C-43 West Basin Storage Reservoir Water Quality Feasibility Study

Deliverable 4.3.1: *Final* Feasibility Study Update

Prepared for

South Florida Water Management District

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Prepared by

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Acronyms and Abbreviations

ac	Acre
ADS	Air Diffusion System
Alum	Aluminum sulfate
ASR	Aquifer storage and recovery
BOD	Biochemical oxygen demand
CERP	Comprehensive Everglades Restoration Plan
cfs	Cubic feet per second
cm/d	Centimeter per day
CRE	Caloosahatchee River Estuary
DAF	Dissolved air flotation
DEP	Florida Department of Environmental Protection
EAA	Everglades Agricultural Area
EAV	Emergent aquatic vegetation
FAV	Floating aquatic vegetation
floc	flocculant
FTW	Floating treatment wetland
gpm/ft^2	Gallon per minute per square foot
HAB	Harmful algal bloom
HDPE	High-density polyethylene
hp	Horsepower
HWTT	Hybrid wetlands treatment technology
J-Tech	Jacobs Engineering and Tetra Tech, Inc.
kWh	Kilowatt-hour
lbs/yr	pounds per year
LF	Linear foot
MFL	Minimum flow and level
MG	Million gallons
MGD	Million gallons per day
mg/L	Milligrams per liter
NPV	Net present value
NTU	Nephelometric turbidity units
O&M	Operation and maintenance
ppb	Parts per billion
SAV	Submerged aquatic vegetation
SCADA	Supervisory Control and Data Acquisition System
SFWMD	South Florida Water Management District
STA	Stormwater treatment area
Study	C-43 West Basin Storage Reservoir Water Quality Feasibility Study
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UV	Ultraviolet
WBSR	C-43 West Basin Storage Reservoir
Working Group	C-43 Water Quality Feasibility Study Working Group

WQATT	C-43 Water Quality Alternative Treatment Technology
WQC	Water Quality Component
WQTTP	Water Quality Treatment and Testing Project
WSI	Wetland Solutions, Inc.

Executive Summary

On January 10, 2019, Governor Ron DeSantis signed Executive Order 19-12, calling for greater protection of Florida's environment and water quality. The Executive Order directed the state's agencies to take an aggressive approach to address some of the environmental issues plaguing the state, with a significant emphasis on south Florida and recent harmful algal blooms (HABs) associated with blue-green algae. Specifically, the Executive Order directed the Florida Department of Environmental Protection (DEP) to "work with the South Florida Water Management District [SFWMD] to add stormwater treatment to the C-43 Reservoir to provide additional treatment and improve the quality of water leaving this important storage component" of the Comprehensive Everglades Restoration Plan.

To examine conventional and innovative biological, physical, and chemical technologies available and applicable to treating water entering and discharging from the C-43 West Basin Storage Reservoir (WBSR) or reducing potential algal biomass within the C-43 WBSR, SFWMD, DEP, and local governments have partnered to develop the C-43 WBSR Water Quality Feasibility Study (Study). Collectively, representatives of SFWMD, DEP, Hendry County, Lee County, City of Cape Coral, City of Sanibel, and Lehigh Acres Municipal Services Improvement District make up the C-43 Study Working Group (Working Group). The Working Group provides guidance to the SFWMD Project Manager, who is responsible for administering the contract and acting as the liaison between the Working Group and C-43 Study consultant, J-Tech (Jacobs Engineering and Tetra Tech, Inc.), who was selected to complete the Study.

The first step in the Study process was to prepare an Information Collection Summary Report, which provided a summary of available, technically feasible, conventional, and innovative biological, chemical, and physical treatment technologies for water quality improvement for eventual pre-treatment, in-reservoir treatment, and/or post-treatment application to the C-43 WBSR. The conventional water quality treatment alternatives were predominantly gathered from the DEP Accepted Water Technologies Library (DEP, 2020) but also include information submitted directly to J-Tech and Working Group members from additional technology vendors. The summary of available conventional and natural treatment technologies described in this report indicates that a wide range of approaches are available. A total of 38 technologies were gathered and assessed for their applicability to the Study. Technologies were removed from further consideration if they could not be scaled up to the flow rates that will be necessary at the C-43 WBSR, were meant for an urban watershed scale, were better suited for removal of pollutants from a conventional stormwater system, or if the vendor did not provide enough details to fully evaluate the technology's applicability to C-43 WBSR treatment. The Information Collection Summary Report recommended 25 technologies for further evaluation.

After the completion of the Information Collection Summary Report, the remaining 25 technologies were further evaluated to reduce the list of technologies to 10, for detailed analysis. The technologies that did not have Florida case studies or had insufficient vendor-provided data were removed from further evaluation. Technologies that could not be scaled to the expected flows and nutrient concentrations at the C-43 WBSR were also removed. In addition, technologies with very high costs, large amounts of residuals, and/or the potential to harm the ecosystem were also removed. The 10 technologies evaluated as part of this Study included:

- Treatment wetlands
- Sand filtration
- Air diffusion system (ADS)
- MPC-Buoy
- Alum treatment
- Hybrid Wetlands Treatment Technology (HWTT)
- ElectroCoagulation
- AquaLutions®™
- Bold & Gold®
- NutriGone™

Additional information about these 10 technologies was developed by J-Tech and gathered from the vendors. J-Tech requested additional detailed information from the vendors about technology sizing and performance for a system that treats flows within a range of 300–600 cubic feet per second (cfs) that could be applied to the C-43 WBSR. Additionally, to directly compare the technologies' ability to reduce nutrients, specific water quality targets were provided. The water quality targets proposed included reducing total nitrogen (TN) from 1.5 milligrams per liter (mg/L) to 1.0 mg/L, total phosphorus (TP) from 0.16 mg/L to 0.08 mg/L, and total suspended solids (TSS) from 20 mg/L to 10 mg/L. These targets were based on specific percentiles of measured water quality data in the river, chosen by J-Tech, and were intended to provide a standard of comparison across technologies. These targets were not intended to set final design criteria for the future water quality project.

