1998) also suggested that a flushing system may dilute the slurry and thereby reduce TKN concentrations. These findings fail to explain the observed increases in TKN concentration in the IR effluent.

Average Nitrate-Nitrite Nitrogen (NNN) concentrations for LP, LS, and IR are presented in Fig. 24. Following the pre-treatment sample in May 2006, NNN concentration fluctuated considerably for both LP and LS, especially towards the end of the treatment where significant reduction of NNN concentration were observed for all sampling locations (Fig. 24). Overall, no clear trends of NNN concentration reduction were observed for LP and LS, although its concentration was reduced by 11% for the IR effluent. Variation in NNN concentrations was likely due to flush water added to the lagoon. Findings from Bicudo et al. (1999) support this; their studies show that 60-70% of the soluble NNN is contained in the effluent. Overall, no significant differences in NNN concentration were observed among LP, LS and IR effluent (Table 7) suggesting that this treatment was not effective in reducing NNN concentrations.

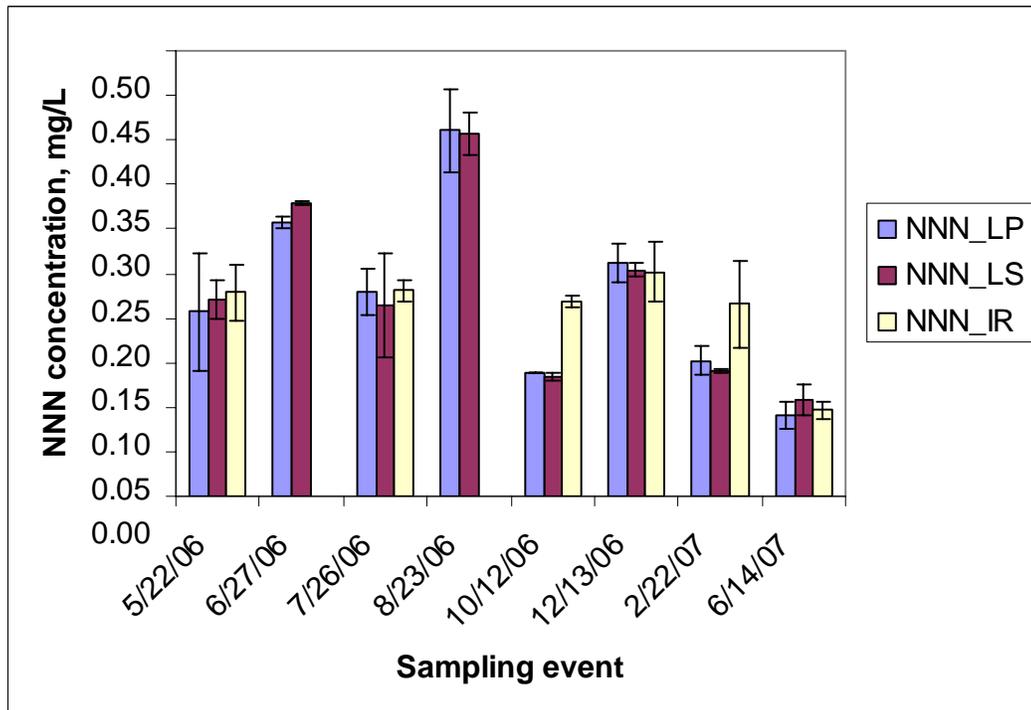


Fig. 24. Nitrite-Nitrate Nitrogen (NNN) concentration trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Average K concentration for LP, LS and IR during each sampling event is presented in Fig 25. The highest K concentration was observed in December 2006 and no significant changes in the concentration of K occurred until the end of sampling. This variation in concentration was likely due to runoff water contribution and variation in flush water added to the lagoon and K's high water-solubility (Gustafson et al., 2007). Average K concentrations are listed in Table 7 and show no significant differences concentration in any sample set. It is apparent that this microbial treatment was not effective in reducing the concentration of K.

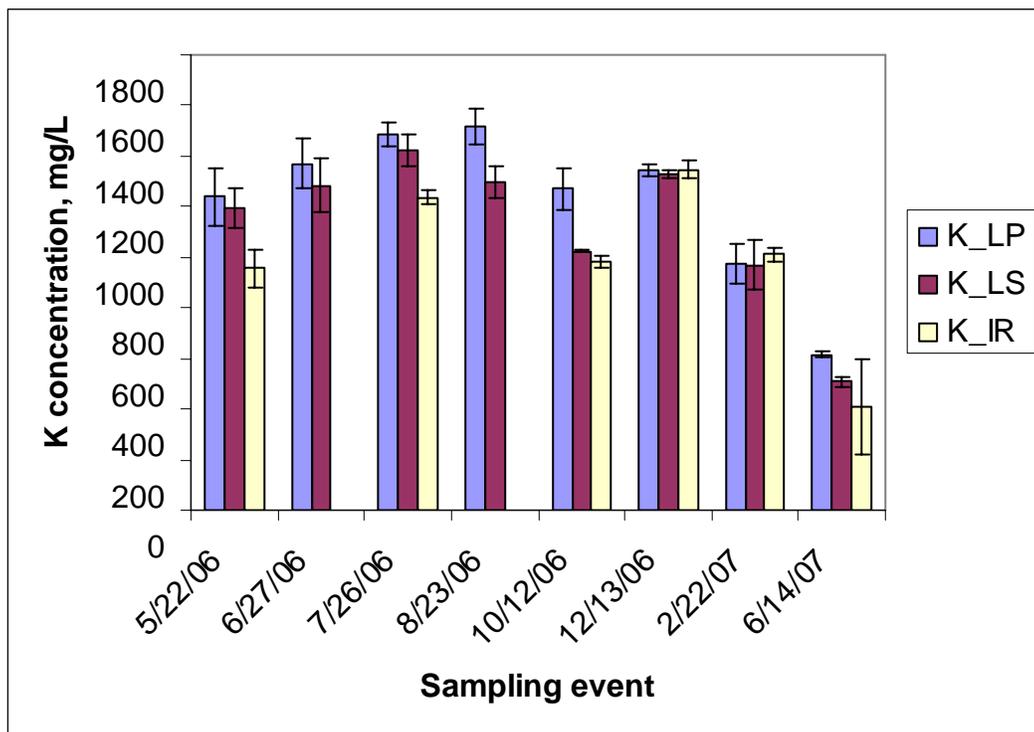


Fig. 25. Potassium (K) concentration trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

Nutrient data analyses suggest that L4DB® treatment was somewhat effective in reducing TP, TKN, but not SRP, K and NNN concentration in LP, LS and IR. This implies

that this microbial treatment was not highly effective in reducing nutrients that are water soluble. Without accurate measurements of sludge nutrient content, it was difficult to ascertain that the reduction of nutrients from these profiles was likely due to settling of solids including dead and degraded bacterial mass accumulated at the bottom of lagoon. All nutrient concentrations received from TIAER are also listed in tables I through III in Appendix A.

Metals

Metals in animal manure largely reflect the metals concentration in feeds that the animals consumed (Nicholson et al., 1999). Following microbial treatment, aluminum (Al) concentration in LS decreased gradually until December 2006 but then fluctuated toward the end of the demonstration (Fig. 26). The highest Al concentration reduction in LS was observed in December 2006 (96%) and the overall reduction was 82%. Aluminum concentration in LP fluctuated considerably throughout the monitoring period, but remained significantly lower than the pre-treatment concentrations; overall, Al concentrations were reduced by 62% in LP.

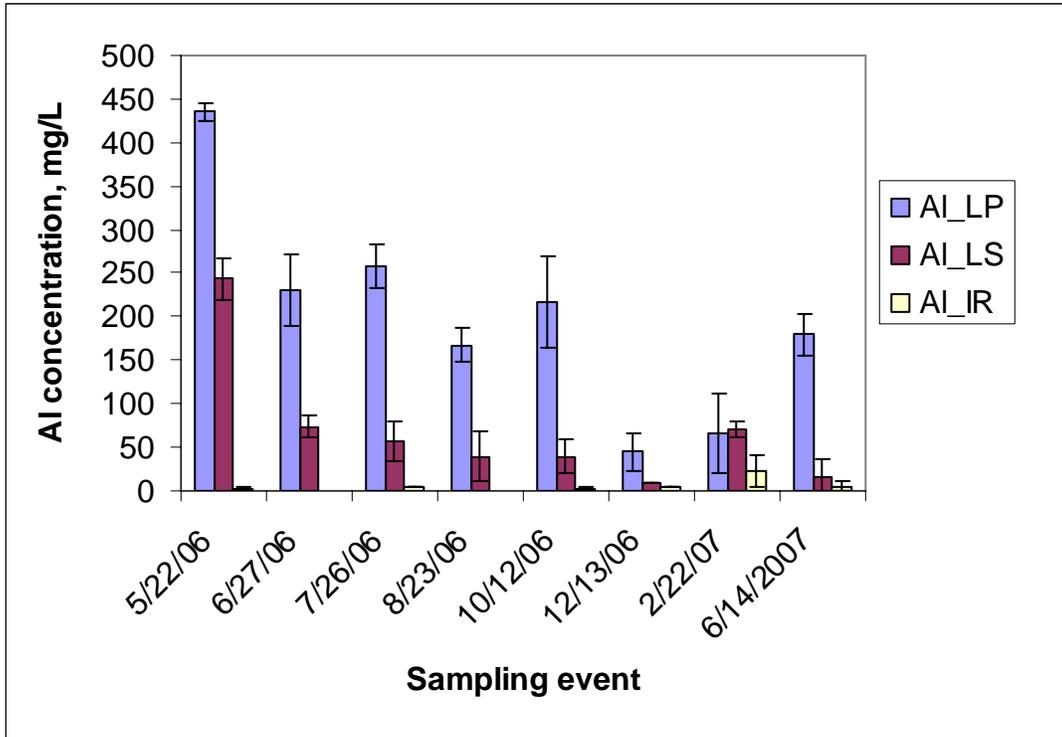


Fig. 26. Aluminum (Al) concentration trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pre-treatment sampling)

Similar or greater reductions than the average Al concentrations in LP, LS and IR samples were observed in all metals except Mg. Average metals concentrations at different sampling events for LP, LS and IR are listed in Tables 8 & 9. Overall Al, Ca, Cu, Fe, Mg, and Mn concentration reduction for the LP were 62, 57, 58, 56, 22 and 55% respectively while these values for LS were 82, 70, 80, 81, 42, and 62% respectively. These concentration reductions are likely due to microbial activities as well as variation in feed composition, which was not explored in this study and was beyond the scope work.

Table. 8. Average concentration of aluminum (Al) Calcium (Ca), Copper (Cu) concentration for LP, LS and IR at different sampling events

Date	Al (mg/L)			Ca (mg/L)			Cu (mg/L)		
	LP	LS	IR	LP	LS	IR	LP	LS	IR
5/22/06	435.50a ±10.60	244.00a ±24.04	3.10b ±0.43	5785a ±120	3140a ±665	325cd ±25	16.80a ±0.98	11.29a ±3.26	1.00b ±0.0
6/27/06	230.00cb ±41.01	73.60b ±12.58	N/A	3575cb ±530	1450b ±339	N/A	12.45b ±0.49	3.26b ±1.04	N/A
7/26/06	258.50b ±24.74	56.85cb ±22.69	4.52b ±0.43	4315b ±233	1320cb ±127	396cb ±11	14.75ba ±1.20	2.68b ±0.65	0.46c ±0.04
8/23/06	167.50c ±19.09	39.95cbd ±29.62	N/A	2200ed ±99	861cbd ±423	N/A	5.95dc ±0.25	2.07b ±1.37	N/A
10/12/06	216.00cb ±52.32	39.65cbd ±19.44	3.26b ±0.26	2810cd ±594	813cbd ±307	304cd ±14	6.71c ±1.45	1.58b ±0.82	1.00b ±0.00
12/13/06	44.55d ±20.85	8.60d ±0.57	4.72b ±0.79	1078f ±313	577cd ±11	505b ±11	1.62e ±0.87	1.00b ±0.00	1.00b ±0.00
2/22/07	65.75d ±45.74	70.60b ±9.47	22.20a ±18.52	1433f ±829	1225cb ±64	657a ±190	3.33de ±2.34	3.28b ±0.47	1.565a ±0.77
6/14/07	179.50cb ±23.33	16.55cd ±19.73	5.38b ±6.14	2099edf ±239	354d ±177	209d ±65	4.30dce ±0.53	2.00b ±0.00	2.00a ±0.00

*Averages within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

Table. 9. Average concentration of iron (Fe), magnesium (Mg), and manganese (Mn) for LP, LS and IR at different sampling events

Date	Fe (mg/L)			Mg (mg/L)			Mn (mg/L)		
	LP	LS	IR	LP	LS	IR	LP	LS	IR
5/22/06	385.50a ±2.12	213a ±31.11	3.08b ±0.26	597ba ±117	524a ±55.15	210b ±15.43	20.05a ±3.89	13.35a ±2.89	1.01c ±0.02
6/27/06	269b ±33.23	73.50b ±21.07	N/A	591ba ±28.28	392b ±52.32	N/A	14.690a ±1.27	6.02b ±1.55	N/A
7/26/06	303b ±31.82	61.65b ±18.03	4.48b ±0.23	694a ±12.02	374b ±26.16	256a ±4.32	16.65a ±1.34	5.50b ±1.06	1.66b ±0.03
8/23/06	140c ±2.82	36.45cb ±31.18	N/A	504bc ±30.40	321cb ±38.18	N/A	8.67b ±0.29	3.97cb ±1.13	N/A
10/12/06	193c ±49.49	36.50cb ±19.09	2.041b ±0.10	502bc ±46.66	261cd ±37.47	195b ±6.73	5.79b ±4.73	11.55a ±1.63	1.08cb ±0.04
12/13/06	39d ±15.90	8.45c ±0.24	4.38bb ±0.57	304d ±16.26	261cd ±0.70	260a ±10	3.26b ±0.60	1.70c ±0.04	1.40cb ±0.03
2/22/07	57d ±38.89	60.25b ±7.28	18.03a ±13.77	334d ±129	298c ±0.70	222b ±27.19	5.41b ±3.15	5.44b ±0.77	2.41a ±0.96
6/14/07	178c ±16.97	10.15c ±11.52	4.95b ±5.90	352dc ±18.38	189d ±13.43	131c ±45.49	7.99b ±0.84	1.021c ±0.30	1.00c ±0.00

*Averages within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests

For LP and LS, metals concentrations were highly correlated with solids ($R^2= 0.77$ to 0.92 for LP and $R^2= 0.63$ to 0.93 for LS), but no clear trends for metals were observed in IR. Overall, significant differences in metals concentration (i.e., Al, Ca, Cu, Fe, Mg, Mn) were observed among LP, LS and IR; Na was the only metal to show a decrease (Table 10). It is apparent from the low percentage reduction in Na that this treatment system was not effective in reducing Na and other soluble constituents (i.e., SRP, NNN, TDS etc.) in this lagoon.

Table 10. Average metals concentration (mg/L) for lagoon and irrigated effluent samples averaged over all sampling events

Parameter ¹	Sampling location		
	LP	LS	IR
Aluminum (Al)	19.669a [*] ±120	68.73b±73	7.20c±9.87
Calcium (Ca)	2912a±1556	1218b±868	399c±166
Copper (Cu)	8.24a±5.53	3.39b±3.33	1.18b±0.58
Iron (Fe)	195.47a±117	62.49b±67	6.23c±7.69
Manganese (Mn)	10.46a±6.30	6.09b±4.30	1.43c±0.62
Magnesium (Mg)	485a±146	330b±104	212c±49
Sodium (Na)	470a±140	465a±124	424a±146

* Averages within a row followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests

¹ parameter is in mg/L

Nicholson et al. (1999) reported that the mean Cu concentration in dairy cattle slurry collected from commercial farms in England and Wales was 4.73 mg/L (62.3 mg/kg dm; dry matter 7.6%). Ullman and Mukhtar (2007) reported Cu concentrations in dairy lagoons in central Texas in the range of 8.1-19.2 mg/L depending on management practices applied at the specific dairy. In this study, average Cu concentration for LP was 8.24 mg/L and was similar to concentrations found in other studies. Cu concentration in manure is related to Cu added as

a supplement to feed (Li et al., 2005). In general, manures will contain higher Cu concentration if feeds contained higher concentrations of Cu (Nicholson et al. 1999). In this study feed composition was not analyzed; however, average concentration of metals (i.e., Ca, Mg, Fe, etc.), except Mn, was much higher than those reported by Ullman and Mukhtar (2007). All metals concentrations as received from TIAER are also listed in tables VI through IX in Appendix A.

Conductivity

The average conductivity for LP, LS and IR are presented in Fig. 27, where L4DB® microbial treatment appeared to cause little or no reduction in EC levels until the end of the demonstration. A sharp increase in EC during December 2006 was observed in LP and LS samples and was likely due to greater amount of nutrients present during that time (due to lower irrigation frequency and additional solids loading) compared to the previous sampling, since dissolved mineral salts (Stevens et al., 1995; Scotford et al., 1998; Yayintas et al., 2007) change conductivity. Typically, when salinity increases, conductivity increases. Conductivity and K, for this lagoon, exhibited good correlation in IR ($R^2 = 0.57$) and LS ($R^2 = 0.53$) samples, but were somewhat correlated in LP ($R^2 = 0.22$). Scotford et al. (1998) also observed strong correlation ($R^2 = 0.80$) between K and EC. Although conductivity exhibited some variability in this study, no significant differences were observed among LP, LS and IR samples.

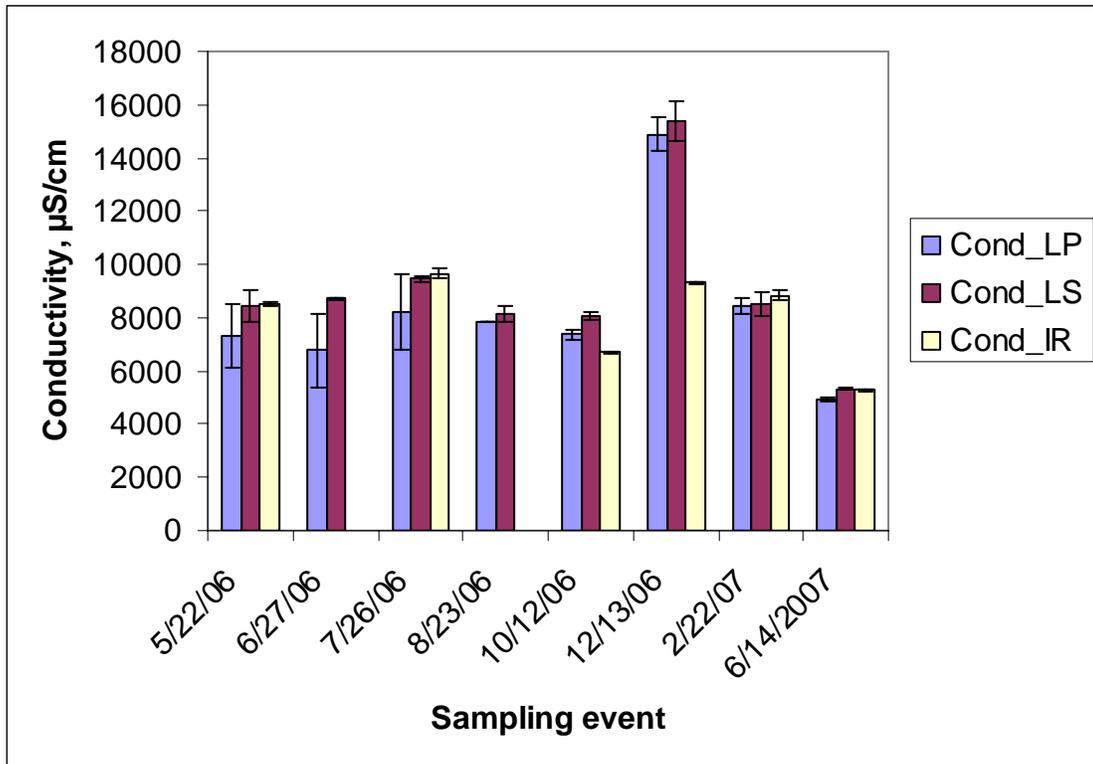


Fig. 27. Conductivity trends over time for the L4DB® treatment. LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent (Note: May 2006 sampling is the pretreatment sampling)

While statistically similar, the average conductivity for LS ($9,184 \pm 2,052 \mu\text{S/cm}$), was slightly higher than LP ($8,379 \pm 2,193 \mu\text{S/cm}$) and IR ($8,356 \pm 1,360 \mu\text{S/cm}$). Safley et al. (1993) reported that EC value of $8,000 \mu\text{S/cm}$ can inhibit bacterial population in livestock treatment lagoon. In this lagoon, EC was higher than this suggested threshold value and might have impacted L4DB® microbial performance in reducing physiochemical parameters of slurry. All conductivity values as received from TIAER are also listed in tables I through III in Appendix A.

TREATMENT COSTS

Costs to implement this lagoon treatment method varied based on the daily amount of manure and wastewater that is added to the lagoon, the existing lagoon capacity and sludge depth, prior wastewater treatment (e.g., pretreatment of flushed manure for solids separation before it flows to the lagoon), lagoon depth, and the number of lagoon cells in the wastewater management system. In addition, the treatment costs will also vary with the type of manure alley cleaning system used, such as flushing or vacuuming. The following cost matrix was also provided by the technology provider:

Table 11. Cost to treat a lagoon with L4DB® microbial treatment

Herd size	Unit cost (\$/cow/month)	\$/cow/year
1000	1.00	12
1001-7000	0.60 ~ 0.90	7.2 ~ 10.8
>7001	0.30 ~ 0.60	3.6 ~ 7.2

Based upon the information in Table 11, for this 300-head dairy, the total cost to treat the lagoon was estimated at \$3900 for a 13 months period or \$12/cow/year.