Each of the 10 technologies was then evaluated and ranked against a series of attributes and for cost effectiveness to determine which technologies would work best to provide water quality treatment for the C-43 WBSR. The first step in the ranking process was to evaluate the technologies based on key attributes that were separate from the ability of each technology to attain the prescribed nutrient removal. **Table ES-1** summarizes these attributes, the weight assigned, and the justification for that weight. In the table, attributes are grouped by color, i.e., cells with attributes of the highest importance are green, cells with attributes of medium importance are yellow, and cells with attributes of lower importance are orange. Attributes that are more important to the success of the project were given a greater weight. The highest weight, which indicates the most important attribute, is a 5. The lowest weight, which indicates a less important attribute, is a 1.

Table ES-1. Ranking Attributes and Assigned Weights

Attribute	Weight	Justification
Scalable	5	Experience with technology at a similar scale
Confidence in Performance Estimates	5	Must have a high confidence in removal estimates provided
Available Florida Case Study	4	Reduced risk based on reliability of data with Florida case studies; however, this Study supports innovation
Residuals Production	4	Preference for technology that does not produce residuals or require management
Habitat	3	Ancillary benefits to fish and wildlife by providing habitat

Attribute	Weight	Justification
Ecosystem Services	2	Ancillary benefits to humans by provisioning services, regulating services, cultural services, and supporting services
Energy Efficiency	2	Preference for technology with lower carbon footprint
Land Requirements	2	Relative footprint area needed to provide for water quality treatment
O&M	2	Preference for technologies with less complexity of operations and less operator involvement
Schedule of Implementation	1	Time needed to construct and implement the treatment technology

The next step in the process was to evaluate cost effectiveness. The capital and operations and maintenance (O&M) costs were either based on estimates developed by J-Tech or provided by the vendors. These costs were used to calculate the net present value (NPV) costs over a 20-year period. The NPV costs were then divided by the TN, TP, and TSS (used as a proxy for algae) mass removals (in pounds per year) to determine the cost effectiveness (dollar per pound removed). The most cost-effective option was given a score of 1 and the least cost-effective was assigned a score of 10, with the remaining options scaled proportionately. For a few technologies, TN and/or TP reductions were not provided by the vendor; therefore, the TN and/or TP cost-effectiveness was given the lowest score.

The final step was to determine composite ranking using the scores by attribute and cost-effectiveness. Of the total weight, 50% was assigned to the attributes scoring and 50% was assigned to the cost-effectiveness scoring. For the cost-effectiveness scores, TN and TP cost-effectiveness values were weighted two times more than the TSS values. This higher weight was intended to reflect the importance of nutrient reduction for protection of downstream estuarine resources. The final score and ranking are summarized in **Table ES-2**.

Table ES-2. **Final Composite Ranking**

Technology	Cost Effectiveness Ranking			Attribute Ranking	Weighted Score	Final Ranking Based on Weighed Score
	TP	TN	TSS			
Weight -->	**0.4**	**0.4**	**0.2**	**1.0**		
Alum Treatment	1.0	2.3	2.5	2	1.9	1
Treatment Wetland	2.1	3.3	3.6	1	1.9	2
HWTT	1.4	2.9	3.2	2	2.2	3
Bold & Gold	2.9	4.1	4.5	5	4.3	4
Sand Filtration	4.0	5.1	5.7	4	4.4	5
ADS	10.0	1.0	1.0	6	5.3	6
Electrocoagulation	3.0	4.2	4.6	8	5.9	7
NutriGone^{TM}	3.0	4.2	4.7	10	6.9	8
AquaLutions	8.0	9.0	10.0	7	7.9	9
MPC Buoy	10.0	10.0	1.3	8	8.1	10

Based on this evaluation, the highest ranked technologies were treatment wetlands, alum treatment, and HWTT. The next highest ranked technologies included Bold & Gold®, sand filtration, ADS, and ElectroCoagulation. The lowest ranked technologies were NutriGone^{TM}, AquaLutions, and MPC-Buoy. The lowest ranked technologies were removed from further consideration in identifying alternatives. In addition, ADS was removed from further evaluation as the relative lack of information provided for TN, TP, and TSS removal did not support further consideration of this technology.

The higher ranked technologies from the composite ranking were further evaluated for implementation for treatment either as individual components or as part of a treatment train. Treatment trains were developed considering compatibility between treatments. The alternatives that were identified for the detailed cost-benefit analysis included:

- Alum treatment – both as an offline treatment facility and online, in-reservoir treatment system
- Full scale treatment wetland
- HWTT
- Smaller treatment wetland with parallel Bold & Gold® treatment
- Sand filter with parallel Bold & Gold® treatment
- ElectroCoagulation

In addition to the capital costs to construct these systems, estimated costs for the infrastructure to connect the treatment facility, O&M, and monitoring were included for designs that would produce nutrient reductions based upon those used for the purpose of this Study comparison. A detailed cost-benefit analysis was conducted to evaluate these six alternatives and the results are presented in **Figure ES-1**. Based on this evaluation the following alternatives are recommended for further evaluation:

- Alum treatment – both as an offline treatment facility and online, in-reservoir treatment system
- 1,000-ac treatment wetland with parallel 104-ac Bold & Gold® treatment
- 668-ac HWTT
- 200-ac sand filter with parallel 104-ac Bold & Gold® treatment

Based on the cost benefit analysis, the offline alum treatment system resulted in the lowest cost per pound for nutrient removal, to the levels used for this Study comparison, as well as the smallest land requirements. In-reservoir alum treatment was also evaluated and found to be even more cost effective with no additional land requirements. For these reasons, online alum injection is recommended to be included as a component of the ultimate C-43 WBSR water quality treatment. However, while alum injection provides a measure of control over nutrient concentrations and algal production within the reservoir, the duration of water storage may lead to changes in the water quality in the WBSR. Additional treatment capacity of the reservoir discharge is recommended, given the primary objective of the C-43 WBRS water quality component is to ensure that water released from the reservoir does not contribute to impairments of downstream water quality compared to existing conditions in the Caloosahatchee River Basin. The parallel treatment system that combines a smaller STA with Bold & Gold®, either as a pre-storage or post-storage system, was the next most cost-effective alternative. The parallel treatments provide flexibility in the volumes of flows that can be treated prior to discharge, where one technology is used for lower flows and the other is on standby for higher flow conditions. For example, the STA may be sized to receive a continuous baseflow during discharge while media filtration may be sized to treat the remainder of flow from the reservoir, which is expected to vary. Further technology evaluation may determine that a smaller and less expensive system could treat similar flow volumes. The HWTT system, the third most cost-effective alternative, is well studied in Florida systems and this Study confirmed that it is cost effective for removing nutrients. The parallel treatment system that combines a smaller sand filter with Bold & Gold® was the fourth most cost-effective alternative.

The next phase of the project will be the C- 43 WBSR Water Quality Component (WQC) Siting Evaluation. The top recommended alternatives from this Study will be evaluated as viable alternatives based on a more in-depth analysis of expected water quality and chemistry to more specifically evaluate project performance and identify target TN, TP, and TSS removal rates; identify maximum water quality treatment efficiencies for each alternative; optimize conceptual costs; and develop a siting study to determine land availability and specific infrastructure needs to select an alternative as the WQC Plan. The WQC Plan will be the basis for the Statement of Work for detailed design with the goal of project construction to be completed and online concurrently with full operation of the reservoir.