CONCLUSIONS

Effectiveness of L4DB® microbial treatment on an anaerobic lagoon was monitored for one year. It appears that L4DB® microbial treatment was somewhat effective in reducing solids and resulted in reducing sludge depth by 24% (however, this reduction was 16% excluding the measurement anomaly in August 2006). The L4DB® treatment was also highly

effective in reducing TS, TSS, TVS and TFS in the LS, but less effective in reducing these solids from LP and no clear trends were observed for irrigation effluent (IR). Over time, L4DB® treatment reduced TS (43%), TSS (45%), TDS (42%), TVS (31%), and TFS (51%) in LP samples, while they were reduced by 60, 71, 44, 58, and 62% respectively for LS samples. Similarly, reductions of phosphorus were likely due to microbial uptake of P from LS and LP; however, P continues to be mobile until settling occurs (Farve et al., 2004). The trend shown in this report confirms that due to microbial activities P was very mobile in LP profile as compared to LS. Overall, L4DB® treatment was somewhat effective in reducing TP, TKN, but was not effective in reducing SRP, NNN and K concentrations. Average concentrations of TP and TKN in the LP were reduced by 27 and 36%, respectively while these constituents were reduced by 52 and 48% in the LS. Significant metal concentration reductions were observed for the LP (ranged from 22 to 62%) and the LS (ranged from 42 to 82%), while metals concentration increased slightly for IR over time. Although conductivity exhibited considerable variability, no significant differences in conductivity were observed among LP, LS and IR samples.

Variable performance and poor reduction of nutrients in few cases were likely due to over loading of the lagoon as well as varied treatment application rates. The technology provider pre-determined the application rate for this lagoon based on experiences, but not by measuring environmental conditions of the lagoon. It might be useful to conduct a lab-scale study to determine the effective application rate based on varying conditions of temperature, manure nutrient and metals loading and existing sludge level in lagoons to be treated.

Therefore, it could be inferred that most of these solids, nutrients, and metal reduction were likely due to microbial treatment, dilution of lagoon slurry due to excessive rain and

runoff water as well as settling of dead and degraded bacterial mass accumulated at the bottom of lagoon. Additional measurements of lagoon sludge accumulation rate and constituents are warranted to assess possible increase in nutrients and solids due to accelerated solids settling and increased accumulation of microbial mass at the lagoon bottom.

CHALLENGES

Tanks were used to mimic the repeatability of lagoon treatment with microbes and to get additional information on treatment effectiveness. Tank evaporation losses caused significant difficulty in maintaining a consistent TS and TP sampling depth in tanks. As a result, it remains a challenge to obtain replicated data on treatment effectiveness in outdoor environmental conditions under tank environment. It is apparent that microbial treatment was more effective in the lagoon supernatant than the entire profile but, without accurate assessment of pre- and post-treatment sludge characteristics, it is premature to conclude how effective the treatment was in reducing nutrient, metals and solids in the lagoon. The foremost challenge is to collect and monitor the lagoon sludge sample for an extended period of time prior to, during and after treatment to determine solids, nutrients and metal content of the lagoon that will enable a determination to be made regarding the effectiveness of the applied treatment.

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APPENDIX C-I

Table I. pH, conductance ($\mu\text{S}/\text{cm}$), and nutrients concentration (mg/L) in LP samples at different sampling events

Site ID	Collection Date	pH	Conductance	NNN	ORP	TP	TKN
LP1	5/22/2006	7.5	8140	0.254	7.83	810	3040
LP1	6/27/2006	7.57	5900	0.312	7.04	713	2760
LP1	7/26/2006	7.57	9570	0.21	5.49	847	2660
LP1	8/23/2006	7.64	9510	0.451	8.27	464	1740
LP1	10/12/2006	7.34	7440	0.139	11.1	462	1380
LP1	12/13/2006	7.38	13300	0.249	13	237	1120
LP1	2/22/2007	7.13	8650	0.141	11.4	741	2290
LP1	6/14/2007	7.27	5630	0.078	18.5	356	1307
LP2	5/22/2006	7.41	6470	0.16	11.7	640	2840
LP2	6/27/2006	7.53	7870	0.303	9.09	870	3190
LP2	7/26/2006	7.56	7480	0.248	5.24	908	3140
LP2	8/23/2006	7.76	9540	0.37	5.02	480	1660
LP2	10/12/2006	7.44	7220	0.138	8.52	524	1500
LP2	12/13/2006	7.57	12500	0.275	4.77	175	825
LP2	2/22/2007	7.38	9070	0.164	7.06	281	1460
LP2	6/14/2007	7.3	5780	0.103	13.8	377 ^{SR}	1455

Table II. pH, conductance ($\mu\text{S}/\text{cm}$), and nutrients concentration (mg/L) in LS samples at different sampling events

Site ID	Collection Date	pH	Conductance	NNN	ORP	TP	TKN
LS1	5/22/2006	7.32	8880	0.206	9.05	470	2060
LS1	6/27/2006	7.58	8910	0.331	7.08	356	1760
LS1	7/26/2006	7.8	9910	0.172	4.88	292	1480
LS1	8/23/2006	7.86	9630	0.387	9.7	293	1210
LS1	10/12/2006	7.5	7920	0.131	14.1	261	957
LS1	12/13/2006	7.43	13800	0.249	12.3	113	719
LS1	2/22/2007	7.37	8620	0.139	9.85	374	1660
LS1	6/14/2007	7.38	6100	0.095	17	69.9 ^{SR}	499
LS2	5/22/2006	7.35	8020	0.236	8.69	502	2400
LS2	6/27/2006	7.56	8840	0.327	8.28	435	2030
LS2	7/26/2006	7.77	9730	0.257	5.4	318	1600
LS2	8/23/2006	7.75	10100	0.427	5.92	163	889
LS2	10/12/2006	7.59	8150	0.138	11.6	153	693
LS2	12/13/2006	7.63	12900	0.258	3.96	123	730
LS2	2/22/2007	7.43	9250	0.142	5.51	205	1250
LS2	6/14/2007	7.43	6190	0.123	15.2	118 ^{SR}	666

Table III. pH, conductance ($\mu\text{S}/\text{cm}$), and nutrients concentration (mg/L) in IR samples at different sampling events

Site ID	Collection Date	pH	Conductance	NNN	ORP	TP	TKN
IR1	5/22/2006	7.69	8450	0.209	6.33	82.6	684
IR1	7/26/2006	7.78	10100	0.242	3.69	132	928
IR1	10/12/2006	7.54	8070	0.211	5.26	103	579
IR1	12/13/2006	7.54	8070	0.277	4.77	111	730
IR1	2/22/2007	7.58	9400	0.14	9.92	127	971
IR1	6/14/2007	7.41	6130	0.093	14.6	61.1	455
IR2	5/22/2006	7.53	8610	0.204	10.2	81.4	647
IR2	7/26/2006	7.79	10100	0.231	3.62	132	940
IR2	10/12/2006	7.58	8060	0.219	5.96	100	553
IR2	12/13/2006	7.58	8060	0.275	10.4	111	718
IR2	2/22/2007	7.6	9380	0.236	8.23	132	1020
IR2	6/14/2007	7.4	6040	0.114	14.2	67.2	472
IR3	5/22/2006	7.55	8520	0.229	10.9	99.9	738
IR3	7/26/2006	7.77	10100	0.225	3.75	130	943
IR3	10/12/2006	7.53	8120	0.228	11.3	97.7	548
IR3	12/13/2006	7.53	8120	0.221	9.19	114	731
IR3	2/22/2007	7.5	9000	0.246	10.1	247	1240
IR3	6/14/2007	7.4	6070	0.092	15.1	70.5	497
IR4	5/22/2006	7.6	8480	0.273	8.07	95.3	759
IR4	7/26/2006	7.76	10100	0.226	3.62	125	897
IR4	10/12/2006	7.53	8080	0.216	12.2	89.9	527
IR4	12/13/2006	7.53	8080	0.233	7.36	111	708
IR4	2/22/2007	7.54	9320	0.242	9.32	162	1020
IR4	6/14/2007	7.38	6080	0.088	15.9	71.7	502

Table IV. Concentration of solids (%) in LP samples at different sampling events

Site ID	Collection Date	TS	TSS	TVS	TDS	TFS
LP1	5/22/2006	11.6	9.89	4.78	1.68	6.82
LP1	6/27/2006	10.3	5.43	5.09	4.89	5.21
LP1	7/26/2006	9.23	8.68	4.24	0.548	4.99
LP1	8/23/2006	4.76	4.1	2.56	0.658	2.2
LP1	10/12/2006	4.99	4.82	2.69	0.166	2.3
LP1	12/13/2006	1.99	1.14	0.994	0.85	0.996
LP1	2/22/2007	5.47	4.76	3.22	0.713	2.25
LP1	6/14/2007	4	2.14	2.16	1.86	1.84
LP2	5/22/2006	8.95	9.04	3.83	0.4044	5.12
LP2	6/27/2006	11.1	8.03	5.48	3.05	5.62
LP2	7/26/2006	11.6	13.6	4.4	0.4675	7.2
LP2	8/23/2006	4.23	3.66	2.24	0.567	1.99
LP2	10/12/2006	5.96	5.62	3.01	0.339	2.95
LP2	12/13/2006	1.69	0.78	0.914	0.908	0.776
LP2	2/22/2007	2.62	1.74	1.58	0.875	1.03
LP2	6/14/2007	4.69	1.86	2.86	2.83	1.83

Table V. Concentration of solids (%) in LS samples at different sampling events

Site ID	Collection Date	TS	TSS	TVS	TDS	TFS
LS1	5/22/2006	6.7	5.62	3.49	1.08	3.21
LS1	6/27/2006	3.89	3.19	2.34	0.697	1.55
LS1	7/26/2006	2.41	1.35	1.4	1.06	1.01
LS1	8/23/2006	2.46	1.64	1.35	0.816	1.11
LS1	10/12/2006	2.14	1.64	1.18	0.498	0.96
LS1	12/13/2006	1.19	0.4	0.544	0.788	0.646
LS1	2/22/2007	2.9	2.42	1.75	0.48	1.15
LS1	6/14/2007	0.463	0.084	0.205	0.379	0.258
LS2	5/22/2006	5.08	5.45	2.82	0	2.26
LS2	6/27/2006	5.01	3.87	2.89	1.14	2.12
LS2	7/26/2006	2.64	2.26	1.48	0.382	1.16
LS2	8/23/2006	1.3	0.43	0.627	0.866	0.673
LS2	10/12/2006	1.17	0.5	0.599	0.673	0.571
LS2	12/13/2006	1.27	0.24	0.641	1.03	0.629
LS2	2/22/2007	1.85	1.3	1.09	0.547	0.754
LS2	6/14/2007	2.14	0.56	1.58	1.58	0.56

Table VI. Concentration of solids (%) in IR samples at different sampling events

Site ID	Collection Date	TS	TSS	TVS	TDS	TFS
IR1	5/22/2006	0.843	0.11	0.358	0.733	0.485
IR1	7/26/2006	0.972	0.366	0.401	0.606	0.571
IR1	10/12/2006	0.843	0.152	0.377	0.691	0.466
IR1	12/13/2006	1.07	0.11	0.495	0.958	0.575
IR1	2/22/2007	1.08	0.3	0.593	0.782	0.49
IR1	6/14/2007	0.456	0.054	0.188	0.405	0.268
IR2	5/22/2006	0.878	0.128	0.376	0.75	0.502
IR2	7/26/2006	1	0.324	0.424	0.676	0.576
IR2	10/12/2006	0.826	0.122	0.374	0.704	0.452
IR2	12/13/2006	1.06	0.145	0.492	0.919	0.568
IR2	2/22/2007	1.08	0.33	0.591	0.749	0.487
IR2	6/14/2007	0.459	0.064	0.184	0.395	0.275
IR3	5/22/2006	0.881	0.13	0.382	0.751	0.499
IR3	7/26/2006	0.997	0.195	0.42	0.802	0.577
IR3	10/12/2006	0.82	0.096	0.37	0.724	0.45
IR3	12/13/2006	1.06	0.135	0.498	0.92	0.562
IR3	2/22/2007	1.92	1.32	1.15	0.601	0.767
IR3	6/14/2007	0.457	0.062	0.191	0.395	0.266
IR4	5/22/2006	0.877	0.127	0.377	0.75	0.5
IR4	7/26/2006	1.02	0.2	0.431	0.822	0.589
IR4	10/12/2006	0.826	0.11	0.371	0.736	0.455
IR4	12/13/2006	1.07	0.135	0.508	0.935	0.562
IR4	2/22/2007	1.25	0.56	0.701	0.686	0.545
IR4	6/14/2007	0.469	0.074	0.199	0.395	0.27

Table VII. Metals concentration (mg/L) in LP samples at different sampling events

Site ID	Collection Date	Al	Ca	Cu	Fe	K	Mg	Mn	Na
LP1	5/22/2006	428	5870	16.1	387	1320	680	22.8	499
LP1	6/27/2006	201	3200	12.1	245	1300	571	14	497
LP1	7/26/2006	241	4150	13.9	280	1450	703	16.7	581
LP1	8/23/2006	154	2130	5.77	142	1470	483	8.46	247
LP1	10/12/2006	179	2390	5.69	158	1210	469	2.44	499
LP1	12/13/2006	59.3	1300	2.24	50.4	1360	316	3.69	630
LP1	2/22/2007	98.1	2020	4.99	84.6	1030	425	7.64	377
LP1	6/14/2007	196 ^{SR}	E2268 ^D	4.68 ^{SR}	190 ^{D, SR}	626	365 ^{D, SR}	8.59	255
LP2	5/22/2006	443	5700	17.5	384	1160	515	17.3	411
LP2	6/27/2006	259	3950	12.8	292	1440	611	15.8	550
LP2	7/26/2006	276	4480	15.6	325	1520	686	18.6	587
LP2	8/23/2006	181	2270	6.13	138	1570	526	8.88	654
LP2	10/12/2006	253	3230	7.74	228	1330	535	9.14	538
LP2	12/13/2006	29.8	857	1	27.9	1330	293	2.84	602
LP2	2/22/2007	33.4	847	1.68	29.6	918	243	3.18	349
LP2	6/14/2007	163 ^{SR}	1930 ^D	3.93	166 ^{D, SR}	606	339 ^D	7.39	239

Table VIII. Metals concentration (mg/L) in LS samples at different sampling events

Site ID	Collection Date	Al	Ca	Cu	Fe	K	Mg	Mn	Na
LS1	5/22/2006	261	3610	13.6	235	1250	563	15.4	481
LS1	6/27/2006	64.7	1210	2.52	58.6	1210	355	4.92	449
LS1	7/26/2006	40.8	1230	2.22	48.9	1380	375	4.75	591
LS1	8/23/2006	60.9	1160	3.05	58.5	1250	348	4.78	519
LS1	10/12/2006	53.4	1030	2.16	50	1030	288	10.4	425
LS1	12/13/2006	8.19	585	1	8.62	1320	261	1.73	589
LS1	2/22/2007	77.3	1270	3.62	65.4	898	297	5.99	348
LS1	6/14/2007	2.60 ^{SR}	229 ^D	< 2 ^{SR}	< 2 ^{SR}	495	179 ^{D, SR}	<1	213
LS2	5/22/2006	227	2670	8.98	191	1140	485	11.3	443
LS2	6/27/2006	82.5	1690	4	88.4	1360	429	7.12	502
LS2	7/26/2006	72.9	1410	3.14	74.4	1470	412	6.25	598
LS2	8/23/2006	19	562	1.1	14.4	1340	294	3.17	542
LS2	10/12/2006	25.9	596	1	23	1020	235	12.7	451
LS2	12/13/2006	9.01	570	1	8.28	1340	260	1.67	643
LS2	2/22/2007	63.9	1180	2.95	55.1	1040	298	4.9	421
LS2	6/14/2007	30.5 ^{SR}	480 ^D	< 2	18.3 ^{SR}	520	198 ^D	1.43	227

Table IX. Metals concentration (mg/L) in IR samples at different sampling events

Site ID	Collection Date	Al	Ca	Cu	Fe	K	Mg	Mn	Na
IR1	5/22/2006	3.57	316	1	3.41	920	204	1	379
IR1	7/26/2006	4.44	388	0.507	4.42	1210	252	1.68	513
IR1	10/12/2006	2.93	318	1	2.27	987	197	1.02	399
IR1	12/13/2006	5.52	521	1	4.94	1400	273	1.43	658
IR1	2/22/2007	9	550	1.25	9.35	1040	211	1.79	417
IR1	6/14/2007	14.6 ^{SR}	307 ^D	< 2 ^{SR}	13.8 ^{SR}	130	62.4 ^{SR}	<1	64.9
IR2	5/22/2006	2.57	360	1	2.79	1060	232	1	426
IR2	7/26/2006	4.32	394	0.429	4.2	1250	256	1.62	505
IR2	10/12/2006	3.18	313	1	2.44	1010	203	1.1	454
IR2	12/13/2006	4.94	502	1	4.62	1320	250	1.42	584
IR2	2/22/2007	11	519	1.1	9.4	981	199	1.82	403
IR2	6/14/2007	2.51 ^{SR}	176	< 2 ^{SR}	< 2 ^{SR}	497	151 ^{SR}	<1	211 ^{SR}
IR3	5/22/2006	2.93	322	1	2.99	960	210	1.02	383
IR3	7/26/2006	5.15	391	0.442	4.77	1220	254	1.65	510
IR3	10/12/2006	3.43	289	1	2.45	954	187	1.11	475
IR3	12/13/2006	4.8	500	1	4.35	1340	253	1.4	621
IR3	2/22/2007	49.1	935	2.79	38.3	1030	261	3.83	392
IR3	6/14/2007	2.09 ^{SR}	175	< 2 ^{SR}	< 2 ^{SR}	508	154 ^{SR}	<1	212 ^{SR}
IR4	5/22/2006	3.32	302	1	3.16	888	196	1.05	352
IR4	7/26/2006	4.16	412	0.461	4.56	1270	262	1.71	513
IR4	10/12/2006	3.52	295	1	2.5	989	193	1.09	436
IR4	12/13/2006	3.63	498	1	3.6	1330	263	1.35	663
IR4	2/22/2007	19.7	623	1.46	15.1	1000	215	2.22	407
IR4	6/14/2007	2.34 ^{SR}	180	< 2	< 2 ^{SR}	510	155 ^{SR}	<1	201 ^{SR}

Appendix D

Agriculture is Life!

Cycling of Geotube[®] Solids from Dairy Lagoons Through Turfgrass Sod

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Summary

Polymer – Abbreviation for polyacrylamide is used in water purification to flocculate suspended organic matter. Although polyacrylamide is designated as a non-toxic additive by USDA, its building block, acrylamide, is a potential nerve toxin in humans and causes birth defects and cancer in animals. A concentration limit of 500 ppm acrylamide in polyacrylamide preparations has been established for water treatment applications.

Geotube[®] solids – particulate matter collected from wastewater pumped from lagoon into semi-permeable fibrous sock.

Lysimeter – Container in which the volume of soil used to grow plants is isolated hydrologically from surrounding soil to control and measure water and nutrient inputs and losses.

Mineralization – Conversion of organic N to NH_4^+ . Heterotrophic microorganisms use organic carbon compounds as an energy source for the conversion process.

Introduction

The Geotube[®] Dewatering System (Miratech Division of Ten Cate Nicolon Corporation; Commerce, Ga.) collects manure solids or sludge from wastewater in large, porous tubes or socks made of synthetic fibers. Alum (aluminum sulfate) and polymers are injected into wastewater during pumping from lagoons into the socks to facilitate particle flocculation as water drains out of the tube through pores in the fabric. Solids are trapped inside the sock (0440 ft³), or Geotube[®], while water drains from socks and is collected in a secondary lagoon. The injection of aluminum or other metal salts and/or polymers enhances separation of solids from lagoon wastewater and retention of particulate forms of nitrogen (N), phosphorus (P), and other nutrients within socks compared to wastewater filtering without chemical treatments (Worley et al. 2008). The use of chemical treatments also enhances water flow through porous Geotube[®] walls and improves system efficiency ultimately resulting in reduced total solids in wastewater by 93.5%, soluble P by 85%, and total P by 96% (Mukhtar et al. 2007).

Disposal of residual solids from the Geotube[®] poses another challenge. The injection of alum and polymers during effluent treatment raises questions about the sustainability of Geotube[®] solids application to agricultural or urban soils within or outside watersheds on which dairies are located (Sims et al. 2005). Sustainable systems for managing residual solids require maintenance of farm level and regional nutrient balances (Bergstrom et al. 2005).

Application and export of the nutrients in Geotube[®] solids through turfgrass sod or other high-value, non-food crops could enable repeated applications of the solids on land proximate to confined animal feeding operations (Vietor et al. 2002). However, the alum and polymers in treated solids could be detrimental to soil's physical, chemical and biological properties and turfgrass growth (Aggelides and Londra, 2000; Malecki-Brown et al. 2007; Wang et al. 1998). In addition, application of Geotube[®] solids to soil could contribute to leaching loss of soluble nutrient forms and in turn be detrimental to water quality (Maguire and Sims 2002).

The goal of this project was to evaluate the sustainability of systems for cycling Geotube[®] solids through turfgrass production for value-added export with sod. The first objective was to evaluate

turfgrass establishment and physical, chemical, and biological properties of contrasting soil textures with and without incorporation of increasing rates of Geotube[®] solids. The second objective was to evaluate leaching losses of nutrients from contrasting soil textures with and without incorporation of Geotube[®] solids during turfgrass establishment.

Methods

Turfgrass growth, water and nutrient use

An experiment was designed to evaluate six treatment combinations made up of two soil types and three application rates of Geotube[®] solids. Each treatment combination was replicated four times. Geotube[®] solids were collected from a demonstration site on the XXX Dairy in Comanche County (Fig. 1). The solids were air-dried and sieved through a screen (0.25-inch mesh) before sampling, analysis, and incorporation in soil. The two contrasting soil types were a Windthorst fine sandy loam and Weswood sandy clay loam.



Figure 1. Geotube[®] solids were sampled one year after separation from wastewater pumped from the primary lagoon of XXX Dairy in Comanche County, Texas.

Soils were packed into polyvinyl chloride (PVC) cylinders (4-in. diameter x 12-in. depth) over a layer of glass fiber cloth, which separated soil from a 2-in. depth of washed gravel. The 4- to 12-in. depth comprised soil without Geotube[®] solids. The 0- to 4-in. depth of soil was amended with Geotube[®] solids at three rates: 0, 12.5, and 25% by volume. The soil with or without Geotube[®] solids was packed within 2-



Figure 2. Tifway bermudagrass grown in soil columns with varying soil and Geotube[®] material amendments

in. increments to achieve a consistent bulk density throughout the cylinder. All treatments were sprigged with Tifway bermudagrass (*Cynodon dactylon* L. Pers. X *C. transvaalensis* Burtt-Davey) after soil was firmly packed into cylinders (Fig. 2). The hydrostatic pressure of a water column was used to wet soil initially from the bottom to the surface within cylinders after sprigging. Excess water, which drained through fittings in caps sealed on the bottom of cylinders, was collected for analysis. Subsequent irrigation was applied on the soil surface. Given water and nutrient inputs and loss were monitored, the cylinders of soil functioned as lysimeters over the 90-d study.

One pore volume of leachate was displaced through surface irrigation of soil in cylinders and was collected at each 45 and 90 days after sprigging. Leachate volumes were measured and subsampled for analysis. Leachate was filtered (pore size < 0.45 μm) for colorimetric analysis of dissolved reactive P (DRP) and ammonium ($\text{NH}_4\text{-N}$), for spectroscopic analysis of total dissolved P (TDP), and for automated analysis of nitrate ($\text{NO}_3\text{-N}$). Soil and Geotube[®] solids were sampled, dried, ground (< 0.1 in.), and digested prior to analysis of total and extractable nutrients, cations and organic carbon. Turfgrass was clipped to a 2-in. height when plant height exceeded 6 in. Clippings were dried, combined over cutting dates, weighed, ground, and digested for analysis of total N and P

Decomposition of solids

Decomposition of Geotube[®] solids was measured for the six treatment combinations comprising the two soil types mixed with three rates of solids. The six treatments were replicated four times. Soil was mixed with Geotube[®] solids as described above for the 0- to 4-in. depth of the cylinders of soil. After incorporating Geotube[®] solids, soil was incubated under laboratory conditions to evaluate release of CO₂ and inorganic N from organic carbon and N over time. Soil was enclosed within glass jars for 56 days at 77° F. Alkali traps (0.25 N NaOH) adsorbed CO₂ released from soil, which was titrated with acid (0.25 N HCl) at 1, 2, 3, 7, 14, 21, 28, 35, 42, 49, and 56 days after solids were mixed with soil. Inorganic N (NO₃-N + NH₄-N) in extracts of soil sampled before and after the incubation period were measured as described above to estimate rates of N release from soil.

Results

Turfgrass responses in cylinders of soil (lysimeters)

Under greenhouse conditions, mean productivity of Tifway bermudagrass over the 90-d experiment increased ($P=0.05$) as the volume-based rate of Geotube[®] solids increased from 0 to 25% (Fig. 3). In addition, turfgrass productivity without Geotube[®] solids was greater for the Windthorst fine sandy loam than for the Weswood sandy clay loam soil ($P=0.05$). The results indicated neither the alum nor polymers were injected during solids separation in the Geotube[®] were detrimental to turfgrass growth in soils amended with volume-based rates of the solids and irrigated with well water.

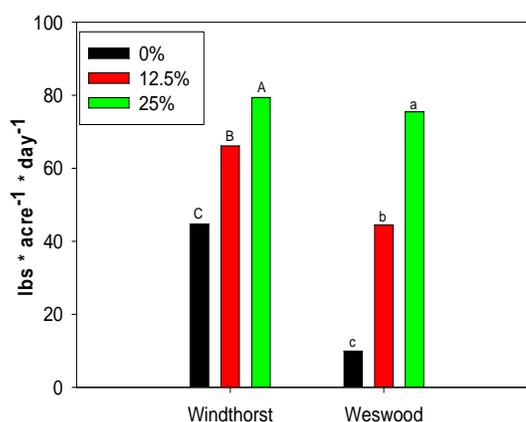


Figure 3. Mean productivity of Tifway bermudagrass in two soil types amended with 0%, 12.5% and 25% by volume of Geotube[®] solids during a 90-d period after sprigging under greenhouse conditions.

Effect of Geotube[®] solids on soil properties

Analysis of soil before incorporation of Geotube[®] solids indicated concentrations of total N and P and extractable P were similar between the Windthorst and Weswood soils (Table 1). In contrast, the concentration of extractable NO₃-N was greater for the Windthorst soil than the Weswood soil. The analysis of Geotube[®] solids indicated concentrations of total P and water-extractable P (WEP) were lower than concentrations of various dairy manure sources as reported by Leytem et al. (2004) (Table 1). In contrast, analyses of Geotube[®] solids indicated NO₃-N concentrations were very high compared to concentrations for composted dairy manure (Johnson et al. 2006). The volume-based rates of 12.5% and 25% by volume of Geotube[®] solids in soil resulted in large concentrations of total N, total P, and total organic C within the 0- to 4-in. depth of soil within PVC cylinders.

	pH	TOC %	TN %	TP ppm	M3P ppm	WEP ppm	NO ₃ ppm
Windthorst	6.4	0.3	0.05	211	12.5	4.1	45.8
Weswood	8.3	1.2	0.04	285	16.9	4.6	1.9
Geotube Solids	5.7	22.1	2.1	1586	-	18.6	3277

Table 1. Chemical properties of soil and Geotube[®] solids before mixing and packing into PVC cylinders. Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP), Mehlich-3 P (M3P), Water Extractable P (WEP), and Nitrate (NO₃) were measured.

The increasing rates of Geotube[®] solids incorporated in the top 4 in. of soil increased TOC concentrations and decreased soil bulk density (Table 2). Incorporating solids at 25% by volume increased mean TOC concentration to 5.8 times greater ($P= 0.001$) than soil without solids. Similarly, 12.5% by volume of Geotube[®] solids increased TOC to triple ($P= 0.001$) that of concentrations in soil without added solids. Soil bulk density decreased ($P= 0.05$) 14.4% for soils amended with 25% by volume of Geotube[®] solids, compared to soil without solids. Similar reductions (19.7%) in soil bulk density have been reported for loamy soils after incorporation of volume based rates (160 yd³ ac⁻¹) of compost (Aggelides and Londra 2000).

Geo residue rate %	pH	density lb ft ³	GWC lb lb ⁻¹	TOC %	TN %	TP ppm
Windthorst 0	8.6	82	0.22	0.33	0.04	43
Windthorst 12.5%	8.3	78	0.21	1.15	0.12	239
Windthorst 25%	8.1	71	0.12	2.23	0.21	594
Weswood 0	8.7	81	0.31	0.43	0.05	272
Weswood 12.5%	8.6	74	0.28	1.15	0.12	432
Weswood 25%	8.3	69	0.26	2.13	0.19	683
std error of means	0.08	5.6	0.02	0.06	0.005	46.7

Table 2. Variation of soil physical and chemical properties (0- to 4-in. depth) as rates of incorporated Geotube[®] solids are increased in two soil types. Variation of mean gravimetric water content (GWC) and total organic carbon (TOC), total N (TN), total P (TP) was evaluated for soil sampled after a 90-d period of turfgrass establishment.

Previous studies demonstrated additions of organic residues increased soil water content (Aggelides and Londra 2000). In contrast, gravimetric soil water content was lower for soil amended with 25% by volume of Geotube[®] solids ($P = 0.05$) than soil with 12.5% by volume solids or no solids (Table 2). In the present study, variation of gravimetric soil water content sampled at 90 d was inversely related to variation of turfgrass productivity among treatments over the 90-d period ($R^2=0.55$). Greater turfgrass uptake and transpiration of water for soils

amended with 25% by volume of Geotube[®] solids could have depleted soil water content compared to soil with less or no added solids. If large, volume-based rates of Geotube[®] solids increase turfgrass growth and water use, soil water content could be reduced if rainfall or irrigation is not sufficient to balance plant water uptake and loss.

Incorporating increasing rates of Geotube[®] solids increased concentrations of total and extractable P and N in soil sampled from cylinders after 90 d of turfgrass establishment (Tables 2 and 3).

Geo residue rate % by Volume	M3P ppm	WEP ppm	NO₃ ppm	NH₄ ppm	M3AI ppm
Windthorst 0	16.1	1.9	79.4	13.9	53.2
Windthorst 12.5%	94.5	10.2	104.1	24.8	48.4
Windthorst 25%	173.2	15.3	114.8	41.6	48.0
Weswood 0	20.7	1.8	55.7	11.5	14.5
Weswood 12.5%	79.2	10.4	102.8	23.4	17.7
Weswood 25%	151.1	13.6	116.8	40.4	17.4
std error of means	4.6	1.2	20.51	7.0	1.5

Table 3. Variation of Mehlich-3 P (M3P), Water Extractable P (WEP), Mehlich-3 Al (M3AI), and inorganic N in soils 90 d after incorporation (0- to 4-in. depth) of increasing rates of Geotube[®] solids.

Incorporating 12.5% by volume of solids increased (P=0.001) soil total N 2.7-fold, total P 2.1-fold, and Mehlich-3 P 4.7 fold compared to soil without solids. In addition, incorporating the highest rate of solids (25% by volume) resulted in greater (P=0.001) soil total N, total P, and Mehlich-3 P than the lower rate of solids or un-amended soil. Moreover, as the rate of Geotube[®] solids increased, soil WEP concentration increased (P= 0.001) (Table 3).

Although soil was sampled after the second leaching event, increasing rates of Geotube[®] solids remained evident as greater mean concentrations of inorganic N (NO₃ and NH₄) in amended soils. At the relatively high soil pH observed after 90 d of irrigation with well water, increasing application rates of incorporated Geotube[®] solids did not increase soil Mehlich-3-extractable Al compared to soil without solids. Yet, Mehlich-3 Al was greater for the Windthorst (P= 0.001) than the Weswood soil.

Effect of Geotube[®] solids on leaching loss

Total dissolved P concentration in leachate collected following wetting of soil in cylinders at day 1 was less than 0.15 ppm and was similar among rates of Geotube[®] solids and between soil types. In contrast, incorporation of 12.5% and 25% by volume of Geotube[®] solids increased TDP concentration in leachate collected at 45 d ($P= 0.001$) and 90 d ($P= 0.001$) compared to control soils (Table 4). In addition, the mass loss of TDP in leachate was greater ($P=0.01$) for soils amended with Geotube[®] solids than un-amended controls at 45 d and 90 d (Table 4). Concentration of TDP in leachate collected at 90 d was linearly ($R^2 = 0.67$) related to concentration of WEP in soil. Although incorporation of Geotube[®] solids increased TDP concentration in leachate, concentrations in the present study were much lower than those reported for soil amended with livestock manure in previous studies (Chardon et al. 2007).

Dissolved reactive P (DRP) concentration in leachate, which is indicative to inorganic P forms, was below detection limits for even the highest rate of Geotube[®] solids (25% by volume) in leachate collected at 45 and 90 d for both soil types. Mean DRP concentration in leachate from both leaching events for the Weswood soil was 0.014 ppm without Geotube[®] solids and was 0.01 ppm for the intermediate rate of solids (12.5%). The low leachate concentrations of DRP are consistent with expected effects of alum and polymer additions on inorganic P forms in the lagoon wastewater during solids collection in the Geotube[®] sock.

Dissolved un-reactive P (DUP) was defined as $DUP = TDP - DRP$ for leachate that was filtered through a 0.45 μm pore size to remove sediment. The DUP was attributed to organic P forms in the filtered leachate. A large fraction of TDP in filtered leachate was DUP for soil with and without Geotube[®] solids.

For leachate collected at 45 and 90 d, DUP was greater ($P= 0.01$) for soils receiving Geotube[®] solids than soils without the amendment (Table 4). The percentage of TDP quantified as DUP ranged from 60 to 90% for soils without incorporated solids and from 87 to 100% for soils amended with increasing rates of the Geotube[®] solids at 90 d. Chardon et al. observed that 90% of TP in leachate was DUP for soil columns amended with animal slurries or manure (1997,

2007). The large percentages of DUP in leachate supported the hypothesis that polymers and alum within the Geotube[®] solids adsorbed DRP in the soil solution; however, a portion of the DUP in soil was soluble and transported in leachate.

Geo residue rate m ³ m ⁻³	45 days			90 days		
	TDP	DUP	TDP	TDP	DUP	TDP
	ppm	ppm	lb ac ⁻¹	ppm	ppm	lb ac ⁻¹
Windthorst 0	0.09	0.09	0.032	0.11	0.10	0.056
Windthorst 0.125	0.15	0.15	0.051	0.23	0.21	0.086
Windthorst 0.25	0.14	0.14	0.044	0.27	0.27	0.082
Weswood 0	0.06	0.05	0.022	0.05	0.03	0.047
Weswood 0.125	0.13	0.12	0.041	0.11	0.09	0.056
Weswood 0.25	0.19	0.18	0.056	0.19	0.18	0.059
std error of means	0.01	0.01	0.005	0.02	0.01	0.006

Table 4. Concentration and mass loss of total dissolved P (TDP) and dissolved un-reactive P (DUP) in leachate collected at 45 and 90 days.

In contrast to the low concentrations of soluble P forms, NO₃-N concentrations in leachate volumes were high and differed (P=0.05) among rates of Geotube[®] solids for one or both soils at 45 and 90 d after sprigging (Table 5). At 45 d, leachate concentration of NO₃-N was greater for soil with Geotube[®] solids (P=0.05) than soil without Geotube[®] solids. Increasing the rate of Geotube[®] solids incorporated in the Windthorst soil increased NO₃-N concentration in leachate 187% and 270% for the respective rates at 45 days (Table 5). In addition, both leachate concentrations and mass loss were greater (P= 0.05) for Windthorst than Weswood soil with or without incorporated solids at 45 and 90 d after sprigging. Although greater for the Windthorst soil, concentrations of NO₃-N in leachate declined for all rates of solids at 90 d compared to 45 d. The leachate concentration of NO₃-N for Windthorst soil amended with 25% Geotube solids decreased 72% from 45 to 90 d. Mass loss of NO₃-N and turfgrass uptake of N may have contributed to reductions in leachate NO₃-N concentrations from 45 to 90 d.

Geotube residue rate m ³ m ⁻³	45 d NO ₃ -N ppm	90 d NO ₃ -N ppm
Windthorst 0	85.7	0.3
Windthorst 0.125	160.6	1.2
Windthorst 0.25	231.6	64.5
Weswood 0	0.02	0.1
Weswood 0.125	77.5	0.1
Weswood 0.25	72.8	1.0
std error of mean	39.1	11.0

Table 5. Concentration of NO₃-N in leachate at 45 and 90 days

Incorporation of Geotube[®] solids in soil increased NO₃-N concentrations in leachate well above the health advisory level for drinking water set by the USEPA. Similar high concentrations of NO₃-N have been reported after incorporation of composted manures at 3800 lb ac⁻¹ (Evanylo et al. 2008). Applications of Geotube[®] solids at the volume-based rates could exceed potential turfgrass N uptake during establishment and pose a threat to water quality. Yet, the NO₃-N applied with the Geotube[®] solids and subsequent release of inorganic N from degrading organic N contributed to increased productivity of turfgrass compared to soils without incorporated solids (Fig. 2) (Evanylo et al. 2008).

Decomposition of incorporated solids in soil

Decomposition rates for organic carbon, which are indicative of inorganic N release rates or mineralization from organic N, decreased over time for soils with and without Geotube[®] solids. Increasing the rate of incorporated solids in both soil types increased (P= 0.005) decomposition rate for organic carbon. Incorporating 12.5% by volume of Geotube[®] solids increased decomposition rate of organic carbon 230% compared to un-amended control soil. Similarly, the volume-based rate of 25% incorporated solids increased decomposition rate 337% compared to soil without solids. Decomposition rates of organic carbon comparable to the present study were reported for soils receiving 42 tons per acre of compost (Bernal et al. 1998). Similar to organic carbon observations, increasing the rate of Geotube[®] solids significantly increased (P= 0.05) mineralization rate of organic N (Fig. 4). Large quantities of inorganic N were released from the organic N forms in Geotube[®] solids,

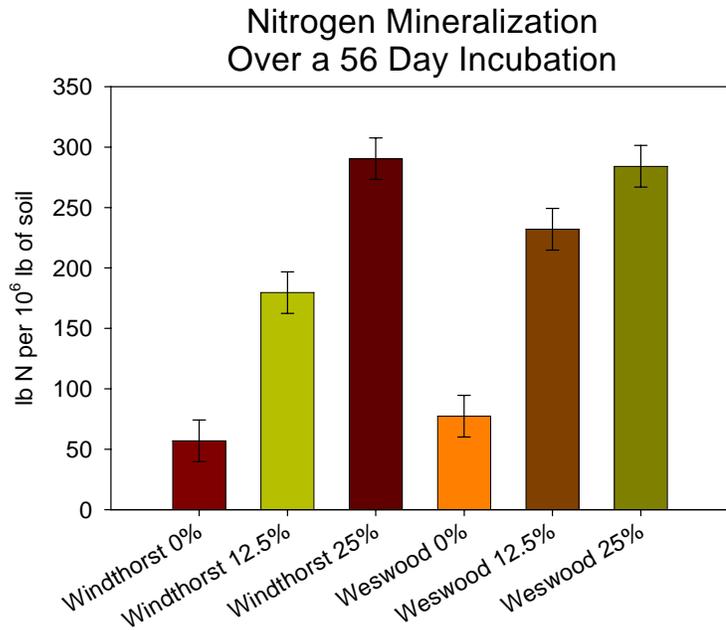


Fig. 4. Rate of inorganic N release from organic N in soils with and without Geotube[®] solids over a 56 day incubation. The two rates incorporated in soil were 12.5% and 25% by volume of Geotube[®] solids.

but no significant difference was observed between soil types. Incorporating 12.5% of solids increased the amount of N mineralized from organic N 2-fold and incorporating 25% by volume increased N mineralization 2.8-fold compared to soil without Geotube[®] solids. Similar organic N mineralization rates were reported by Flavel and Murphey for soils amended with compost (2006). High NO₃-N concentrations in the Geotube[®] solids sampled one year after collection, combined with continued mineralization of organic N, will necessitate analysis before application. The amount of inorganic N and other nutrients available from Geotube[®] solids must be managed in combination with fertilizer N sources to provide turfgrass requirements during establishment and maintenance and protect environmental quality.

Conclusion

Observed improvements in turfgrass productivity and soil properties combined with low leaching losses of SRP at high soil pH were indicative of the potential benefits of Geotube[®] solids. Increases in Tifway bermudagrass clipping yields during establishment and maintenance provided evidence that incorporated, volume-based rates of Geotube[®] solids were an excellent source of inorganic and organic sources of P and N. In addition, the organic carbon incorporated through volume-based rates of solids reduced soil bulk density. Despite benefits to turfgrass and soil properties, the rates of Geotube[®] solids need to be managed to prevent detrimental effects on groundwater quality. High NO₃-N concentrations in the volume-based rates applied in the present study exceeded Tifway bermudagrass requirements during establishment, which contributed to high NO₃-N concentrations in soil and leachate. In contrast, leaching loss of DRP from soil amended with the Geotube[®] solids was low even though volume-based rates increased total, soil-test, and water-extractable P to concentrations above plant requirements. Under the high soil pH conditions in the present study, the alum and/or polymers added during solids separation in the Geotube[®] could have limited solubility of reactive inorganic P forms even after the solids were incorporated in soil. Although leaching loss of SRP from volume-based rates of Geotube[®] solids was not problematic, observed leaching losses of inorganic N and organic P forms indicated rates less than 12.5% by volume may be necessary during turfgrass establishment.

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Appendix E

Agriculture is Life!

Field Demonstration of the Performance of Wastewater Treatment Solution (WTS®) to Reduce Phosphorus and other Substances from Dairy Lagoon Effluent

**Final Report
August 2008**

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Partners:

**Texas AgriLife Extension Service
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Ozona Environmental® LLC, Ozona, Texas**

**Texas Water Resources Institute Technical Report
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Table of Contents

Summary	2
Introduction	5
Wastewater treatment solution (WTS®) treatment system	6
Methods	9
Layout of sampling scheme	9
Sludge depth (SD) measurement	11
Lagoon and tank effluent sample collection	12
Sample preparation and analysis	14
Statistical analysis	15
Results and Discussion	17
Environmental conditions	17
Lagoon Performance	18
Sludge depth	18
Physicochemical characteristics of lagoon	19
pH	19
Solids	21
Nutrients	30
Metals	40
Conductivity	44
Treatment Costs	46
Conclusion	47
Challenges	49
Acknowledgements	50
References	51
Appendix I	55

Summary

In 1998 two upper North Bosque River segments were designated as impaired due to point source and nonpoint source (NPS) pollution of phosphorus (P) in these segments of 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 (SRP) concentrations by about 50%. Under the Clean Water Act (Section 319(h)), a new technologies demonstration project was funded by the U. S. Environmental Protection Agency (USEPA) Region 6 and administered by the Texas State Soil and Water Conservation Board (TSSWCB) for reducing water pollution associated with dairy animal production systems. As part of this demonstration, the efficacy of a prospective new technology (i.e. wastewater treatment solution, WTS[®]) was evaluated, which may assist dairy farmers in reducing P from lagoon effluent. In many cases, this effluent is applied to waste application fields (WAF) as irrigation water. Therefore, reducing P in the effluent can have a direct impact on NPS pollution in the watershed.