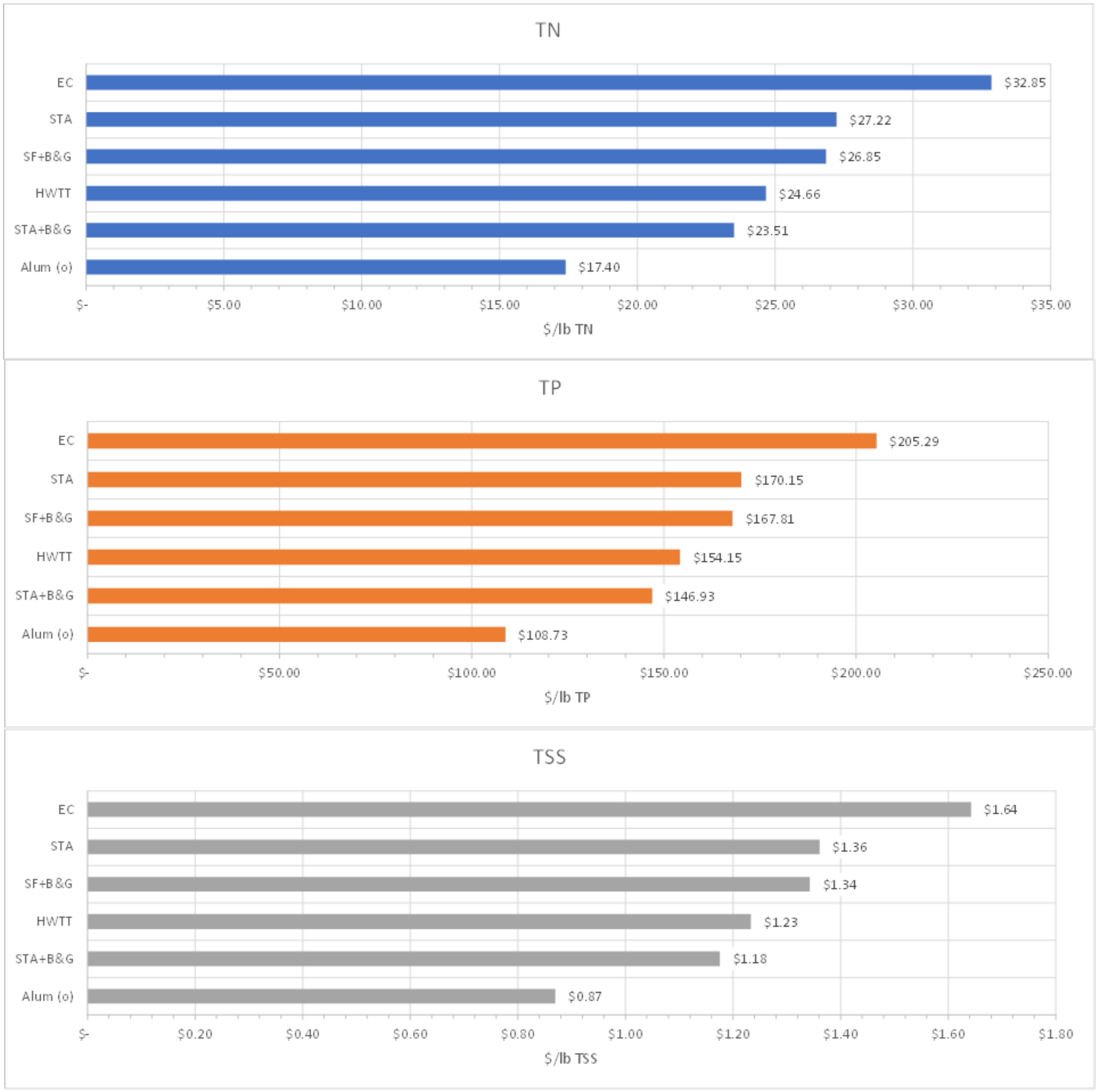


Figure ES-1. Unit Costs of Water Quality Benefits by Alternative for TN (top), TP (middle), and TSS (bottom)

J-Tech currently recommends that the final WQC Plan include both in-reservoir treatment with alum to help prevent algal blooms within the reservoir itself, as well as a post-storage water quality component to treat reservoir discharges that can be closely monitored prior to being returned to the Caloosahatchee River and Estuary.

1.0 Background/Introduction

On January 10, 2019, Governor Ron DeSantis signed Executive Order 19-12, calling for greater protection of Florida's environment and water quality. The Executive Order directed the state agencies to take a more aggressive approach to address some of the environmental issues plaguing the state, with a significant emphasis on south Florida and the harmful algal blooms (HABs) associated with blue-green algae. Specifically, the Executive Order directed the Florida Department of Environmental Protection (DEP) to "work with the South Florida Water Management District (SFWMD) to add stormwater treatment to the C-43 Reservoir to provide additional treatment and improve the quality of water leaving this important storage component" of the Comprehensive Everglades Restoration Plan (CERP).

The C-43 West Basin Storage Reservoir (WBSR) project is designed to capture and store water from Lake Okeechobee and the C-43 basin during Florida's rainy season. The reservoir is under construction on a 10,700-acre (ac) parcel owned by SFWMD in Hendry County (**Figure 1-1**) and is a 50-50 cost-share between SFWMD and the United States Army Corps of Engineers. Fully constructed, the C-43 WBSR will store approximately 57 billion gallons of water (approximately 170,000 acre-feet), for the congressionally authorized CERP project. The project, expected to be completed in 2023, will include construction of two 5,000-ac reservoir storage cells (Cells 1 and 2), three pump stations, a perimeter canal along with associated water control structures, and required improvements to the State Road 80 Bridge and the Townsend Canal, which ultimately connects to the Caloosahatchee River.

The C-43 WBSR project's goal is to work in conjunction with other regional projects and efforts to reduce the frequency and intensity of harmful freshwater discharges and provide beneficial freshwater during periods of reduced inflows into the Caloosahatchee River Estuary (CRE). Once completed, the project is anticipated to provide immediate environmental restoration benefits by:

- Capturing and storing stormwater runoff from the C-43 basin and regulatory discharges from Lake Okeechobee, thus reducing excess freshwater flows to the estuary.
- Helping to maintain a desirable salinity balance by controlling peak flows during the wet season and providing essential freshwater flows during the dry season.
- Helping to sustain a healthy estuarine nursery that supports recreational and commercial fisheries.
- Reducing nutrient loading to the CRE, an incidental benefit resulting from settling of nutrient-rich particulate matter in the reservoir.
- Providing beneficial freshwater during periods of reduced inflows to the CRE.

Depending on storage needs, water depth in the reservoir will range from 15 to 25 feet. Water stored in the reservoir is protected for the environment by a water reservation rule and will be released on a regulated schedule to help achieve minimum flow requirements at the S-79 structure (Franklin Lock and Dam) during dry season low-flow conditions. The water reservations rule for the Caloosahatchee River (C-43) WBSR is defined in subsection 40E-10.041(3), Florida Administrative Code. This project is one component of a larger restoration project for the Caloosahatchee River and Estuary and will comprise a large portion of the overall water storage requirement for the Caloosahatchee River Watershed.