Before treating a dairy's anaerobic lagoon with WTS[®] and an oxygenating additive, O2T, three separate background (pre-treatment) samplings were conducted to gather baseline information on nutrients (e.g., total phosphorus [TP], soluble reactive phosphorus [SRP], and total Kjeldahl nitrogen [TKN]) and solids (e.g., total solids [TS], total suspended solids [TSS], total dissolved solids [TDS]) data prior to inoculation. Following the third pre-treatment sampling in September 2007, the anaerobic lagoon was treated with WTS[®] at an averaged application rate of 1 gallon/head as a start-up. Thereafter, WTS[®] was applied at a rate of 0.5 gal/100 head-day (based on 600 heads), while O2T was applied at a rate of 0.1 gal/100 head-day (based on 600 heads). To mimic the repeatability of lagoon treatment, two large tanks were filled with untreated flushed manure to assess the treatment effect on flushed manure from free-stall. Tank 1 (T1) was treated manually on a monthly basis, with WTS[®] at a rate of 16 oz (0.5 L) and with O2T at a rate of 7 oz (0.25 L) and Tank 2 (T2) was used as the control (no treatment was applied).

Following treatment, lagoon samples were collected monthly or bi-monthly from two different profiles: lagoon supernatant (LS), sampled from the top of the liquid level to 2 ft (0.61 m) depth and lagoon profile (LP), sampled from the entire depth of the lagoon using a sludge judge (a

sampling tube with a check valve at the bottom to take lagoon sample at different depths). For each LP and LS, 27 samples (3 samples per location \times 9 locations) were collected during each sampling event. A set of 9 LP and 9 LS samples were mixed separately to get two composites of each for nutrients including P, solids, pH, conductivity and metals. Similarly, samples were collected from tank supernatant (1 ft or 0.30 m below liquid surface) and profile (from the entire depth of the tank) in each sampling event. During each sampling event, a total 36 (9 samples per tank \times 2 tanks \times 2 profiles) samples were collected from the two tanks. Each set of 9 tank supernatant and 9 tank profile sample bottles were mixed separately to get two tank supernatant (T1S and T2S) and two tank profile (T1P and T2P) composite samples of each for analysis.

WTS[®] treatment was somewhat effective in reducing sludge depth by 10% compared to its pre-treatment level. This reduction of sludge depth was due to microbial treatment, which will likely improve lagoon effluent characteristics, increase lagoon capacity and reduce maintenance cost for this lagoon. This treatment system increases pH in the LS significantly as compared to LP. Similar to lagoon pH, the treated tank T1 had a slightly higher pH as compared to untreated tank T2 in both tank profiles, although differences were not statistically significant. There was no significant reduction in TS either in lagoon or tank environments due to WTS[®] treatment. Overall TSS was reduced by 7% and 9% for LP and LS, respectively, when concentrations of these parameters averaged across post-treatment events were compared with the averages across pre-treatment events. There were no differences in TSS concentrations of treated and untreated tank samples at either LS or LP. Following microbial treatment of the lagoon, TDS concentration both in LS and LP increased, although no significant differences were observed between the two profiles. Overall, the TDS concentration in LS was 13% higher than that of LP.

There was not a significant reduction in TP in either lagoon sampling profile. TP concentration in the treated tank profile was reduced by 17%, yet increased by 2% in the untreated tank profile samples. However, TP reduction values for treated and untreated tank supernatant samples were 60 and 55%, respectively. This suggested that the differences in TP reduction between treated and untreated samples were due to treatment effects. SRP concentration in both LP and LS samples increased gradually, although differences were not significant between LP and LS. A similar SRP increasing trend was also observed for tank samples, but differed in that the treated

tank had a higher SRP concentration than that of untreated tank samples, due to greater TDS in tank supernatant. TKN in LP and LS reduced by 29 and 19%, respectively, but a greater TKN reduction was observed in tank profile (60 and 47% in treated and untreated tank profile samples, respectively) and tank supernatant samples (88 to 86% in treated and untreated tank supernatant samples, respectively) as compared to lagoon samples. Following the microbial treatment, the conductivity and potassium (K) concentration increased in both profiles of the lagoon and treated tank (T2). Three chemical quality parameters indicate the effectiveness of a wastewater treatment system such as biological oxygen demand (BOD), suspended solids, and TP (van Loon and Duffy 2000). Suspended solids and TP were both monitored in this study and had insignificant variation between pre-treatment and post-treatment. The purpose of this study was to evaluate the effectiveness of WTS[®] in reducing P and other substances from lagoon effluent to be applied to WAFs. Therefore, this treatment system was not very effective in reducing phosphorus and other nutrients from the lagoon effluent, especially soluble parameters. Conclusions indicate that more studies are needed to assess the effectiveness of this treatment over a longer time period.

Introduction

The bulk of the manure from animal feeding operations (AFOs) in the United States is applied to crop and pastureland because it is an excellent resource for plant nutrients and soil conditioning. Excessive land application rates and improper uses of manure, however, can lead to environmental concerns and problems. Manure phosphorus (P) not used by plants represents one concern that can significantly impact surface water quality. Water quality degradation due to nonpoint source P contribution from effluent and manure applied to waste application fields (WAFs) is a major concern in the Bosque River watershed. In 1998, two upper North Bosque River segments (that is, 1255 and 1226) were designated as impaired segments on the Texas Clean Water Act, Section 303(d) list (TNRCC 2001). This designation was the result of excessive nutrient loading and aquatic plant growth in those segments. The changes in the status of the Bosque River segments prompted the Texas Commission on Environmental Quality (TCEQ) to develop Total Maximum Daily Loads (TMDLs) that address P loading in these designated segments. In December 2002, TCEQ approved the implementation plan for these TMDLs; these plans were also approved by the Texas State Soil and Water Conservation Board (TSSWCB) in January 2003. The TMDLs call for a reduction of the annual loading and annual average soluble reactive phosphorus (SRP) concentrations by about 50%.

The TCEQ has cited pollution from nonpoint source agricultural operations (by way of runoff) as the main source of contamination to these segments. As a result, reducing P from dairy effluent applied to WAFs is a vital step in protecting the quality of these waterbodies. Runoff from WAFs is not currently regulated as a point source, but its impact on waterbodies can be minimized by using on-farm management practices to reduce potential pollutants in the dairy lagoon effluent prior to WAF application. Currently, a number of dairy operations in the watershed have been using best management practices (BMPs) for removing P and SRP from the wastewater. However, to meet the goals of the established TMDLs, new, more effective and efficient BMPs are needed. One prospective BMP is the use of wastewater treatment solution (WTS[®]) microbial treatment to remove P and other constituents from the effluent stored and treated in dairy lagoons.

This report outlines the performance of a patented liquid-borne WTS[®] introduced by Ozona Environmental[®] LLC, Ozona, Texas. The demonstration evaluated under this project was set up to treat a primary anaerobic dairy lagoon, which has 600-head lactating cows in a free-stall dairy in the Bosque River watershed. Free-stall alleys were flushed twice a day and scraped in the remaining time. As needed, effluent from the lagoon was used to irrigate nearby cropland at the dairy operation using a big gun irrigation system.

Wastewater treatment solution (WTS[®]) treatment system

The WTS[®] treatment system consisted of two parts: a microbial stimulant (WTS[®]) and an oxygenating (O2T) additive (Fig. 1), applied to the lagoon simultaneously. According to the technology provider, microbial treatment systems introduce and stimulate indigenous populations of microorganism, resulting in reduced organic matter and nutrients in the wastewater. The O2T additive provides oxygen to the wastewater to accelerate microbial activity.

In the lagoon, 1 gallon/head of WTS[®] was applied directly to the lagoon in the initial inoculation; thereafter, WTS[®] was applied at a rate of 0.5 gal/100 head-day (based on 600 heads), while O2T was applied at a rate of 0.1 gal/100 head-day (based on 600 heads). A schematic of the WTS[®] treatment system is presented in Fig. 1. As shown in the schematic, two Viking injectors (Viking injector, Kyjac Inc., Pa,) were used for controlling flow rates of WTS[®] and O2T in the lagoon. One additional Viking injector was used to control WTS[®] flow in the treated tank at a predefined rate and interval. This whole system was powered by alkaline lantern batteries.

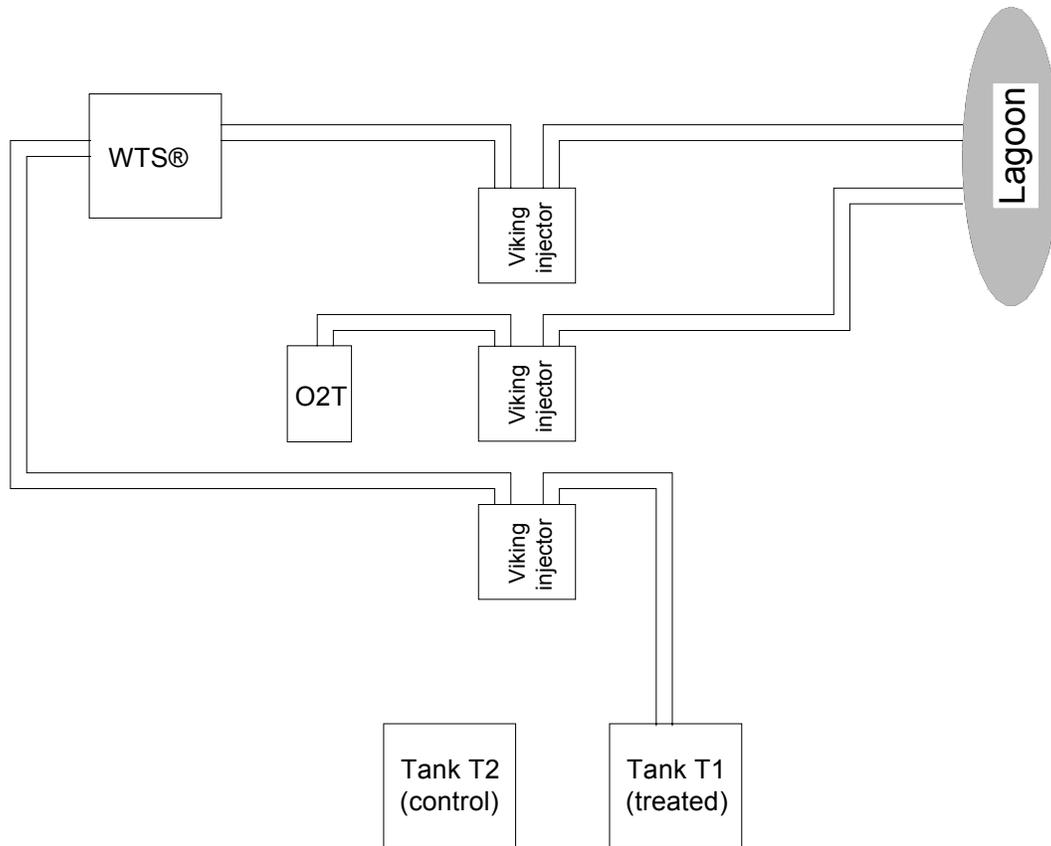


Figure 1. Schematic of WTS[®] treatment system for an anaerobic lagoon and tank (drawing not to scale)

Additionally, to mimic the repeatability of lagoon treatment, two large tanks (volume of liquid in Tank 1 [T1] and Tank 2 [T2] was 267 gal (1011 L) and 279 gal (1057 L), respectively) were filled with untreated flushed manure to assess the WTS[®] treatment effect on flushed manure from free-stall (Fig. 2). Tank T1 was treated manually once a month with 16 oz (0.5 L) of WTS[®] and 7 oz (0.25L) of O2T. Tank T2 was used as the control (no treatment was applied). To minimize evaporation losses from both tanks, shade cloth covered both tanks and no water was added to compensate for evaporation losses.



Figure 2. Treated tank T1 and control tank T2 used in this study.

Methods

Layout of sampling scheme

Prior to sampling, the lagoon was divided into three, roughly equal, sections by transect lines running along the width and length of the lagoon. The location of each transect was marked with a float and supported by a weight anchored to the float (Fig. 3a). Each intersection was marked and noted as sampling location 1 through 9 (Fig. 3b). In addition, the 10th sampling location was chosen near the flush water inlet (Fig. 3b). A summary of sampling events is listed in Table 1.



Figure 3a. White floats indicating sampling location.

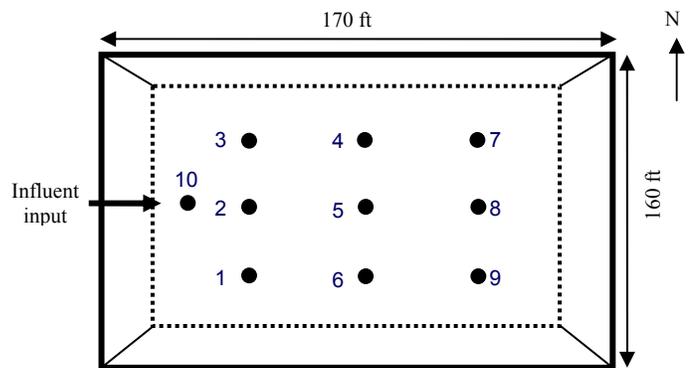


Figure 3b. Schematic of lagoon sampling layout (not to scale).

● Indicates lagoon sampling and sludge depth measurement locations (not to scale).

At each lagoon sampling location, three lagoon supernatant (from top of the liquid level, LS hereafter) and three lagoon profile (from the entire depth of the lagoon, LP hereafter) samples were taken (Fig. 4) for subsequent analysis.

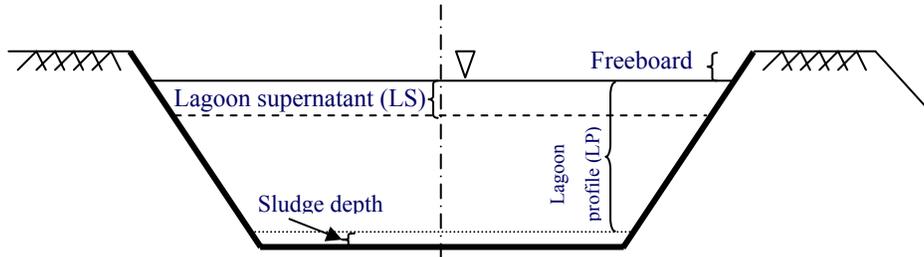


Figure 4. Schematic of lagoon and sampling profile (not to scale).

Component/Date	July, 07	Aug, 07	Sep, 07 ^[a]	Oct, 07	Nov, 07	Jan, 08	Mar, 08
	Pre-treatment sampling			Post-treatment sampling			
Lagoon profile (LP)	√	√	√	√	√	√	√
Lagoon supernatant (LS)	√	√	√	√	√	√	√
Tank supernatant			√*	√	√	√	√
Tank profile			√*	√	√	√	√

Table 1. Sampling events

* Tanks were filled with flushed water and pre-treatment samples were collected from both control and treated tanks.

^[a.] Following pre-treatment samples, treatment begins for both lagoon and tanks.

Similarly, tank samples were also collected from tank supernatant from top of the liquid level to 1 ft (30 cm) depth, and tank profile from the entire depth of the tank in each sampling event as shown in Fig. 5.

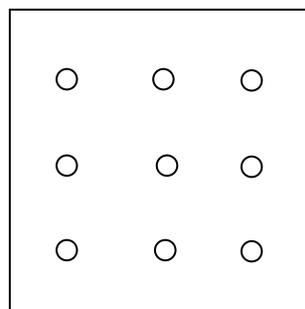


Figure 5. Approximate tank sampling location

Sludge depth (SD) measurement

Typically, reduction of total suspended solids (TSS) in lagoon supernatant is accompanied by reduction of P and a potential change in sludge depth. Therefore, accurate tracking of sludge depth is important to evaluate the performance of WTS[®] treatment effectively. During each sampling event, total depth (TD) and the depth above dense sludge (DADS) for the lagoon and tanks were measured using a measuring tape tied to a metal conduit fitted with an end cap (Fig. 6a). All depth measurements in the lagoon were taken at the same location as liquid samples were collected. Sludge depth (SD) of lagoon and tanks was estimated by subtracting the DADS from the TD of the lagoon and tanks, respectively.

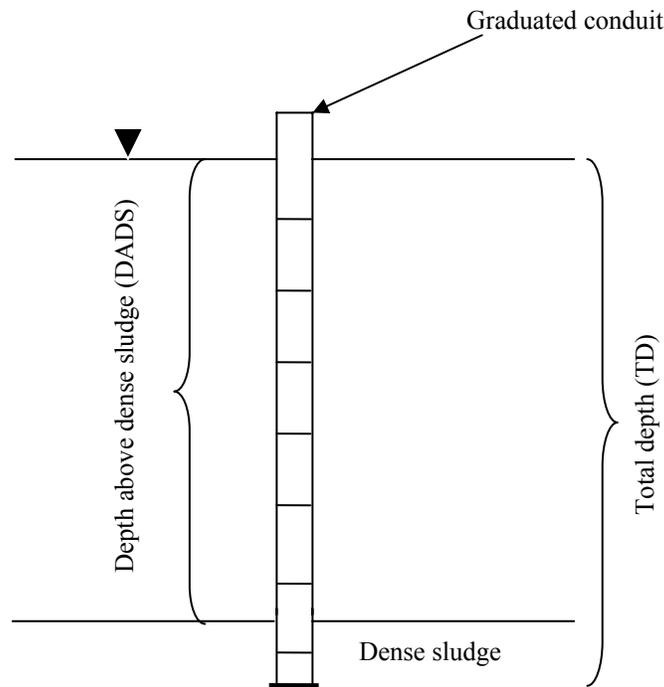


Figure 6a. Schematic of lagoon depth measurement.



Figure 6b. Actual depth measurement using a graduated scale attached to a solid conduit with a flat bottom.

Lagoon and tank effluent sample collection

In order to ensure consistent sampling and monitoring, lagoon sampling locations and the sampling profile were predetermined (Figs. 3b & 4). Before treating the lagoon with WTS[®] and O2T, three background (pre-treatment) samples were taken as described in Table 1 to gather baseline information on nutrients (total phosphorus [TP], SRP, and total Kjeldahl nitrogen [TKN]) and solids data (total solids [TS], TSS, and total dissolved solids [TDS]). For each of the first two pre-treatment sampling events (July and August 2007), 9 composite samples were collected in each sampling event and analyzed (one composite sample from each location as shown in Fig. 3b). Samples were collected using the “Ultra Sludge Judge” (Nasco, Fort Atkinson, WI), which consisted of three 5 ft (1.52 m) sections of 1.25 inch (0.03 m) diameter acrylic tube and a ball check valve at the bottom end (Fig. 7). For LS sampling, the sludge sampler was lowered slowly to the desired depth (2 ft, or 0.61 m), while for LP sampling, the sampler was lowered slowly until it rested above the dense sludge at the bottom of lagoon. After lowering the sludge sampler at desired depth, it was gently pulled out of lagoon as straight as possible.

Based on the first two pre-treatment sample analysis results, all LS and LP samples were divided into three groups (group1: locations 1-3, group 2: locations 4-6, and group 3: locations 7-9). For

subsequent pre- and post-treatment sampling, three LS and three LP samples were taken from each location within a group. A total of 27 LS (3 samples per location \times 9 locations) and 27 LP (3 samples per location \times 9 locations) samples were collected from the lagoon during each sampling event. Sample preparation and analysis for LS and LP will be discussed in the following section.



Figure 7. Lagoon sampling using a sludge judge.

Following the lagoon sampling procedures, 9 tank supernatant and 9 tank profile samples were collected from each tank using sludge sampler (Fig. 8). Thus, 36 (9 samples per tank \times 2 tanks \times 2 profiles) samples were collected from two tanks during each sampling event. Sample preparation and analysis for tank supernatant and tank profile will be discussed in the following section.



Figure 8. Tank sampling using a sludge judge.

Within an hour of conducting sampling, bottles kept on ice were transported to Texas Institute for Applied Environmental Research (TIAER) laboratory at Tarleton State University in Stephenville, Texas, for physicochemical parameters analysis (i.e., nutrients, solids, metals, pH and conductivity).

Sample preparation and analysis

After each sampling event, 9 LS samples were mixed together to obtain one LS composite sample. Similarly, 9 LP samples were mixed together to obtain one LP composite sample. In this way, three LS and three LP composite samples (LS1 & LP1 composited samples from group 1, LS2 & LP2 composited samples from group 2, and LS3 & LP3 composited samples from group 3) were prepared for analysis. Similarly, each set of 9 tank supernatant and 9 tank profile sample bottles were mixed separately to get two tank supernatant (T1S and T2S) and two tank profile (T1P and T2P) composite samples of each for analysis.

Using EPA laboratory procedures (Budde, 1995) and Standard Methods (APHA, 2005) (Table 2), all composited samples were analyzed for: TS, total volatile solids (TVS), total fixed solids (TFS), TSS, SRP, TP, nitrate/nitrite-nitrogen (NNN), TKN,, potassium (K), aluminum (Al),

calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), iron (Fe), and Copper (Cu). Concentrations of TDS were found by subtracting the concentrations of TSS from TS. Also pH and conductivity were measured for each composite sample.

Table 2. Laboratory analytical methods

Parameter	Method	Equipment Used
Nitrite + Nitrate Nitrogen	EPA 353.2 and SSSA 38-1148	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Kjeldahl Nitrogen (TKN)	EPA 353.2, modified	Perstorp® or Lachat® QuickChem Autoanalyzer
Potassium	EPA 200.7	Spectro® ICP
Calcium	EPA 200.7	Spectro® ICP
Magnesium	EPA 200.7	Spectro® ICP
Sodium	EPA 200.7	Spectro® ICP
Manganese	EPA 200.7	Spectro® ICP
Iron	EPA 200.7	Spectro® ICP
Copper	EPA 200.7	Spectro® ICP
Orthophosphate Phosphorus	EPA 365.2	Beckman® DU 640 Spectrophotometer
Total Phosphorus	EPA 365.4, modified	Perstorp® or Lachat® QuickChem Autoanalyzer
Total Suspended Solids	EPA 160.2	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Total Solids	SM 2540C	Sartorius® AC210P or Mettler® AT261 analytical balance, oven
Total Volatile Solids	SM 2450G	Sartorius® AC210P or Mettler® AT261 analytical balance, oven, muffle furnace
Total Volatile Solids	EPA 160.4	Sartorius® AC210P or Mettler® AT261 analytical balance, oven, muffle furnace
Potential Hydrogen	EPA 150.1 and EPA 9045A	Accument® AB15 Plus pH meter
Conductivity	EPA 120.1 and EPA 9050A	YSI® 3200 conductivity meter
Aluminum	EPA 200.7	Spectro® ICP

EPA = Methods for Chemical Analysis of Water and Wastes, March 1983 and version 2, June 1999. There is no difference between EPA methods 200.7 and 6010B. Method 200.7 is a newer version and will yield the same results.

Statistical analysis

Analysis of variance (ANOVA) was performed to examine the treatment effects on nutrients, solids, metals, and other water quality parameters for different sampling profiles (LP, LS, tank supernatant and tank profile). Furthermore, the ANOVA was conducted to investigate the treatment effects among the sampling events and over all sampling events (grand mean). All statistical analyses were performed using SAS software (SAS, 1999) and the Generalized Linear

Model (GLM) procedure. The treatment means were then separated with the Duncan's Multiple Range Test ((Steel and Torrie 1997) at a significance level P of 0.05), if the main treatment effect was significant in the ANOVA.

Results and Discussion

Environmental conditions

Monthly precipitation data for the dairy was provided by the producer and is presented in Fig. 9a. The study area generally received less than four inches of rain per month during the sampling period of August 2007 to March 2008. Higher ambient temperatures were observed during the months of June through September (Fig. 9b) while much lower ambient temperature in December, January, and February were recorded at the study area.

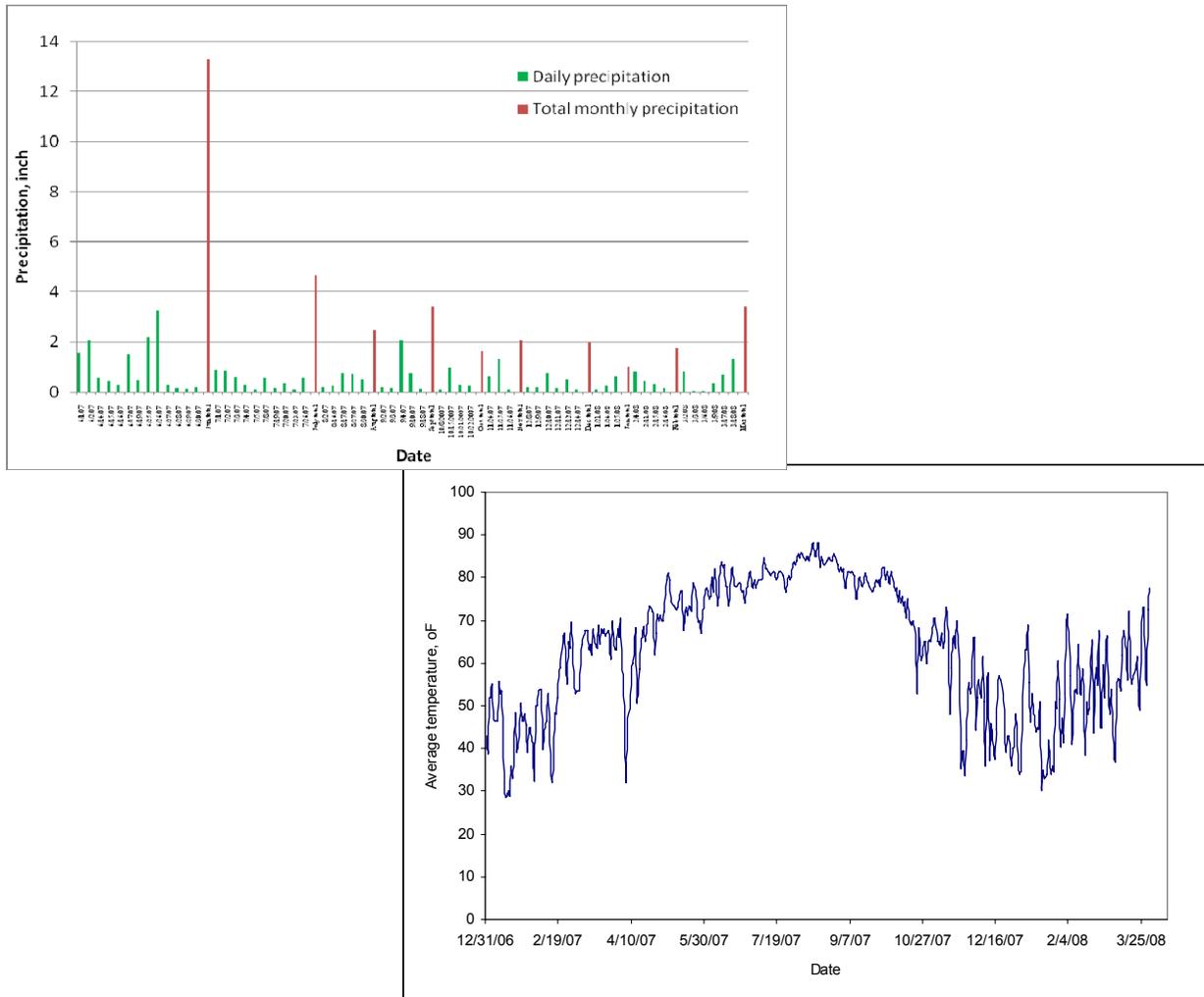


Figure 9b. Recorded ambient temperature trend in the study area.

Lagoon Performance

Sludge Depth

Average TD and SD of the lagoon during each sampling event are shown in Fig. 10. The TD fluctuation was likely due to variations in precipitation, volume of effluent used for irrigation, and evaporation during the monitoring period. The variation in DADS was likely due to variation of settling and re-suspension of solids from microbial activities. Following the first treatment in September 2007, the sludge depth decreased by as much as 20% in October 2007 (Fig. 10). Thereafter, lagoon depths fluctuated slightly, but SD remained lower than the pre-treatment sludge depth (Fig. 10).

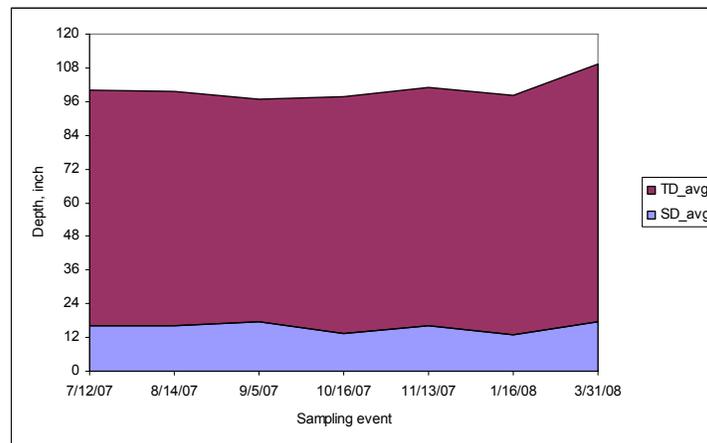


Figure 10. Total and sludge depths of the lagoon (Note: September, 2007 sampling is the pretreatment depth).

The likely causes of SD reduction was the loosening of dense sludge from the bottom of the lagoon that came up to the surface due to internal mixing (Zhang et al. 1997) caused by the microbial activities in the lagoon, which was shown during the sampling events. With the tank, it was difficult to measure sludge depth accumulation due to very loose sludge at the bottom of the tank. As a result, no sludge accumulations in the tanks were reported.

Since sludge accumulation is composed of fixed and slowly degradable volatile solids (Chastain et al., 2001), variations in SD are likely due to variation of these solids in this lagoon. In addition, high variability in sludge depth was likely due to internal mixing caused by the microbial activities in the lagoon (Zhang et al. 1997), wind-driven turbulence, gas lift (Reed et

al., 1995), annual cycle of storage, heating, and organic matter accumulation (Hamilton et al., 2006; Westerman et al. 2006). Overall, WTS[®] treatment was somewhat effective in reducing sludge depth by 10% compared to its pre-treatment level. Average SD for this lagoon was 19% of the TD, which is less than 25% of total lagoon depth when rapid sludge accumulation begins (Westerman et al. 2006). Overall TD, DADS, and SD for this lagoon during the monitoring period were 7.06 ft (± 1.01), 5.89 ft (± 0.78), and 1.31 ft (± 0.79), respectively.

Physicochemical characteristics of lagoon

Physicochemical parameters (solids, nutrients, and metals) were analyzed for LP, LS, tank supernatant, and tank profile samples (untreated and treated with bacteria). These parameters were compared between sampling profiles and among sampling events, and averaged over all sampling events (grand mean). All results are the average of composite sample analysis for each sampling event.

pH

The WTS[®] treatment system generally increased pH in the LS as compared to LP (Fig. 11). Significant differences in pH averaged over sampling events were also observed between LS and LP. However, there were no significant differences in pH for LS or LP among sampling events. To begin with, the LS showed slightly higher pH as compared to LP and this difference increased as the treatment process continued. This was likely due to the addition of the WTS[®] solution to the lagoon on a daily basis. Average pH trends in LP and LS are presented in Fig. 11 and average pH for LP and LS were 7.23(± 0.07) and 7.32(± 0.11), respectively.

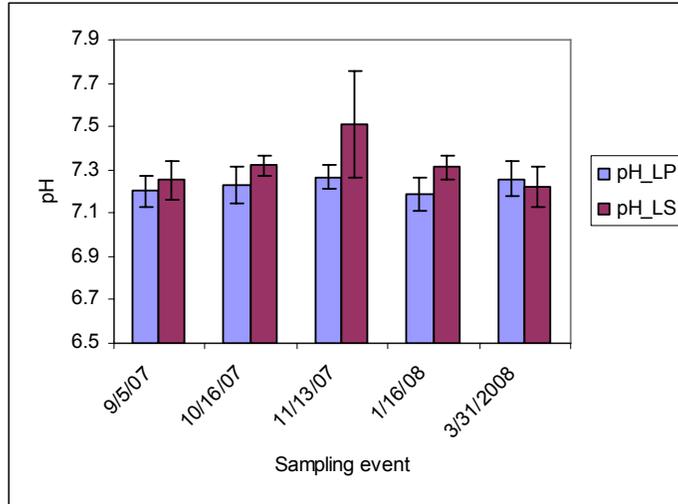


Figure 11. Average pH trends over time for the WTS[®] treatment. LP: liquid profile, and LS: Liquid supernatant. (Note: September 2007 sampling is the pretreatment sampling.)

Initially, both T1 and T2 tank samples showed similar pH (Fig. 12). Over time, T1 had slightly higher but statistically similar pH to T2 as observed for lagoon pH for LS and LP depths. Slightly increased pH in treated tank T1 samples was likely due to microbial stimulant added to tank T1 and microbial conversion of solids into dissolved solids. Overall, pH of tank profile T1P and T2P were 8.39(±0.87) and 7.92(±0.44), respectively, and pH of tank supernatant T1S and T2S were 8.68(±0.93) and 8.31(±0.57), respectively.

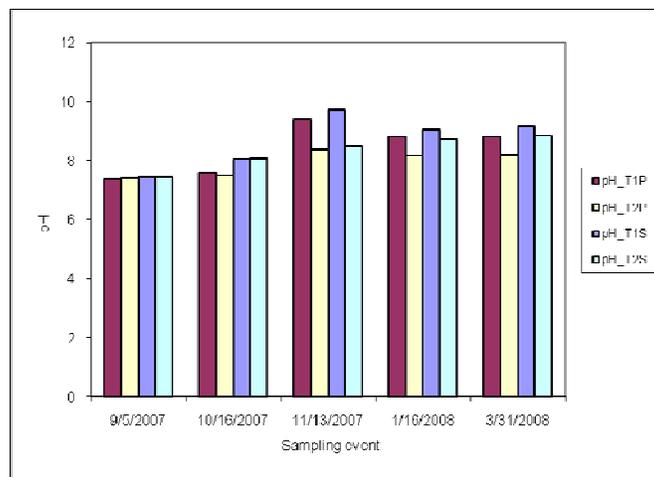
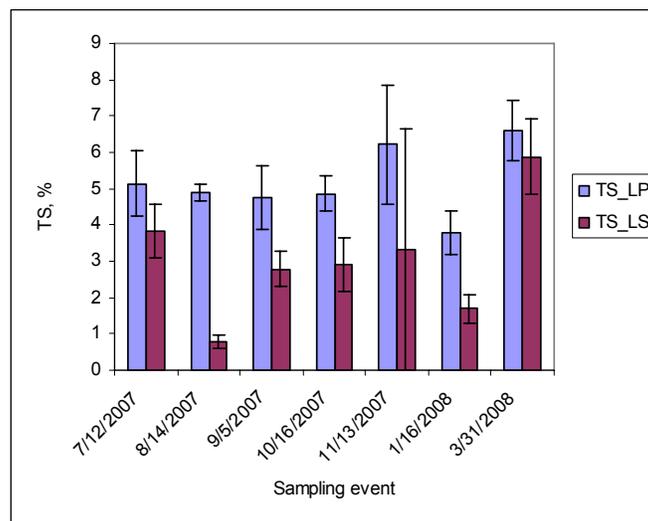


Figure 12. WTS[®] treatment effects on pH in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Average pH of lagoon (7.28 ± 0.10) was lower than that of the tanks (8.32 ± 0.30), since new flush water was added to the lagoon on a daily basis diluting lagoon wastewater. On the other hand, tanks were filled with flush water at one time and evaporation losses of water from tanks were not compensated with additional water contributing to relatively higher pH in tanks compare to the lagoon. Since pH of the medium profoundly affects the growth of microorganism, slightly higher pH in tanks might slow down the microbial activities and may increase volatilization loss of nutrients. All pH values as received from TIAER lab are listed in tables I through III in Appendix-A.

Solids

Average TS concentrations during each sampling event are shown in Fig. 13 and the overall concentration of TS in LP and LS are listed in Table 3. All solids concentrations as received from the TIAER lab are listed in tables I through III in Appendix-A. Following treatment, TS in both LS and LP increased slightly throughout the monitoring period except during the January 2008 sampling. This may be due to microbial treatment loosening the sludge from the bottom and allowing it to mix with the liquid surface (Zhang et al., 1997) as a result of microbial activities in the lagoon. Overall, TS in LP increased by 9% when averaged over sampling events, whereas TS values in LS increased notably (40%). However, no significant differences in TS were observed when TS was compared between pre-treatment and post-treatment samples within LP and LS profiles. Significant differences in TS were observed between LP and LS, which was expected.



**Figure 13. WTS[®] treatment effects on total solids (TS). LP: liquid profile, LS: Liquid supernatant.
(Note: July – Sept. 2007 sampling are the pre-treatment sampling.)**

Table 3. pH, TS, TSS, TDS, TVS and TFS for lagoon samples averaged over sampling events

Parameter	Sampling location			
	LP		LS	
	Pre-trt	Post-trt	Pre-trt	Post-trt
pH	7.20b*±0.07	7.23b±0.07	7.25a±0.1	7.34a±0.16
Total solids (TS), %	4.29a±1.06	4.99a±1.70	2.21b±1.16	3.32b±2.15
Total suspended solids (TSS), %	4.04a±1.13	3.84a±1.67	1.97b±1.17	2.55b±1.69
Total dissolved solids (TDS), %	0.14b±0.16	0.93a±0.70	0.81a±0.69	0.73a±0.79
Total volatile solids (TVS)	2.92±0.55	3.40±0.92	1.70±0.31	2.10±1.47
Total fixed solids (TFS)	1.83a±0.31	1.93a±0.55	1.08b±0.17	1.25b±0.72

Pre-trt and post-trt means within a row and profile followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

Average TS content in tank profiles and tank supernatants during each sampling event are shown in Fig. 14. TS in both treated and untreated tank profiles and tank supernatants decreased slightly and followed a trend similar to each other. No significant differences in TS were observed between treated and untreated tank in any profiles. Decrease in TS from both profiles was likely due to intrinsic microbial activities, but not due to WTS[®] treatment since the differences between treated and untreated tank remained similar. Significant differences in TS were observed between tank supernatant and tank profile within each tank as expected (Fig. 14). Overall, no significant reductions in TS were observed in lagoon or tank environments as a result of WTS[®] treatment.

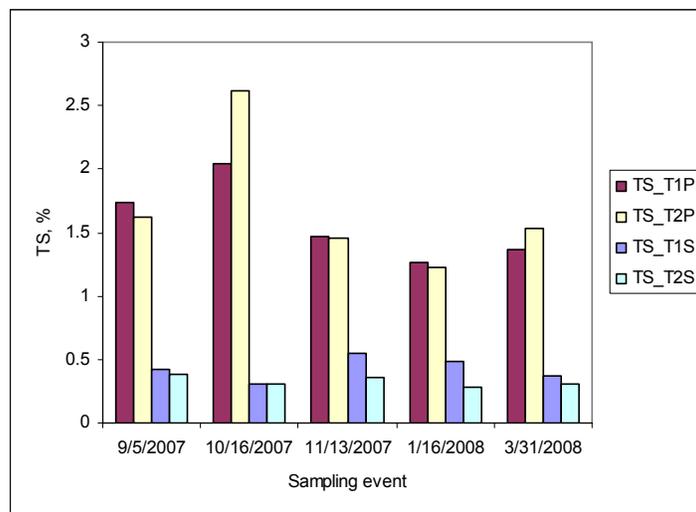


Figure 14. WTS[®] treatment effects on total solids (TS) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Average TS in both tanks was initially lower than that of the lagoon because the tanks were filled with lagoon wastewater pumped at a shallow depth. Compared with lagoon response, TS concentration in the tank profiles decreased over time (Fig. 14), while TS concentration increased slightly in lagoon profile (Fig. 13). This difference was due to differences in waste loading, microbial activities and light intensity between two conditions. For example, light intensity will be greater at shallow water depth in tanks than the lagoon, and as a result under tank conditions, photosynthetic bacteria will dominate and influence microbial activities (Sund et al. 2001). Overall, no significant reduction in TS was observed in lagoon or tank environments.

The majority of TS concentration increase in the lagoon profile samples occurred when temperatures were favorable for enhanced microbial activity that loosens sludge from the lagoon bottom. As a result, an increase in TS was observed due to internal mixing caused by increased microbial activities in the lagoon.

Overall, average TS for LP and LS (Table 3) were slightly greater than TS concentrations observed by Mukhtar et al. (2004), Barker et al. (2001; cited in Mukhtar et al., 2004), and Converse and Karthikeyan (2004). Solids concentration in LS was also slightly higher (2.4 to 2.6%) than the typical 1% found in the supernatant of most anaerobic dairy lagoons. This higher TS content in LS for this lagoon might be a result of higher solids loading than other lagoons as

well as loosening of sludge due to treatment. This could contribute to greater sludge accumulation if the lagoon is not managed properly.

TSS in LP followed a trend similar to TS, but in LS the TSS concentration decreased gradually following WTS[®] treatment except for in March (Fig. 15). Pre-treatment TSS concentration in LP showed little variation as compared to the TSS concentration post treatment (Fig. 15). Overall, TSS concentration in LP was reduced by 5% when averaged over pre-treatment concentration. In LS, pre-treatment TSS values fluctuated; however, following treatment TSS concentration, reduced gradually until January 2008 sampling, but then increased notably (131%) during the March 2008 sampling. Overall, TSS concentration in LS was increased by 29% when averaged over pre-treatment concentration. For this lagoon, TSS concentration was 86% and 79% of the TS for LP and LS, respectively. Therefore, variability of TS concentration in LP and LS for this lagoon was apparently due to variation in TSS concentrations. Suspended solids can settle on the bottom of lagoon or float on the surface of the lagoon and can affect the lagoon's performance. Figure 15 indicates that this treatment system was not effective in reducing TSS from LP, but reduced TSS somewhat from LS during the monitoring period.

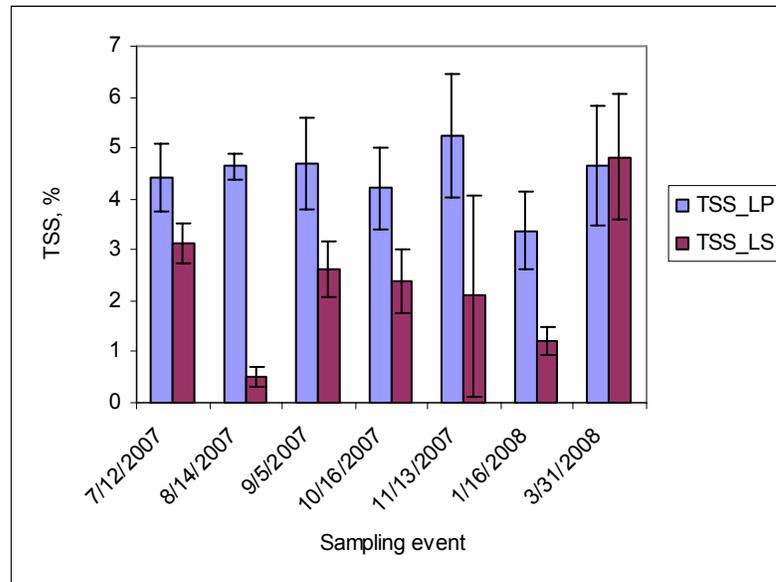


Figure 15. WTS[®] treatment effects on: Total suspended solids (TSS). LP: liquid profile, LS: Liquid supernatant. (Note: July - September 2007 samplings are the pre-treatment sampling.)