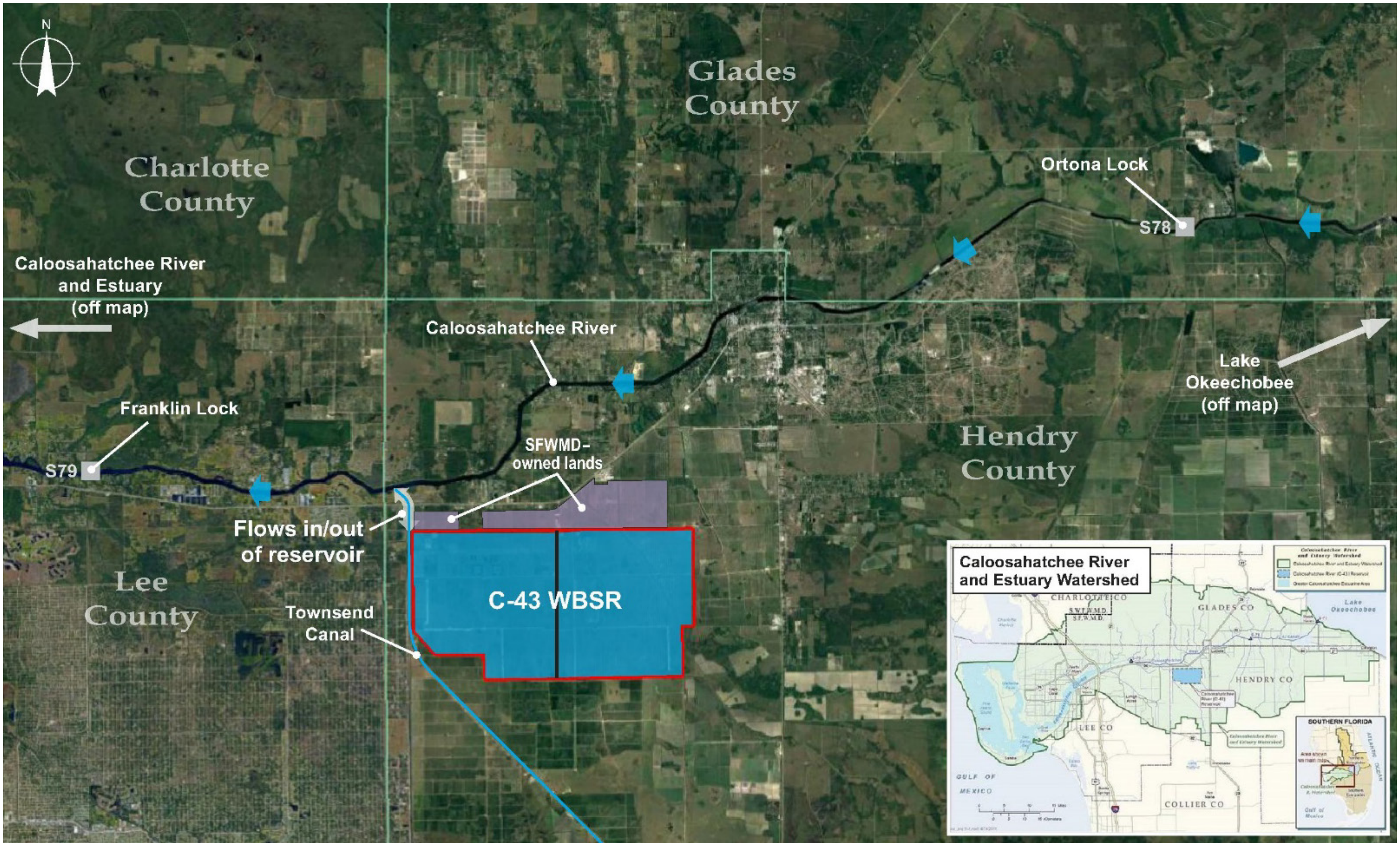


Figure 1-1. Location Map of C-43 West Basin Reservoir

The C-43 WBSR will serve multiple purposes. It is intended to support CRE restoration by helping to attenuate peak stormwater flows during the wet season and to provide additional base flow to the estuary during the dry season. The reservoir will capture and store a portion of both the watershed runoff and regulatory releases from Lake Okeechobee, reducing the frequency and volume of discharges to the CRE during the wet season. In addition, it is envisioned to provide public access and recreational opportunities, and the perimeter canal is intended to maintain allocated water supply to the local agricultural areas adjacent to the reservoir.

The purpose of this C-43 WBSR Water Quality Feasibility Study (Study) is to identify cost-effective, available, technically feasible, conventional and innovative biological, chemical, and physical treatment technologies that will improve the quality of water leaving the C-43 WBSR. DEP identified the CRE to be impaired for total nitrogen (TN) and established a total maximum daily load for the estuary that was approved by the Environmental Protection Agency. DEP has not identified the CRE to be impaired for total phosphorus (TP); however, DEP has identified TP impairments in tributaries throughout the Caloosahatchee River Watershed. Therefore, this nutrient is considered for reduction, as well, in this Study. It should be noted that the selected water quality treatment component is not intended to achieve compliance with the total maximum daily loads within the watershed. The purpose of the water quality treatment component is to ensure that water released from the reservoir does not contribute to impairments of downstream water quality compared to existing conditions in the Caloosahatchee River Basin. The reduction of nutrient concentrations and loads to the CRE is required by the Northern Everglades and Estuary Protection Program passed by the Florida Legislature and signed into law in 2007 and amended in 2016, and by the Caloosahatchee River and Estuary Basin Management Action Plan, adopted in 2012 and amended in 2020. Technologies to improve water quality leaving the C-43 WBSR are evaluated as part of this Study. It is imperative that any treatment technologies considered not affect the congressionally approved C-43 WBSR project purposes, infrastructure, construction schedule, or operation.

SFWMD, DEP, and local governments have partnered to develop this Study to examine conventional and innovative biological, physical, and chemical technologies available and applicable to treating water entering and discharging from the C-43 WBSR or reducing potential algal biomass within the C-43 WBSR. Collectively, representatives of SFWMD, DEP, Hendry County, Lee County, City of Cape Coral, City of Sanibel, and Lehigh Acres Municipal Services Improvement District make up the C-43 Study Working Group (Working Group). The Working Group provides guidance to the SFWMD Project Manager, who is responsible for administering the contract and acting as the liaison between the Working Group and the Study consultant, J-Tech (Jacobs Engineering and Tetra Tech, Inc.).

1.1 Methods for Technology Identification

The initial tasks for the Study included review of available water quality treatment technologies and several public meetings. The Final Information Collection Summary is provided in **Appendix A**. J-Tech reviewed information on available, technically feasible, conventional, and innovative biological, chemical, and physical treatment technologies for water quality improvement for eventual pre-treatment, in-reservoir treatment, and/or post-treatment application to the C-43 WBSR. Technologies considered included physical methods, chemical methods, and biological treatment systems.