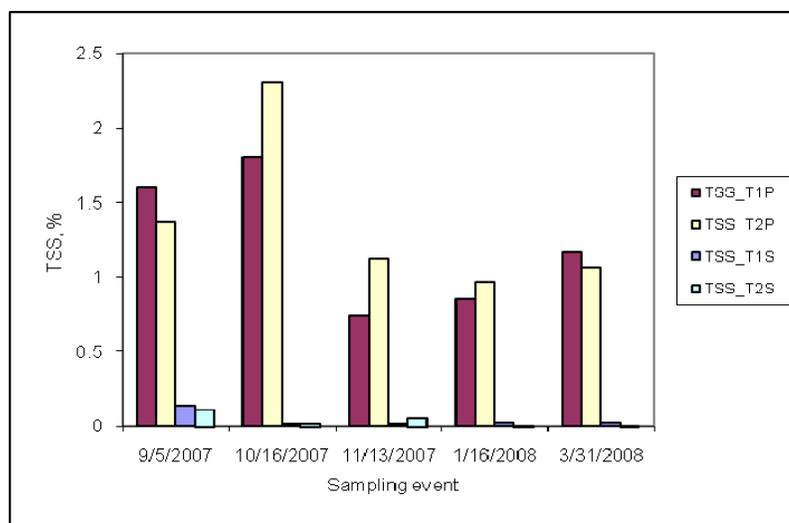


Figure 16. WTS[®] treatment effects on total suspended solids (TSS) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Over time TSS in both treated and untreated tank samples decreased and followed a trend similar to each other (Fig. 16). Similar TSS reduction in both treated and untreated tank samples was likely due to naturally occurring microbial uptake of organic matters. Although the treated tank showed slightly higher TSS to begin with as compared to the untreated tank, as the treatment continued, the treated tank profile T1P had lower TSS compared to the untreated tank profile T2P (Fig. 16). A similar trend was observed in the tank supernatant samples. This TSS difference in tank profile and tank supernatant between treated and untreated tanks was likely due to WTS[®] microbial treatment, although TSS difference between treated and untreated tanks was not statistically significant. In future efforts to assess the effectiveness of this treatment system, it might be necessary to monitor the pre- and post-treatment lagoon and tank samples for an extended period of time.

The TS and TSS concentrations of LP were significantly greater than those of LS (Table 3). Average TSS in the LP was higher than LS since suspended solids degrade slowly and remain suspended in the entire LP. In addition, accumulated dead and degraded bacterial mass at the bottom of lagoon might contribute to increased solids content for LP. A similar trend was observed for the tanks.

TDS are easily degradable organic matter and a measure of total materials that are dissolved in water. There were no significant differences in TDS concentration between LP and LS or among sampling events. However, following microbial treatment of the lagoon, TDS concentration both in LS and LP showed an increasing trend except in January (Fig. 17). The TDS concentration in the LP was 19% higher than that of LS, which was likely due to conversion of suspended solids into dissolved solids by the microbes (Zhu et al. 2000) throughout the lagoon profile. Overall, TDS levels in LP and LS increased post-treatment due to microbial activity suggesting that the treatment may not be effective in reducing soluble nutrients from wastewater.

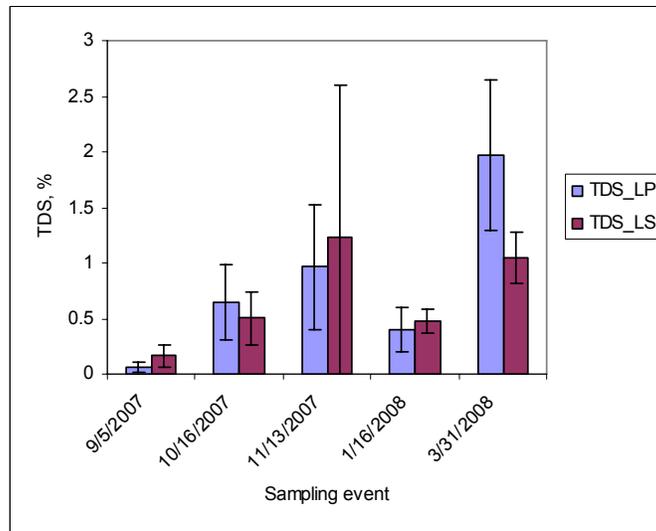


Figure 17. WTS[®] treatment effects on: a) Total dissolved solids (TDS). LP: liquid profile, LS: Liquid supernatant; IR: Irrigation effluent. (Note: July - September 2007 samplings are the pre-treatment sampling.)

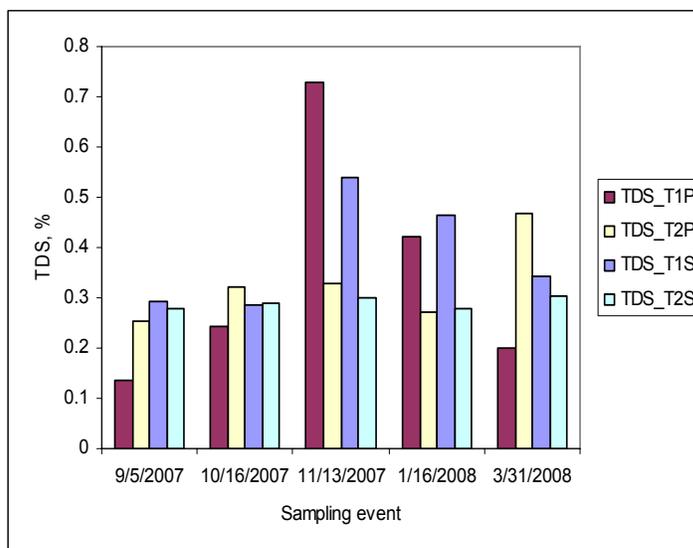


Figure 18. WTS[®] treatment effects on total dissolved solids (TDS) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

A trend similar to lagoon TDS was also observed in the tank profile samples except in March (Fig. 18). In the tank supernatant, concentration of TDS in the treated tank samples increased towards the end of the monitoring period. TDS concentration was similar throughout the monitoring period of the untreated tank. No significant differences in TDS were observed between treated and untreated tanks, and any observed difference in TDS between the treated and untreated tank was likely due to WTS[®] treatment effect.

Overall, TDS/TS ratio was relatively higher in LS (0.22) than that of LP (0.15), implying that microbes are more active in the liquid supernatant at converting suspended solids into dissolved solids as compared to the entire profile. Conversely, TDS/TS ratio in the tank profile for the treated and untreated tanks was 0.22 and 0.19, respectively, while they were 0.9 and 0.88 in the tank supernatant for the treated and untreated tanks, respectively.

TVS data are presented in Fig. 19. TVS levels followed a trend similar to TS (Fig. 13) and their concentration increased as the treatment process continued and did not show significant reduction until January 2008. Overall, TVS concentration in LP increased slightly (15%) and TVS in LP constituted 63% of TS. Total volatile solids in LS responded similarly to LP and no

significant reduction (39%) was noticed until January 2008, but TVS concentration increased by 118% in March 2008. Overall, TVS in LS was increased by 28%, which accounted for 69% of TS. Variation in TVS was likely due to variation in the rate and extent of microbial biodegradation of organic compounds and variation of TVS composition (Wilkie 2005) in flushed water added to the lagoon.

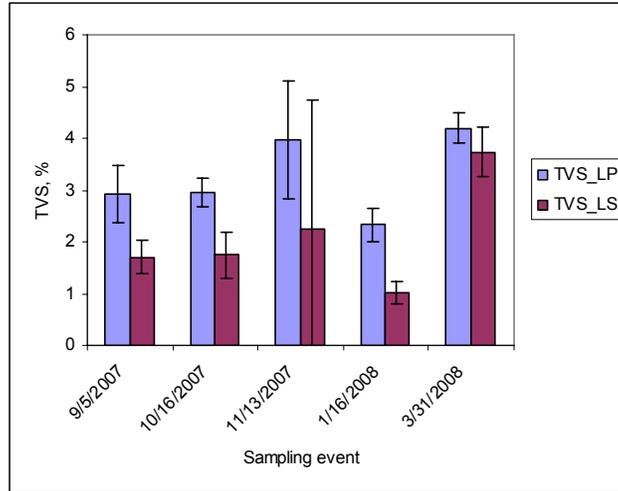


Figure 19. Total volatile solids (TVS) trend over time for the WTS[®] treatment. LP: liquid profile, LS: Liquid supernatant. (Note: July - September 2007 sampling are the pre-treatment sampling.)

Following the first treatment, TVS in the TP for both treated and untreated tanks increased, thereafter they reduced gradually (Fig. 20). Overall, TVS reduction in tank profile of the treated and untreated tanks was 26% and 1% while TVS concentration in the tank supernatant was reduced by 54% and 48% in treated and untreated tanks, respectively. In both cases, differences between treated and untreated tanks were not significant.

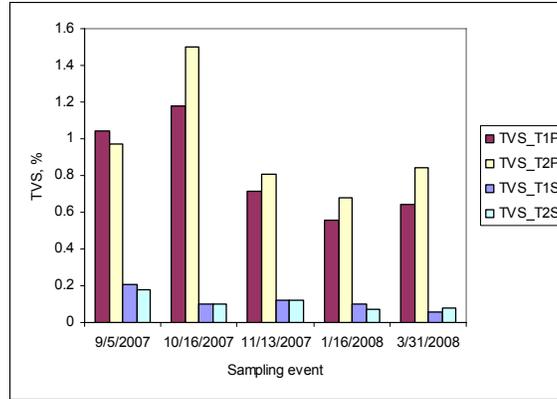


Figure 20. WTS[®] treatment effects on total volatile solids (TVS) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Total fixed solids (TFS) in LP increased gradually until November 2007 and thereafter started to decrease. Ultimately no significant reduction of TFS was noticed in LS until November 2007 (Fig. 21). The overall increase of TFS in LP was insignificant (<2%), but it reduced in LS by 11%. Over the sampling period, TFS in the tank profiles increased slightly in the treated and untreated lagoon. However, the treated tank yielded a slightly higher TFS concentration (Fig. 22). Significant differences were observed in TFS concentrations between tank profile and tank supernatant samples within treated and untreated tank samples.

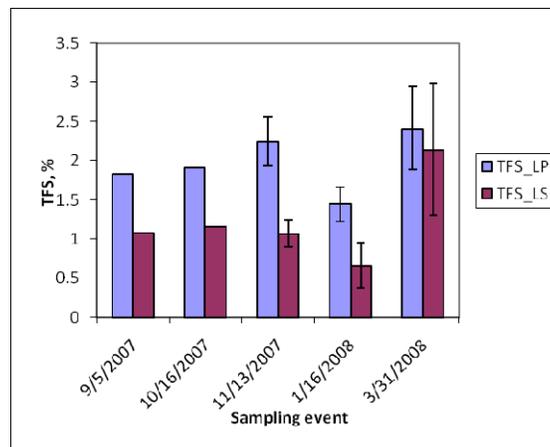


Figure 21. Total fixed solids (TFS) trend over time for the WTS[®] treatment. LP: liquid profile, LS: Liquid supernatant. (Note: July - September 2007 sampling are the pre-treatment sampling.)

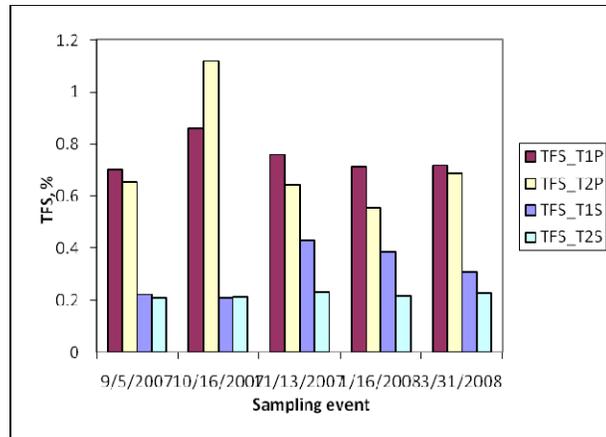
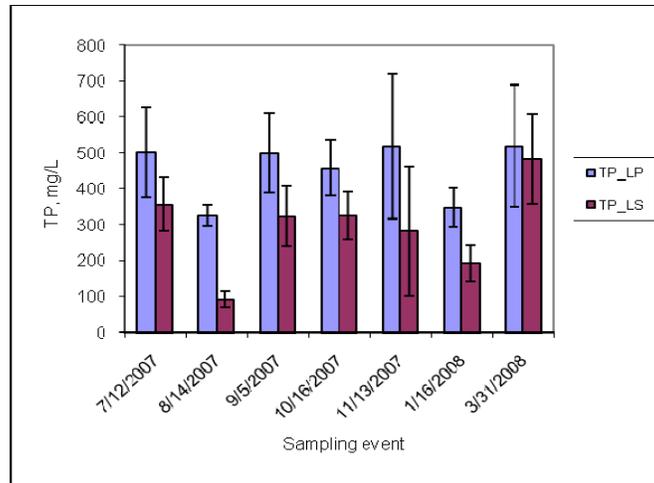


Figure 22. WTS® treatment effects on total fixed solids (TFS) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Typically, TFS is neither chemically reactive nor biologically degradable and theoretically it should stay unchanged (Zhu et al. 2000). For this lagoon, TFS fluctuation suggests that variability in sludge depth was partly due to variation of the solids. Both TDS and TFS for LP were greater than those from LS, although there were no statistically significant differences between LS and LP. Differences were likely due to internal mixing (Zhang et al. 1997) caused by the microbial activities in the lagoon.

Nutrients

Average total P (TP) in LP and LS for each sampling event are presented in Fig. 23 and the concentration averaged over all sampling events is presented in Table 4. The TP in LP was always higher than that in LS for both pre- and post-treatment events (Fig. 23). However, the concentration in both LP and LS fluctuated considerably during the entire sampling period. Overall, no significant reduction in TP was observed but average TP increased about 25% and 4% in LP and LS profiles, respectively, as compare to pre-treatment concentration.



**Figure 23. Total phosphorus (TP) trend over time for the WTS[®] treatment on Total P. LP: liquid profile, LS: Liquid supernatant.
(Note: July - September 2007 sampling are the pre-treatment sampling.)**

As expected, higher TP concentration in LP (Table 4) was likely due to higher TS and TSS concentrations for the LP as compared to LS (Table 3). In addition, degraded microbial cells accumulate at the bottom of the lagoon and runoff water may contribute to increased TP concentration in LP. In this study, no quantitative or qualitative assessment of runoff water additions to the lagoon was conducted, therefore the effects of runoff on the lagoon can not be quantified.

Following the first treatment in September 2007, TP concentration in both tank profiles increased slightly in October 2007, thereafter TP concentration decreased gradually below the pre-treatment concentration (Fig. 24). Overall, TP concentration in the treated tank profile (T1P) decreased by 18%, but increased by 2% in the untreated tank profile samples (T2P). The increase in TP in the untreated tank profile may be due to drastic increase in TP during October 2007 sampling and the reason is unknown. Conversely, TP concentration reductions in treated (T1S) and untreated tank supernatant (T2S) samples were 60% and 55%, respectively. This suggested that the differences in TP reduction between treated and untreated samples were due to treatment effects, whereas reductions of TP in untreated tank samples were likely due to intrinsic microbial activities.

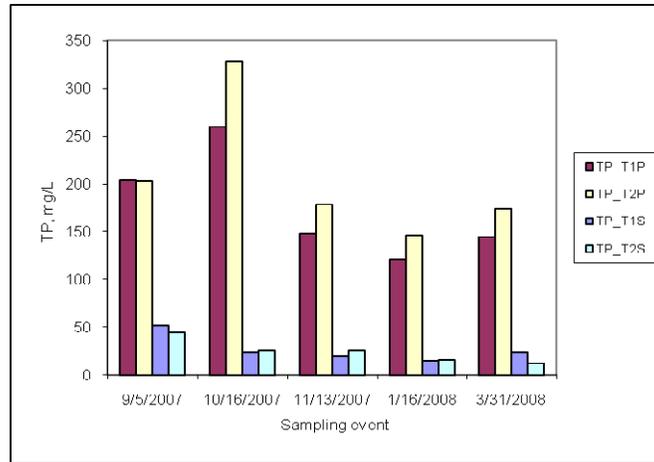


Figure 24. WTS® treatment effects on total phosphorus (TP) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Table 4. Average TP, SRP, and K concentration (mg/L) for lagoon effluent samples averaged over all sampling events

Parameter ¹	Sampling location			
	LP		LS	
	Pre-trt	Post-trt	Pre-trt	Post-trt
Total phosphorus (TP)	385a*±129	397a±185	231b±118	310b±147
Soluble reactive phosphorus (SRP)	11.37a±5.4	13.95a±7.0	10.85a±4.4	13.22a±3.6
Total Kjeldahl nitrogen (TKN)	1666b±642	1258a±405	1323b±258	1029c±399
Nitrate-Nitrite Nitrogen (NNN)	0.06a±0.03	0.34a±0.78	0.06a±0.05	0.08a±0.04
Potassium (K)	404b±29	505a±63	357b±5.9	456a±65

Pre-trt and post-trt means within a row and profile followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

¹ parameter is in mg/L

A weak correlation was observed between TP and TS ($R^2=0.37$) and TSS ($R^2=0.27$) in the LP profile. The relatively weak correlation in LP between TS and TP was unexpected, as P typically shows strong association with solids. Conversely, TP was strongly tied with TS ($R^2=0.86$) and TSS ($R^2=0.91$) in the LS (Fig. 25). McFarland et al. (2003) found that TP is partially tied to TSS. In the lagoon, 80% of the TS were TSS in the LS profile and might have contributed to the high correlation with TP. Therefore, without measuring the sludge's P content, the reduction of P from the entire profile due to treatment cannot be unequivocally determined.

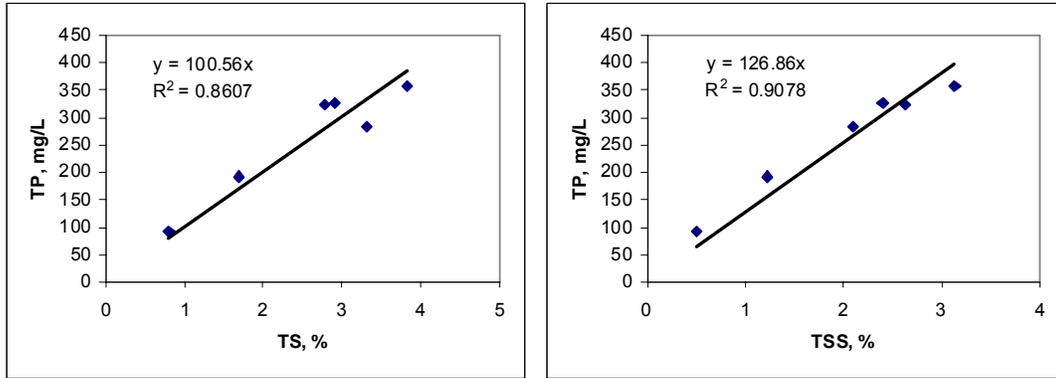


Figure 5. Relationship between TP vs. TS and TP vs. TSS for LS profile.

Average SRP levels in LP and LS during each sampling event are presented in Fig. 26. Pre-treatment SRP varied widely with no definite trend in both cases, but following microbial treatment, SRP concentrations for these sampling locations increased gradually. This increase in SRP concentration was likely due to loosening of sludge from the lagoon bottom as well as runoff water contributions of unknown quality and quantity to the lagoon. The SRP concentrations averaged over all sampling events (combined pre- and post- treatment) in LS and LP were (11.20 ± 3.13) and (11.54 ± 3.44) , respectively, and statistically similar (Table 4).

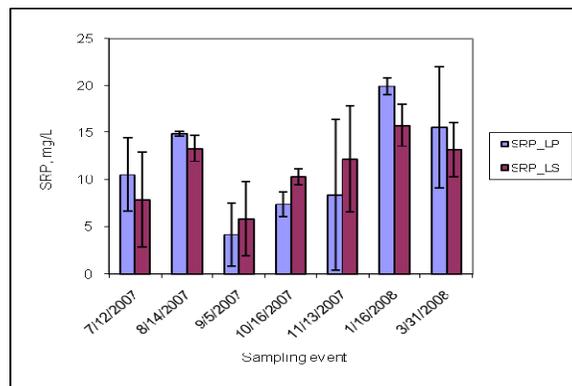


Figure 26. Soluble reactive phosphorus (SRP) concentration trends over time for the WTS® treatment. LP: liquid profile, LS: Liquid supernatant. (Note: July - September 2007 sampling are the pre-treatment sampling.)

A similar SRP increasing trend was observed in tank profile and supernatant samples and the treated tank had higher SRP concentrations than that of untreated tank samples (Fig. 27). This was most likely due to greater TDS in the treated tank samples. Overall, no significant differences in SRP were observed between treated and untreated tank samples. Researchers (Converse and Karthikeyan 2004) have indicated that loosening of the settled solids from the lagoon bottom may cause them to rise to the upper profile, carrying the P associated with them, which might increase SRP. Despite this, variations of solids show little effect on SRP concentration for this lagoon as also observed by other researchers (Vanotti et al. 2007).

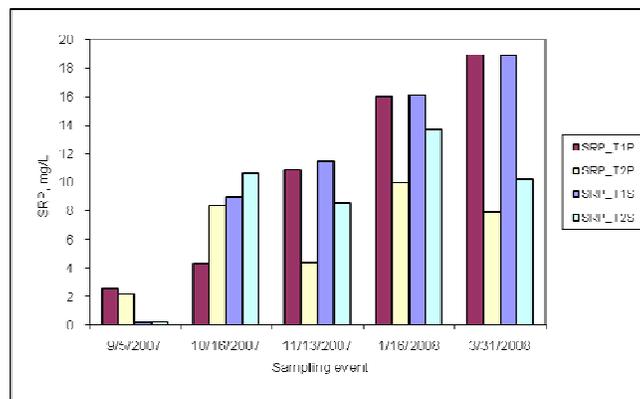


Figure 27. WTS[®] treatment effects on soluble reactive phosphorus (SRP) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Following the pre-treatment sampling in September 2007, post-treatment TKN in LP fluctuated and decreased slightly. The TKN also decreased slightly in LS throughout the monitoring period (Fig. 28). Significant differences in TKN concentrations were observed between pre- and post-treatment for both LP and LS profiles (Table 4), however no significant differences were observed among sampling events within each profile. Overall, TKN reduction in LP and LS were 29% and 19%, respectively. The reduction of TKN concentration in LP and LS were likely due to a combination of ammonia volatilization (Higgins et al. 2004), flush water added to the lagoon (Scotford et al. 1998), and treatment effects.