J-Tech identified technologies for evaluation by reviewing the DEP Accepted Water Technologies Library. As of January 16, 2020, when the Information Collection Summary Report for this Feasibility Study was being prepared, there were 30 accepted technologies in this library. These included 15 physical, 7 chemical, and 8 biological technologies. In addition, J-Tech and Working Group members received technology information directly from 8 technology vendors, which included 5 physical, 2 chemical, and 1 biological treatment technologies. J-Tech also gathered additional information on all 38 technologies through vendor interviews, internet searches, and evaluating studies and projects that used these technologies.

Details about each of the technologies evaluated are included in the Information Collection Summary Report in **Appendix A**. Additional details were requested from the vendors as part of this Study and are outlined in **Section 3.1**.

1.2 Qualitative Assessment

In the Information Collection Summary Report, details about each of the technologies are provided along with examples of locations where each technology has been applied, if applicable. All 38 technologies were reviewed and assessed for their applicability to the Study. The technology evaluation found that a wide range of approaches are available to provide water quality treatment with the C-43 WBSR. All technologies are constrained to varying degrees by limitations on the scale of operation that will be necessary to provide effective treatment for the C-43 WBSR. Technologies were removed from further consideration if they could not be scaled up to the flow rates that will be present at the C-43 WBSR, could not be implemented at a large enough scale for the C-43 WBSR, were meant for an urban watershed scale, were better suited for removal of pollutants from a stormwater system, or the vendor did not provide enough details to fully evaluate the technology's applicability to C-43 WBSR treatment. Additional information on the technologies removed from further evaluation is available in the Information Collection Summary Report in **Appendix A**.

1.3 Results of Information Collection Summary Report

The list of potentially applicable technologies was reduced from 38 to 25 technologies recommended for further evaluation. Key criteria for this initial step included the following:

- Available knowledge base from Florida studies and other literature
- Performance within appropriate concentration ranges for the key water quality parameters
- Scalable to flows within project range
- Applicable Florida case studies
- Availability of unit capital and operational cost information or preliminary estimates of full-scale cost

A technology was retained if 4 or more of these qualitative criteria were met. **Table 1-1** summarizes the list, presented in alphabetical order. For purposes of this evaluation, terms are defined as follows:

- "Long history" means more than 20 years of technology application
- "High flows" means treated flows exceeding 100 cfs
- "Low TN and TP concentrations" means outflow TN concentrations less than 1 milligrams per liter (mg/L) and outflow TP concentrations less than 0.05 mg/L

- "High TSS removal" means a removal efficiency greater than 85%

Additional details are included in the Information Collection Summary Report in **Appendix A**.

Table 1-1. List of 25 Technologies Recommended for Further Evaluation

Technology	Technology Summary
Advanced Wastewater Treatment	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Applicable Florida case studies ▪ Cost information available
Air Diffusion Systems (ADS)	▪ Aeration is a well-established technology ▪ Capable of achieving low TN and TP concentrations ▪ Can be scaled to large volume reservoirs ▪ No Florida case study but multiple case studies available other states ▪ Vendor has provided plans and costs to treat C-43 WBSR
Aluminum Chloride	▪ Long history of application treating wastewater, stormwater and surface water ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Applicable Florida case studies ▪ Cost information available
Aluminum Sulfate (Alum)	▪ Long history of application treating wastewater, stormwater and surface water ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Applicable Florida case studies ▪ Cost information available
AquaLutions®™	▪ Recent application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Vendor confident of capacity to function at high flows ▪ Applicable Florida case studies ▪ Cost information available
Aqua-Swirl®	▪ Common application treating stormwater ▪ Capable of achieving high TSS (total suspended solids, algae) removal ▪ Vendor confident of capacity to configure function at high flows ▪ No documented Florida case studies provided ▪ Cost will need to be estimated specific to application
Bold & Gold®	▪ Recent history of application treating stormwater ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Cost information available
Ciba Krysalis FA/FC	▪ Used to treat Miami River, Port Manatee, and Tampa Bay ▪ Capable of achieving high TSS (algae) removal ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Cost will need to be estimated specific to application
Denitrifying Bioreactor	▪ Long history of application treating stormwater and groundwater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Applicable Florida case studies ▪ Cost will need to be estimated specific to application
Downstream Defender®	▪ Recent history of application treating stormwater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of treating a stream of the total flow to reduce overall concentration ▪ Florida case study not available ▪ Cost will need to be estimated specific to application

Technology	Technology Summary
Dredgeclear 53	▪ Used to treat North Palm Beach Waterway and interior residential canals ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Cost will need to be estimated specific to application
ElectroCoagulation	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations and remove algae ▪ Vendor confident of capacity to configure function at high flows ▪ Applicable Florida case studies ▪ Vendor has provided plans and costs to treat C-43 WBSR
Floating Wetlands (Biohaven)	▪ Increasing application in Florida waters ▪ Capable of achieving measurable TN and TP concentrations ▪ Scaling to large reservoir areas may be difficult ▪ Applicable Florida case studies ▪ Cost information available
FLOPAMTM EM 230	▪ Used before to treat the Gator Sand Mine ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Cost information available
Hybrid Wetlands Treatment Technology (HWTT)	▪ Recent history of application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Unit cost data available based on flow
Managed Recirculation	▪ Experimental approach but based on reservoir circulation studies ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired volume ▪ Florida case study information unavailable ▪ Cost information unavailable
Microbe-Lift	▪ Recent history of application treating surface water ▪ Capacity to achieve low TN and TP concentrations not demonstrated ▪ Capacity to function at similarly large volumes not demonstrated ▪ Applicable Florida case studies ▪ Unit cost information available
MPC-Buoy	▪ Recent history of application treating surface water ▪ Capable of treating algae populations ▪ Capacity to function at similarly large volumes not demonstrated ▪ Applicable Florida case studies just beginning ▪ Unit cost information available
NutriGone™	▪ Recent history of application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Cost will need to be estimated specific to application
Optimer 7194 Plus	▪ Used before to treat eutrophic Lake Maggiore ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies ▪ Cost will need to be estimated specific to application
Sand Filtration	▪ Long history of application treating wastewater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Proven capacity to function at high flows ▪ Applicable Florida case studies ▪ Unit cost data available based on flow

Technology	Technology Summary
SciCLONE™	▪ Recent history of stormwater treatment ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ No Florida case study information available ▪ Cost information available
Southern Algae Control	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Applicable Florida case studies unavailable but Okeechobee applications investigated ▪ Vendor has provided plans and costs to treat C-43 WBSR
StormPro®	▪ Long history of application treating wastewater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ No Florida case study information available
Treatment Wetlands	▪ Long history of application treating stormwater and groundwater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Applicable Florida case studies ▪ Cost information available

Note: Technologies are listed in alphabetical order

1.3.1 Other Treatment Options

During the first three public meetings held to present the Study, comments were received regarding several other water quality improvement technologies, which were not evaluated as part of the Information Collection Summary Report (additional details on the public meetings are included in **Appendix B**). The reasons these technologies were not included in this Study are described in the subsections below.

1.3.1.1 Aquifer Storage and Recovery

Aquifer storage and recovery (ASR) facilities inject and recover treated and untreated groundwater, partially treated surface water, and reclaimed wastewater. ASR provides the ability to store large volumes of water, which can help increase water supplies, and the ability to pump water back up when needed in drought conditions. In 2005, SFWMD conducted a hydrogeologic study to gather data on the potential for ASR wells in conjunction with the C-43 WBSR. This study gathered data on the confinement, hydraulic properties, lithology, and stratigraphic information for the Floridan Aquifer system. The study found that the Floridan Aquifer near the C-43 WBSR was composed of loose, unconsolidated sand, which is not favorable for the high-capacity ASR wells that would need to produce up to 5 million gallons per day (MGD) of water. The option to screen the ASR wells was explored, which would have allowed the wells to produce about 1 MGD of water at a very high cost (SFWMD, 2005). Based on this previous information, ASR was not further evaluated as part of this Study as a water quality treatment option for the C-43 WBSR.

1.3.1.2 Vallisneria americana

Vallisneria americana (*Vallisneria*) is a submerged aquatic plant common to many freshwater and estuarine systems. It is valued for its positive effects on water quality and provides critical nursery habitat for a diverse assemblage of freshwater and estuarine species. *Vallisneria* presence and survivability is controlled by salinity tolerance, light limitation, sediment composition, and grazing by herbivores such as turtles and manatee (SFWMD, 2017b). *Vallisneria* was common in the CRE west of the S-79 (Franklin Lock) structure until about 2000. After 2000, a series of droughts and resulting salinity increases dramatically reduced cover of *Vallisneria* in the C-43 Canal and the CRE (SFWMD, 2017b). Since that time, various groups have promoted efforts to re-establish *Vallisneria* in the C-43, and some success has been achieved using exclosure devices to minimize herbivory (Ceilley and Everham, 2013).

While the restoration of *Vallisneria* can provide benefits to the Caloosahatchee River and Estuary, and *Vallisneria* can be included in the submerged aquatic vegetation plan for a treatment wetland alternative, it was not evaluated further as a stand-alone treatment technology for the following reasons:

- Insufficient data are available from which to develop water quality performance expectations and full-scale implementation cost estimates.
- The selected water quality project will likely need to demonstrate a net improvement in water quality leaving the reservoir. Reliance upon a restoration approach in the C-43 Canal, such as re-establishing *Vallisneria*, will not provide the operational flexibility to ensure that project water quality goals are achieved.
- In-reservoir planting would be challenging to maintain due to operational ranges (fluctuating water levels and dry-out/empty periods) and routine reservoir maintenance requirements.

1.3.1.3 Floating Treatment Wetlands

Floating treatment wetlands (FTWs) are a variant of the treatment wetlands technology that consist of emergent aquatic vegetation (EAV) supported by a raft constructed from a range of synthetic materials. The roots of the vegetation penetrate the raft and extend into the water column below, providing attachment sites for nutrient-removing microbial populations and structure that can physically filter or trap particulate pollutants. In addition, FTWs shade the water column and have been shown to help reduce algal concentrations. FTWs can function over a wider range of water depths than conventional treatment wetlands but require an anchoring system to keep them in place. Design criteria for FTWs are limited with vendors typically recommending covering between 1% and 10% of the surface area of the system in which they are placed.

The scale of the C-43 WBSR raises several concerns with respect to the area requirements, anchoring, and operations and maintenance (O&M) for FTWs. FTW area requirements for the C-43 WBSR are expected to range from 100 to 1,000 ac, which would likely be deployed as multiple units of smaller individual size. There is no precedent for the successful design, deployment, and management of FTW systems of comparable scale. The potential effects of wind and wave action across the surface of the C-43 WBSR during a tropical weather event would likely damage the FTWs or require their removal prior to landfall. For these reasons, FTWs were not considered further.