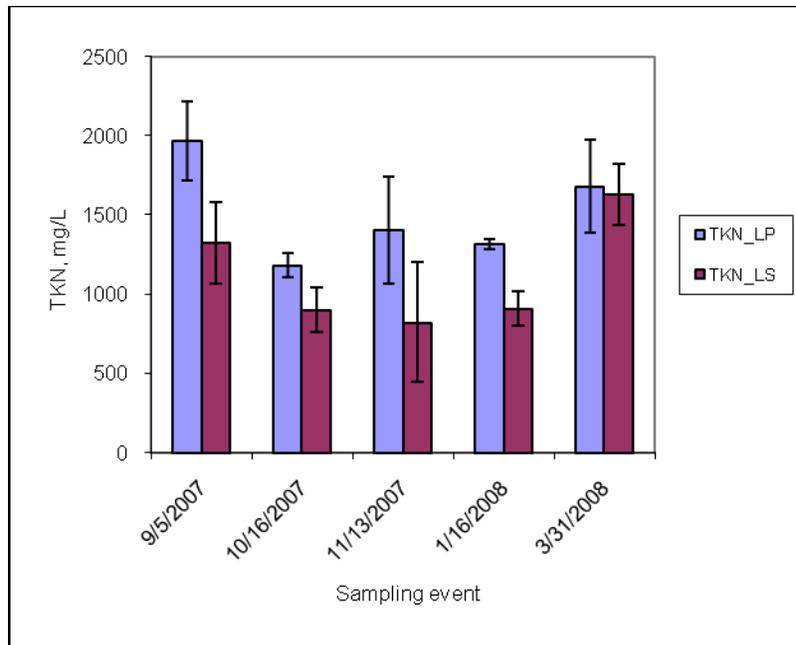


Figure 28. Total Kjeldahl nitrogen (TKN) concentration trends over time for the WTS® treatment. LP: liquid profile, LS: Liquid supernatant. (Note: September 2007 sampling is the pre-treatment sampling.)

The TKN concentration in both the untreated and treated tank profile and tank supernatant samples reduced considerably following pre-treatment sampling in October 2007. These concentrations reduced further in November 2007 and then remained fairly constant till the end of sampling period (Fig. 29). The TKN reduction rate in the tank profile for the treated tank was slightly greater (58%) than that of untreated (47%). Similarly, TKN reductions in tank supernatant in treated and untreated tanks were 88% and 86%, respectively. However, no significant differences in TKN reduction were observed between treated and untreated tank samples (both liquid profile and supernatant). This implies that reduction of TKN under tank conditions was not due to WTS® treatment, but may be due to ammonia volatilization losses.

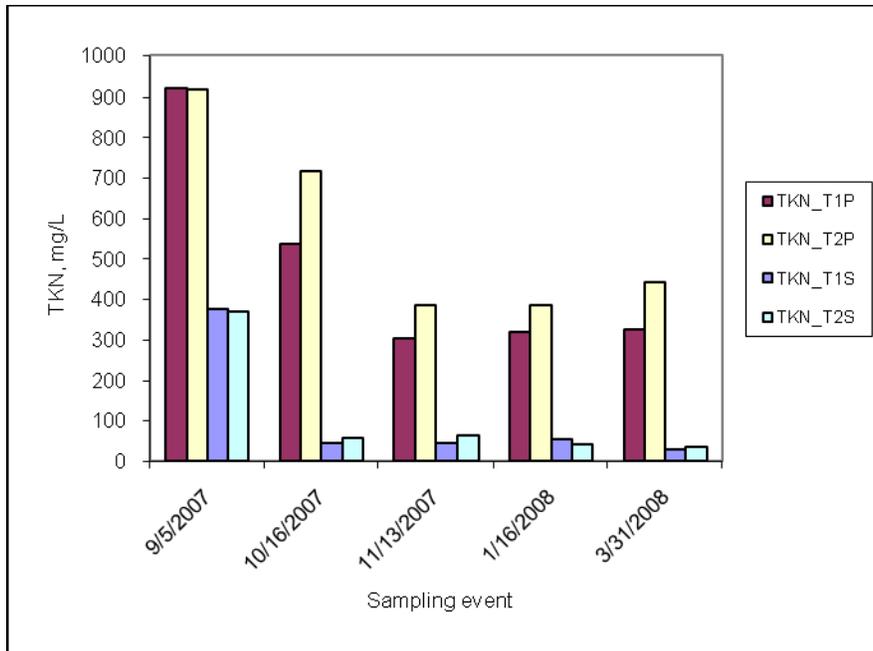


Figure 29. WTS[®] treatment effects on Total Kjeldahl nitrogen (TKN) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Average NNN concentrations for LP and LS are presented in Fig. 30. Following pre-treatment sampling in September 2006, NNN concentration increased tremendously in the LP during October 2007 before gradually decreasing to near pre-treatment concentrations. A similar trend was also observed in LS, however, the magnitude was much smaller than the LP. The NNN concentration increases in these profiles were likely due to ammonia diffusing upward from the bottom of the lagoon profile and converted into nitrate via nitrification process (Nealson 1997). Overall, no significant differences in NNN concentration were observed between LP and LS (Table 4) and this treatment was not effective in reducing NNN concentrations since 60%-70% of NNN is soluble (Bicudo et al. 1999) and it is difficult to reduce soluble concentration.

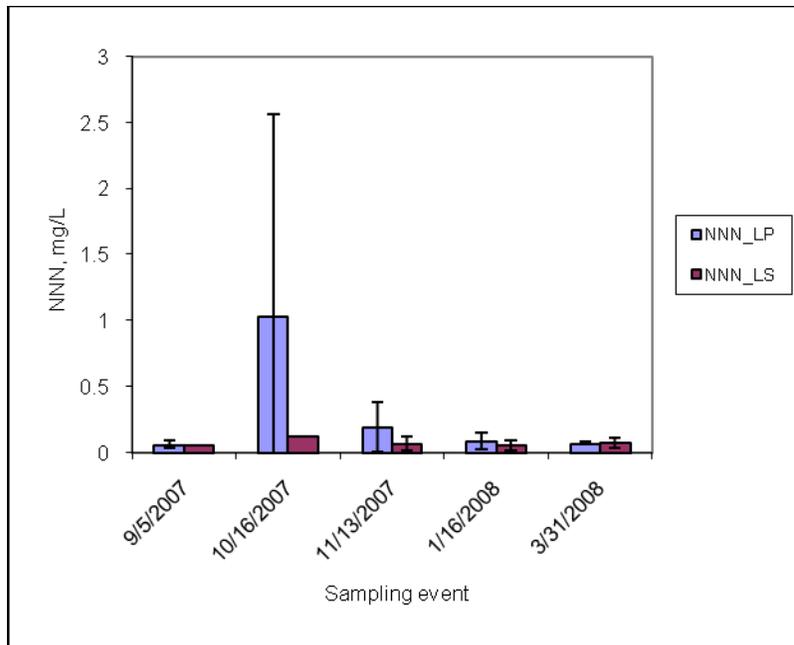


Figure 30. Nitrite-Nitrate Nitrogen (NNN) concentration trends over time for the WTS[®] treatment. LP: liquid profile, LS: Liquid supernatant. (Note: September 2007 sampling is the pre-treatment sampling.)

Similarly, NNN concentrations both in treated and untreated tank profile and tank supernatant samples increased considerably over the time (Fig. 31). The differences between tank profile and tank supernatant as well as pre-treatment and post-treatment samples were not significant. This increase in NNN concentrations in the treated tank samples was likely due to conversion of ammonia nitrogen into nitrite and nitrate nitrogen. In addition, evaporation loss of water might also contribute to greater NNN concentration in both tank samples.

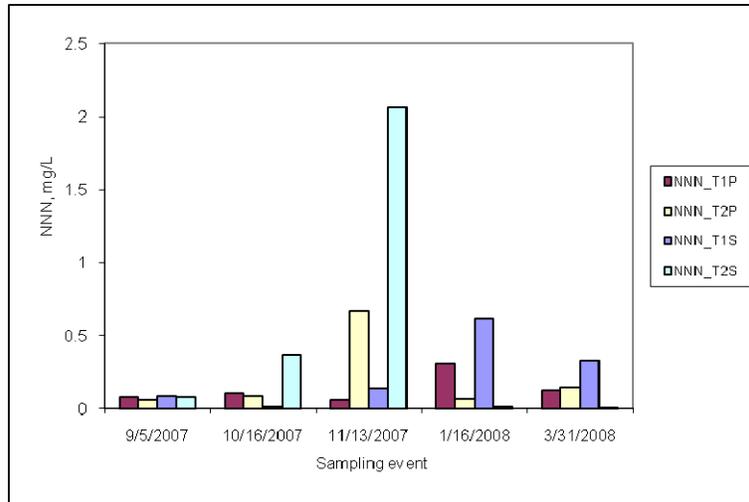


Figure 31. WTS[®] treatment effects on Nitrate-Nitrite Nitrogen (NNN) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

The K concentration in LP was always higher than LS for both pre- and post-treatment sampling events and showed an increasing trend following microbial treatment throughout the monitoring period (Fig. 32). The K concentration followed a trend similar to TDS (Fig. 17). This increase in K concentrations was likely due to runoff water contribution and variations in flush water added to the lagoon. In addition, dissolved solids might also contribute to increased K concentration since K is highly soluble in water (Gustafson et al. 2007). There were significant differences in K concentrations between pre- and post-treatment LP and LS samples (Table 4). It is apparent that this microbial treatment was not effective in reducing K concentrations of any profiles since K is highly soluble.

K concentrations in both treated and untreated tanks also increased over time (Fig. 33). The increase in K concentration in tank samples was likely due to evaporation loss and contributions from increased dissolved solids as a result of K's high solubility. Overall, K concentrations in the treated tank were slightly higher compared to the untreated tank and were due to WTS[®] treatment effects.

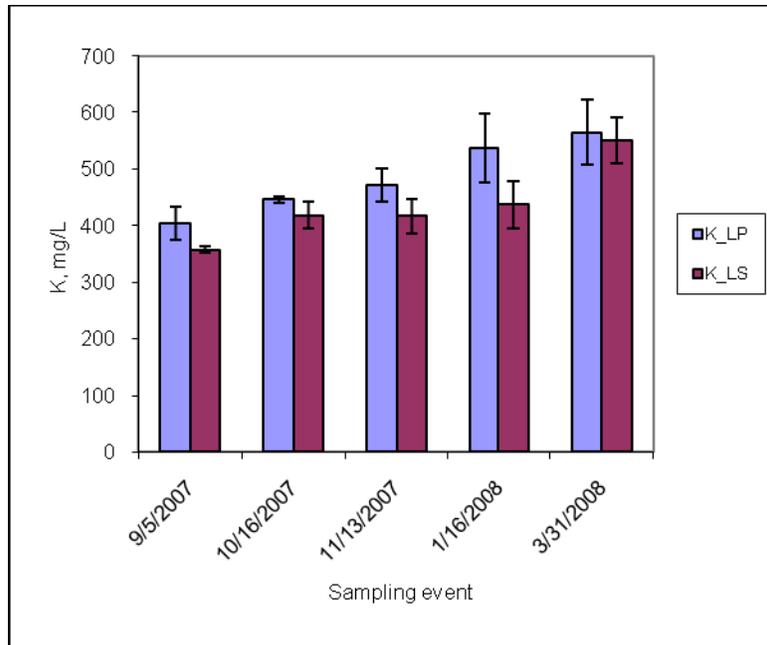


Figure 32. Potassium (K) concentration trends over time for the WTS[®] treatment. LP: liquid profile, LS: Liquid supernatant. (Note: September 2007 sampling is the pre-treatment sampling.)

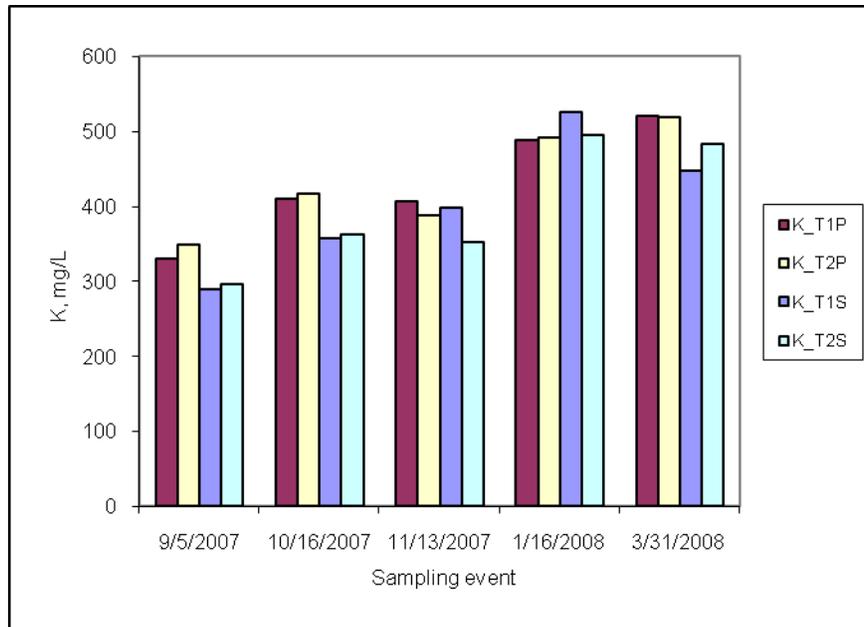


Figure 33. WTS[®] treatment effects on potassium (K) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

Nutrient data analyses suggest that WTS[®] treatment was not effective in reducing TP from any of the lagoon profiles. In the tank environment, notable TP concentration reduction trends were observed for the treated and untreated tank samples with the treated tank showing slightly greater reduction trends. This implies that the treatment was somewhat effective in reducing TP. Conversely, SRP and K in LP and LS increased, while TKN decreased slightly. A similar trend was also observed for these parameters under tank sampling. This implies that the reduction in nutrients under lagoon and tank environment were likely due to combination of WTS[®] treatment and naturally occurring microbial uptake of nutrients, settling of solids, and flush water added to the lagoon. However, without the accurate measurement of sludge nutrient content, especially P in lagoon sludge, it was difficult to ascertain that the reduction or increase of nutrients from these profiles was likely due to settling of solids or WTS[®] treatment effects. All nutrients concentration as received from TIAER lab are also listed in Tables I through III in the Appendix. Typically, three chemical quality parameters indicate the effectiveness of a wastewater treatment system such as biological oxygen demand (BOD), suspended solids, and TP (VanLoon and Duffy 2000). Suspended solids and TP were both monitored in this study and showed insignificant variation between pre-treatment and post-treatment events. Therefore, this treatment system was not very effective in reducing phosphorus and other nutrients from the lagoon effluent, especially soluble parameters.

Metals

Minerals in dietary amount are required for normal growth and reproduction of animals (NRC 2001). The metals content in animal manure is largely a reflection of metals concentration in the feed animals consumed and the efficiency of feed conversion by animals (Nicholson et al. 1999). Following microbial treatment, Al, Ca, Cu, and Fe concentrations in both LP and LS decreased slightly. Mg concentrations in the LP remained same as pre-treatment concentration throughout the monitoring period and its concentration reduced slightly in the LS. In case of Mn, its concentration fluctuated in the LP but gradually decreased in the LS except at the end of sampling period. Either a similar or slight reduction in Al concentrations in both LP and LS samples were observed (Fig. 34). A similar trend was also observed for the concentrations of other metals for different sampling events in LP and LS, except Mg (Tables 5 and 6). Overall, no

notable reduction in concentrations of Al, Ca, Cu, Fe, and Mn were observed from any of these profiles following microbial treatments (Table 7).

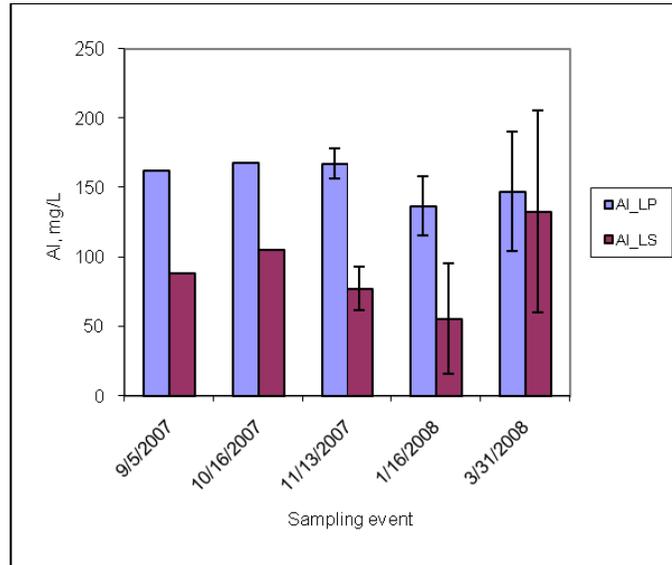


Figure 34. Aluminum (Al) concentration trends over time for the WTS[®] treatment. LP: liquid profile, LS: Liquid supernatant. (Note: July – September 2007 sampling are the pre-treatment sampling.)

Al concentrations in both treated and untreated tank profile and tank supernatant increased in October 2007, thereafter they followed a similar decreasing trend till the end of the sampling events (Fig. 35). A similar trend was observed for Ca and Fe. In addition, samples collected from the treated tank showed higher reduction rates for these metals as compared to the untreated tank and was likely due to treatment effects. Irrespective of treatment, these metals' concentrations decreased from both tank profiles which were likely due to intrinsic microbial metabolic activities. Conversely, Cu, Mg and Mn concentration in the tanks fluctuated over time and was likely due to the environmental conditions in the tank. Microorganisms can promote mineral formation or degradation based on environmental situation (Ehrlich 1997). These variations in metal concentration in both lagoon and tank environmental situation were also likely due to the variations in feed composition, which was not explored because it was beyond the scope of this study.

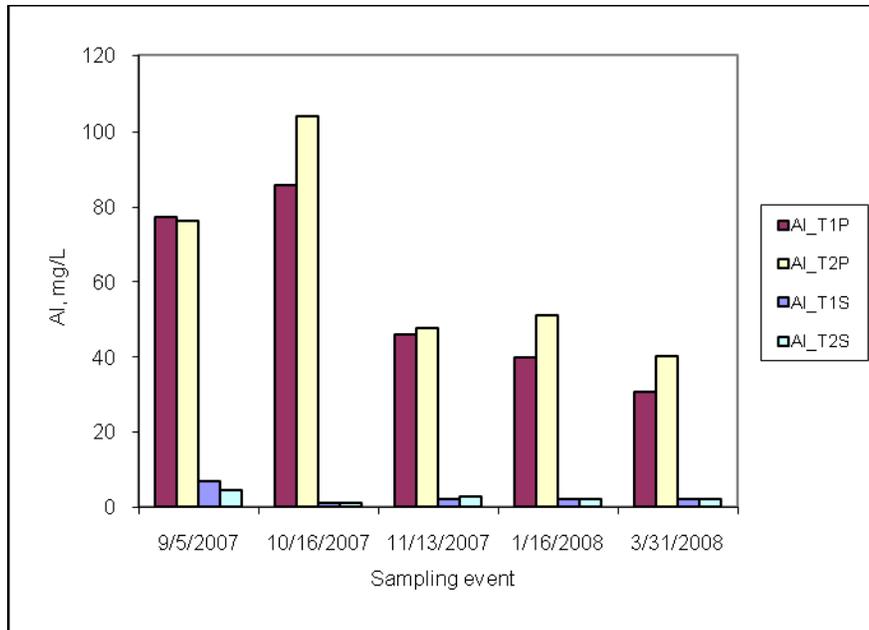


Figure 35: WTS[®] treatment effects on Aluminum (Al) in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: Sep, 2007 sampling is the pre-treatment sampling.)

Table. 5. Average concentration of Calcium (Ca), Copper (Cu) concentration for LP and LS at different sampling events

Date	Ca (mg/L)		Cu (mg/L)		Fe (mg/L)	
	LP	LS	LP	LS	LP	LS
09/05/07	3153a±647	1980ab±272	50.6ab±15.0	30.2b±7.7	171a±26.8	82.8a±12.4
10/16/07	3263a±408	2120ab±448	48.5ab±10.4	30.1b±10.3	169a±17	85.6a±48.2
11/13/07	2980a±938	1450ab±1123	46.7ab±19.7	23.1b±21.7	162a±50	70.2a±70.1
1/16/08	2730a±672	1250b±488	38.3b±13.5	14.9b±7.7	138.4a±45	44.1a±13.1
3/31/08	3627a±1011	3333a±893	73.7a±11.4	68.4a±9.0	197a±60	174b±50

*Averages within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

Table 6. Average concentration of magnesium (Mg), manganese (Mn) and sodium (Na) for LP and LS at different sampling events

Date	Mg(mg/L)		Mn(mg/L)		Na(mg/L)	
	LP	LS	LP	LS	LP	LS
09/05/07	366a±55.4	265b±24	16.5ab±3.1	10.0b±1.6	288ab±11	260b±4
10/16/07	356a±83	304a±40	13.1ab±1.0	8.4b±2.7	277b±95	321a±14
11/13/07	366a±71	251a±86	16.7ab±6.3	8.9b±7.7	313ab±9	293a±8.5
1/16/08	359a±63	232a±42	12.0b±2.6	5.2b±1.9	378a±41	321a±20
03/31/08	421a±93	398a±75	23a±8.4	20.4a±7.2	313ab±21	317a±21

Averages within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests

Table 7. Average metals concentration (mg/L) for LP and LS sampling locations averaged over all sampling events

Parameter ¹	Sampling location			
	LP		LS	
	Pre-trt	Post-trt	Pre-trt	Post-trt
Aluminum (Al)	162a±11	156a±33	89a±16	93a±49
Calcium (Ca)	3153a±647	3150a±761	1980a±272	2038a±1085
Copper (Cu)	171a±27	51.80a±18.38	30a±8	34.14a±24.30
Iron (Fe)	171a±27	167a±45	83a±12	93a±66
Manganese (Mn)	16.53a±3.06	16.20a±6.46	9.96a±1.60	10.71a±7.64
Magnesium (Mg)	366a±55	376a±72	265a±24	296a±87
Sodium (Na)	288a±11	320a±59	260b±59	313a±19

* Averages within a row followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests

Nicholson et al. (1999) reported that the mean Cu concentration in dairy cattle slurry collected from commercial farms in England and Wales was 4.73 mg/L (62.3 mg/kg dm; dry matter 7.6%). Ullman and Mukhtar (2007) reported Cu concentrations in dairy lagoons in central Texas in the range of 8.1-19.2 mg/L depending on management practices applied at the specific dairy. In this study, average Cu concentration in LP and LS was 46.01 ±14.64 and 24.56±11.86 mg/L, respectively, which is much higher than reported elsewhere. Cu concentration in manure is related to Cu added as a supplement to feed (Li et al. 2005). In general, manures will contain higher Cu concentration if feeds contain higher Cu levels (Nicholson et al. 1999). In this study, feed composition was not analyzed, however, average concentrations of metals (i.e., Ca, Mg, Fe, etc.) in the lagoon were similar to those values reported by Mukhtar et al. (2004). The values reported for Ca and Fe were two and nine times higher, respectively, than the values reported by

Mukhtar et al. (2004), but Fe concentration was comparable with North Carolina's reported values. All metals concentrations as received from TIAER lab are also listed in Tables I and II of Appendix A.

Conductivity

The average conductivity in LP and LS is presented in Fig. 36. The microbial treatment (WTS[®]) appeared to cause a slight increase in EC levels until the end of the experiment. However, no significant differences in conductivity were observed between LP and LS samples. On the other hand, conductivity and K demonstrated a strong correlation in LP ($R^2 = 0.99$) and LS ($R^2 = 0.71$) samples. A strong correlation was also observed between conductivity and Na in LP ($R^2 = 0.86$), however a weak correlation for the two parameters was observed in LS ($R^2 = 0.44$). These results showed a good agreement with the findings of Scotford et al. (1998), who observed high correlation ($R^2 = 0.80$) between K and EC.

The treated tank (T1) samples resulted in slightly higher conductivity values than the untreated tank samples (Fig. 37), which was likely due to treatment effects.

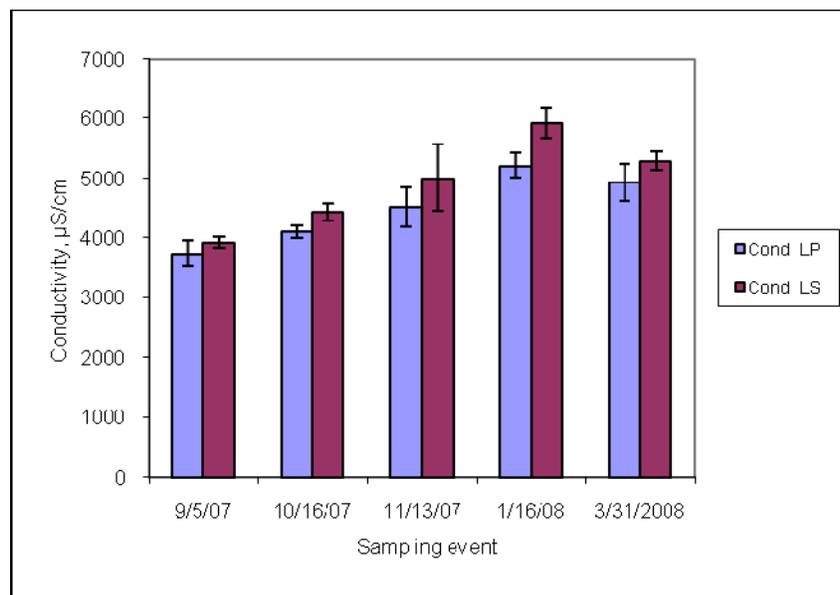


Figure 36. Conductivity trends over time for the WTS[®] treatment. LP: liquid profile, LS: Liquid supernatant. (Note: July - September 2007 sampling are the pre-treatment sampling.)

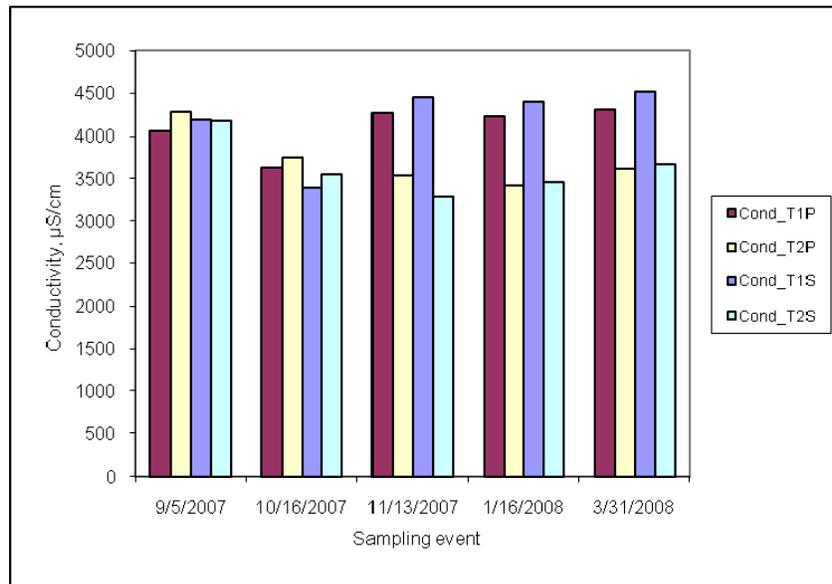


Figure 37. WTS® treatment effects on conductivity in tank profiles. T1P: tank profile in treated tank T1, T2P: tank profile in untreated tank T2, T1S: liquid supernatant in treated tank T1, T2S: liquid supernatant in untreated tank T2. (Note: September 2007 sampling is the pre-treatment sampling.)

While statistically similar, the average conductivity for LS ($4929 \pm 239 \mu\text{S/cm}$), was slightly higher than LP ($4503 \pm 233 \mu\text{S/cm}$). Safley et al. (1993) reported that EC values of $8000 \mu\text{S/cm}$ can inhibit bacterial population in a livestock operation's treatment lagoon. In this lagoon, EC was lower than this suggested threshold value. All conductivity values as received from TIAER lab are listed in Tables I through III in Appendix A.

Treatment Costs

Costs to implement this lagoon treatment method varied based on the daily amount of manure and wastewater added to the lagoon, the existing lagoon capacity and sludge depth, prior wastewater treatment (e.g., pretreatment of flushed manure for solids separation before it flows to the lagoon), lagoon depth, and the number of lagoon cells in the wastewater management system. Treatment costs will also vary with the type of manure alley cleaning system used, such as flushing or vacuuming. The following cost matrix was provided by the technology provider.

Table 8. Cost to treat a lagoon with WTS[®] microbial treatment

Herd size	Unit cost (\$/cow/month)	\$/cow/year
1000	0.50	6
1001-7000		
>7001		

Based upon the information in Table 8, for this 600-head dairy, the total cost to treat the lagoon was estimated at \$2,100 for a 7-month period or \$0.50/cow/month.

Conclusion

The WTS[®] treatment was somewhat effective in reducing sludge depth by 10% compared to its pre-treatment level. This reduction of sludge depth was due to microbial treatment. This treatment system significantly increased lagoon pH in the LS as compared to LP. Similar to lagoon pH, over-time treated tank T1 indicated slightly higher but statistically similar pH as compare to untreated tank T2 in both tank profiles. There was no significant reduction in TS either in lagoon or tank environments due to WTS[®] treatment. Overall, lagoon TSS concentration in LP was reduced by 7% when the post-treatment levels were compared to the pre-treatment levels, whereas, this reduction was 9% in the LS. Over time, TSS in both treated and untreated tank samples decreased and followed trends similar to lagoon TSS concentrations. Following microbial treatment of the lagoon, TDS concentrations both in LS and LP increased, although these differences were not significant. Overall, TDS concentration in the LS was 13% higher than that observed in LP.

There was no significant reduction in TP between treated or non-treated lagoon sampling profiles. Conversely, TP concentration in treated tank profile was reduced by 17% and increased by 2% in the untreated tank profile. On the other hand, the TP values declined in the treated and untreated tank supernatant samples by 60% and 55%, respectively. These differences in TP reduction between treated and untreated samples were due to WTS[®] treatment effects. There were no significant differences in SRP concentrations between LP and LS samples from the lagoon, and they showed increasing trend overtime. A similar increasing trend for SRP was observed in both treated and untreated tank samples. However, the treated tank showed higher SRP concentrations than that of the untreated tank samples as a result of greater TDS in tank supernatant. The TKN in LP and LS decreased by 29% and 19%, respectively, and a larger TKN reduction was observed in the tank profile (60% and 47% in treated and untreated tank profile samples, respectively) and tank supernatant (88% to 86% in treated and untreated tank supernatant samples, respectively) samples as compared to lagoon samples. The K concentration and conductivity increased in both lagoon and tank sample profiles throughout the monitoring period. Overall, there were no significant reductions in TS, TP, and SRP between treated and non-treated lagoon sampling profiles. The main purpose of this study was to observe the

effectiveness of WTS® in reducing P and other substances from lagoon effluent to be applied to WAFs. Therefore, this treatment system was not effective in reducing phosphorus and other nutrients from the lagoon effluent, especially soluble parameters.

Challenges

Tanks were used to mimic the repeatability of lagoon treatment with microbes and to get additional information on treatment effectiveness. Due to evaporation losses, it was difficult to maintain a consistent TS and TP sampling depth in the tanks. It was possible to continue sampling, although TP sampling depth varied due to water losses from tanks. It remains a challenge to obtain replicated data on treatment effectiveness in outdoor environmental conditions under a tank environment. It is apparent that microbial treatment was more effective in the lagoon supernatant than the entire profile but, without accurate assessment of pre- and post-treatment sludge characteristics, it is premature to conclude how effective the treatment was in reducing nutrient, metal, and solids levels in the lagoon. The foremost challenge is to collect and monitor the lagoon sludge sample for an extended period of time prior to, during, and after treatment to determine solids, nutrients and metal content of the lagoon that will enable a determination to be made regarding the effectiveness of the applied treatment.

Acknowledgements

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APPENDIX - E-I

Table I. pH, conductivity, solids, nutrients and metals concentration at different sampling locations and sampling events in LS profiles

Site ID	Date	pH	Cond	NNN	SRP	TP	TKN	TS	TSS	TVS	TDS	TFS	Al	Ca	Cu	Fe	K	Mg	Mn	Na
L1S	9/5/07	7.15	4028	0.031	9.07	240	1090	24500	23200	14800	1310	9700	70.3 ^{SR}	1750 ^{SR}	23.2 ^{SR}	71.9 ^{SR}	353 ^{SR}	241 ^{SR}	8.85	256 ^{SR,D}
L1S	10/16/07	7.28	4607	0.086	10.6	254	760	22900	20600	13800	2320	9100	67.2 ^{SR}	1730 ^{SR}	19.2 ^{SR}	62.8 ^{SR}	408 ^{SR}	272 ^{SR}	7.67	319 ^{SR,D}
L1S	11/13/07	7.37	5490	0.109	16.1	97.4	408	7290	3200	3800	4090	3490	15	409	3.69	15	394	176	1.79	293
L1S	1/16/08	7.25	6150	0.053	13.6	149	809	14200	10400	8990	3800	5210	40.9	841	8.83	33.3	395	194	3.68	302
L1S	3/31/08	7.11	5460	0.085	11.1	395	1600	47400	34400	32100	13000	15300	94.6	2330	58	117	504	314	12.2	293
L2S	9/5/27	7.31	3893	0.031	7.03	323	1280	25700	23000	15700	2710	10000	96 ^{SR}	1910 ^{SR}	28.9 ^{SR}	80.2 ^{SR}	364 ^{SR}	264 ^{SR}	9.23	262 ^{SR,D}
L2S	10/16/07	7.31	4395	0.137	11	384	1040	37100	31200	22400	5880	14700	146 ^{SR}	2610 ^{SR}	39.6 ^{SR}	141 ^{SR}	446 ^{SR}	349 ^{SR}	11.4	336 ^{SR,D}
L2S	11/13/07	7.36	5130	0.063	14.7	297	908	21700	17200	13000	4500	8700	59.8	1300	19	46.5	406	233	7.76	284
L2S	1/16/08	7.34	5660	0.039	15.7	248	1020	21300	15400	12800	5900	8500	72.1	1790	23.6	58.7	479	277	7.35	341
L2S	3/31/08	7.28	5250	0.066	16.5	429	1450	61400	53200	38300	8230	23100	150	3630	73.7	198	569	421	23.5	331
L3S	9/5/27	7.3	3866	0.12	1.42	409	1600	33500	32600	20700	864	12800	99.6 ^{SR}	2280 ^{SR}	38.4 ^{SR}	96.2 ^{SR}	355 ^{SR}	289 ^{SR}	11.8	263 ^{SR,D}
L3S	10/16/07	7.37	4328	0.152	9.34	343	904	27200	20200	16300	6960	10900	102 ^{SR}	2020 ^{SR}	31.6 ^{SR}	53.0 ^{SR}	402 ^{SR}	292 ^{SR}	6.11	308 ^{SR,D}
L3S	11/13/07	7.79	4400	0.037	5.78	454	1150	70600	42400	50600	28200	20000	157	2640	46.6	149	450	345	17	301
L3S	1/16/08	7.35	5980	0.071	18	180	899	15200	10800	8950	4400	6250	53.8	1120	12.2	40.3	438	224	4.57	320
L3S	3/31/08	7.27	5150	0.074	11.9	626	1840	67500	57200	41600	10300	25900	154	4040	73.6	207	578	458	25.5	328

Table II. pH, conductivity, solids, nutrients and metals concentration at different sampling locations and sampling events in LP profiles

Site ID	Date	pH	Cond	NNN	SRP	TP	TKN	TS	TSS	TVS	TDS	TFS	Al	Ca	Cu	Fe	K	Mg	Mn	Na
L1P	9/5/07	7.12	3716	0.044	6.31	399	1770	40100	39800	24600	274	15500	153 ^{SR}	2590 ^{SR}	36.1 ^{SR}	147 ^{SR}	372 ^{SR}	315 ^{SR}	14.2	277 ^{SR,D}
L1P	10/16/07	7.13	4220	2.8	8.71	377	1110	43000	33600	26400	9450	16600	145 ^{SR}	2810 ^{SR}	36.7 ^{SR}	151 ^{SR}	453 ^{SR}	261 ^{SR}	12	322 ^{SR,D}
L1P	11/13/07	7.22	4890	0.151	17.6	335	1100	48200	40400	31000	7800	17200	118 ^{SR}	2000 ^{SR}	26.4	106 ^{SR}	440 ^{SR}	293 ^{SR}	9.47	304 ^{SR}
L1P	1/16/08	7.1	5410	0.157	19.2	302	1350	33900	28000	21700	5900	12200	99.1	2010 ^{SR}	24.8	88.1	470	289	9.34	332 ^{SR}
L1P	3/31/08	7.21	5190	0.084	23	338	1370	56800	37200	38600	19600	18200	104	2540	60.6	130	503	320	13.4	290
L2P	9/5/07	7.25	3963	0.045	5.91	482	1890	45400	44200	27600	1150	17800	159 ^{SR}	3010 ^{SR}	49.6 ^{SR}	167 ^{SR}	410 ^{SR}	358 ^{SR}	15.4	288 ^{SR,D}
L2P	10/16/07	7.27	4078	0.157	7.31	469	1180	50400	43000	30300	7380	20100	187 ^{SR}	3600 ^{SR}	52.4 ^{SR}	170 ^{SR}	445 ^{SR}	402 ^{SR}	13.6	168 ^{SR,D}
L2P	11/13/07	7.25	4440	0.399	4.4	483	1350	57800	52600	35400	5200	22400	188	3070	48	178	476	372	19	315
L2P	1/16/08	7.24	5000	0.071	19.6	409	1320	44500	42600	27000	1900	17500	156	3340	51.7	175	554	409	14.5	393
L2P	3/31/08	7.21	4590	0.066	11.8	546	1730	68900	42400	43100	26500	25800	158	3800	79.4	215	577	440	26.3	320
L3P	9/5/07	7.24	3535	0.093	0.23	620	2250	57200	56800	35400	446	21800	174 ^{SR}	3860 ^{SR}	66.1 ^{SR}	200 ^{SR}	429 ^{SR}	425 ^{SR}	20	299 ^{SR,D}
L3P	10/16/07	7.28	4010	0.132	6.14	530	1260	52500	49600	31800	2850	20700	171 ^{SR}	3380 ^{SR}	56.4 ^{SR}	185 ^{SR}	441 ^{SR}	406 ^{SR}	13.8	340 ^{SR,D}
L3P	11/13/07	7.33	4250	0.032	3.16	736	1770	80300	64400	52500	15900	27800	196	3870	65.7	203	498	434	21.5	321
L3P	1/16/08	7.22	5230	0.03	20.9	336	1280	34900	30800	21200	4100	13700	156	2840	38.3	152	588	380	12.2	410
L3P	3/31/08	7.35	5020	0.06	11.9	675	1950	72500	59600	44100	12900	28400	180	4540	81.2	246	615	502	29.3	330
LP10	9/5/07				14.2	148	753	15800	12000		3850									
L10S	10/16/07				17.6	183	600	18000	15400	11400										
LP10	11/13/07				11.9	73	308	10500	7100		3400									
LP10	1/16/08				24.4	98.7	688	50300	42000	39000	8300	11300								

Table III. pH, conductivity, solids, nutrients and metals concentrations at different sampling locations and sampling events in tank conditions

Site ID	Date	pH	Cond	NNN	SRP	TP	TKN	TS	TSS	TVS	TDS	TFS	Al	Ca	Cu	Fe	K	Mg	Mn	Na
T1S	9/5/07	7.43	4176	0.087	0.14	51.5	375	4270	1340	2070	2930	2200	6.78 ^{SR}	252 ^{SR}	<1.00 ^{SR}	4.74 ^{SR}	289 ^{SR}	132 ^{SR}	<1.00	229 ^{SR,D}
T1S	10/16/07	8.04	3388	<0.011	9.02	23.9	44.8	3040	170	966	2870	2074	<1.00 ^{SR}	42.3 ^{SR}	<1.00 ^{SR}	<1.00 ^{SR}	357 ^{SR}	83.2 ^{SR}	<1.00	284 ^{SR,D}
T1S	11/13/07	9.73	4450	0.142	11.5	19.9	43.1	5500	120	1220	5380	4280	<2	52.6	<2	<2	397	131	<1	668
T1S	1/16/08	9.03	4390	0.618	16.1	15.3	52.7	4850	200	1000	4650	3850	<2	123	<2	<2	526	158	<2	920
T1S	3/31/08	9.17	4520	0.333	18.9	23.2	28	3660	216	602	3440	3058	<2.00	52.5	<2.00	<2.00	447	22.2	<2.00	735
T2S	9/5/07	7.44	4173	0.08	0.224	44.2	368	3880	1080	1800	2800	2080	4.53 ^{SR}	230 ^{SR}	<1.00 ^{SR}	3.29 ^{SR}	295 ^{SR}	132 ^{SR}	<1.00	230 ^{SR,D}
T2S	10/16/07	8.07	3555	0.369	10.7	25.5	55.6	3110	200	1010	2910	2100	<1.00 ^{SR}	57.5 ^{SR}	<1.00 ^{SR}	<1.00 ^{SR}	362 ^{SR}	149 ^{SR}	<1.00	284 ^{SR,D}
T2S	11/13/07	8.48	3290	2.06	8.51	25.6	61.8	3570	570	1250	3000	2320	2.82	71.2	<2	<2	351	131	<1	239
T2S	1/16/08	8.71	3460	<0.015	13.7	15.7	39.5	2850	52	712	2800	2140	<2	49	<2	<2	495	175	<2	389
T2S	3/31/08	8.85	3670	<0.015	10.2	12.7	33.2	3080	60	800	3020	2280	<2.00	34.2	<2.00	<2.00	482	148	<2.00	299
T1P	9/5/07	7.38	4049	0.078	2.57	204	922	17400	16000	10400	1370	7000	77.3 ^{SR}	1380 ^{SR}	17.2 ^{SR}	57.7 ^{SR}	330 ^{SR}	215 ^{SR}	6.39	248 ^{SR,D}
T1P	10/16/07	7.57	3623	0.105	4.32	259	537	20400	18000	11800	2440	8600	85.8 ^{SR}	1620 ^{SR}	15.2 ^{SR}	47.2 ^{SR}	410 ^{SR}	266 ^{SR}	5.35	299 ^{SR,D}
T1P	11/13/07	9.39	4260	0.064	10.9	148	302	14700	7400	7130	7300	7570	46	702	11.7	40.9	406	180	4.3	665
T1P	1/16/08	8.8	4220	0.31	16	121	319	12700	8500	5580	4200	7120	39.8	749	9.47	29.5	488	203	3.1	852
T1P	3/31/08	8.81	4300	0.128	18.9	144	324	13600	11600	6430	2010	7170	30.5	821	11.7	36.6	520	201	4.47	772
T2P	9/5/07	7.41	4271	0.063	2.17	203	919	16200	13700	9680	2540	6520	76 ^{SR}	1360 ^{SR}	16.4 ^{SR}	53.8 ^{SR}	348 ^{SR}	219 ^{SR}	6.19	255 ^{SR,D}
T2P	10/16/07	7.49	3742	0.09	8.37	328	716	26200	23000	15000	3230	11200	104 ^{SR}	2080 ^{SR}	27.5 ^{SR}	65.8 ^{SR}	417 ^{SR}	289 ^{SR}	7.82	311 ^{SR,D}
T2P	11/13/07	8.38	3540	0.669	4.37	178	386	14500	11200	8080	3300	6420	47.6	848	14	43.7	388	195	5.05	313
T2P	1/16/08	8.16	3420	0.07	9.98	146	385	12300	9600	6760	2700	5540	51	863	11.8	37.4	491	227	3.96	356
T2P	3/31/08	8.2	3620	0.153	7.93	174	442	15300	10600	8450	4680	6850	40.2	1050	15.2	45.2	518	233	5.2	312