1.4 Process to Determine the Highest Ranking (10) Technologies for Evaluation

After the completion of the Information Collection Summary Report, the remaining 25 technologies were further evaluated to reduce the list of technologies to 10. The technologies that did not have Florida case studies or for which vendors provided limited data were removed from further evaluation. Technologies that could not be scaled to the expected flows and nutrient concentrations at the C-43 WBSR were also removed. In addition, technologies with very high costs, large amounts of residuals, and/or the potential to harm the ecosystem were also removed. **Table 1-2** summarizes the reasons technologies were not carried forward for further consideration. The remaining technologies had higher levels of nutrient removal and lower amounts of residuals, and some technologies were more natural or provided algae removal in addition to nutrient removal.

Table 1-2. Summary of Technologies Removed from Consideration

Technology	Justification for Removal from Further Consideration
Advanced Wastewater Treatment	▪ Extensive operations and maintenance (O&M) requirements ▪ Full-time staff required to operate the facility ▪ Most flows currently treated by AWT are significantly less than design rates ▪ High residual processing
Aluminum Chloride	▪ Less common for treatment than aluminum sulfate ▪ Typically more expensive than aluminum sulfate ▪ Similar to performance of aluminum sulfate
Aqua-Swirl®	▪ No documented Florida case studies ▪ Limited data on removing algae ▪ No cost information provided
Ciba Krysalis FA/FC	▪ Extensive O&M requirements ▪ Large quantities of coagulant would be needed to treat the reservoir
Denitrifying Bioreactor	▪ No case studies for treatment at the size required ▪ No cost information provided for treatment at this scale
Downstream Defender®	▪ No documented Florida case studies ▪ Large amounts of residuals that would need to be addressed
Dredgeclear 53	▪ Extensive O&M requirements ▪ Large quantities of coagulant would be needed to treat the reservoir
Floating Wetlands (Biohaven)	▪ Large area of the reservoir would need to be covered ▪ Anchoring would be difficult with the design of the reservoir ▪ Extensive O&M requirements to maintain vegetation
FLOPAMTM EM 230	▪ Extensive O&M requirements ▪ Large quantities of coagulant would be needed to treat the reservoir
Managed Recirculation	▪ No documented Florida case studies ▪ Difficulty in managing recirculation within the current reservoir design
Microbe-Lift	▪ Capacity to achieve low TN and TP concentrations not demonstrated ▪ Capacity to function at similarly large volumes not demonstrated ▪ Concerns with introducing microbes into the system
Optimer 7194 Plus	▪ Extensive O&M requirements ▪ Large quantities of coagulant would be needed to treat the reservoir
SciCLONE™	▪ No documented Florida case studies ▪ Large amounts of residuals that would need to be addressed ▪ No cost information available
Southern Algae Control	▪ No documented Florida case studies ▪ Extensive O&M requirements
StormPro®	▪ No documented Florida case studies ▪ Extensive O&M requirements

Note: Technologies are listed in alphabetical order.

The remaining technologies, which are further evaluated in this Study, are as follows:

- Treatment wetlands
- Sand filtration
- Air diffusion system
- MPC-Buoy

- Alum treatment
- HWTT
- ElectroCoagulation
- AquaLutions®™
- Bold & Gold®
- NutriGone™

Additional details about each of these technologies are included in **Section 3.1**.

2.0 Identify Problems, Constraints, and Opportunities

In evaluating alternatives for water quality treatment, J-Tech considered the existing water quality, reservoir constraints, available lands, and conveyance and connectivity opportunities. Each of these considerations is described in this section.

2.1 Existing Water Quality

To compare the treatment technology's ability to reduce nutrients, specific water quality targets were selected by J-Tech by evaluating the existing water quality of the Caloosahatchee River downstream of the discharge location of the C-43 WBSR. The intent of the water quality evaluation was to allow direct comparison of technology removal efficiency and cost effectiveness. Therefore, resulting conceptual designs and facility sizes for the technologies were based to achieve these selected nutrient reduction targets specific to this Study. The following water quality evaluation is not intended to set the water quality targets for the future treatment facility. The C-43 WBSR and the selected water quality treatment technologies are not intended to achieve compliance with the Caloosahatchee River and Estuary Total Maximum Daily Load. The purpose of the selected water quality treatment component(s) is to improve the quality of water delivered to the River from the C-43 WBSR.

Available water quality data from the Ortona Lock (S-78), Franklin Lock (S-79), and Townsend Canal were downloaded from the SFWMD DBHYDRO database (https://www.sfwmd.gov/science-data/dbhydro) for the period of January 1, 2010 through March 16, 2020 (data that had been uploaded at the time of the data pull) (**Appendix C**). Data for the Townsend Canal station were only available in 2011, 2014, and 2015. All data used in the evaluation were from grab samples and not any continuous data. Negative values were removed from the evaluation of the water quality concentrations. Before June 2014, TN was not directly measured at these stations. Therefore, TN was calculated by summing the measured total Kjeldahl nitrogen and nitrate + nitrite. Starting in June 2014 through the end of the data period, direct-measure TN values were used.

The S-78 is located on the river upstream of the C-43 WBSR, and the S-79 is located on the river downstream of the reservoir. The Townsend Canal is to the west of the C-43 WBSR, and the water entering the reservoir will be a combination of water from the river and Townsend Canal (**Figure 1-1**).

Figure 2-1 through **Figure 2-6** provide cumulative frequency distribution curves for TN and TP at each of the three locations. These curves provide information on how many of the measured data points occur at different concentrations. For instance, in **Figure 2-1**, approximately 60% of the measured TN concentrations at S-78 were 1.5 mg/L or lower.

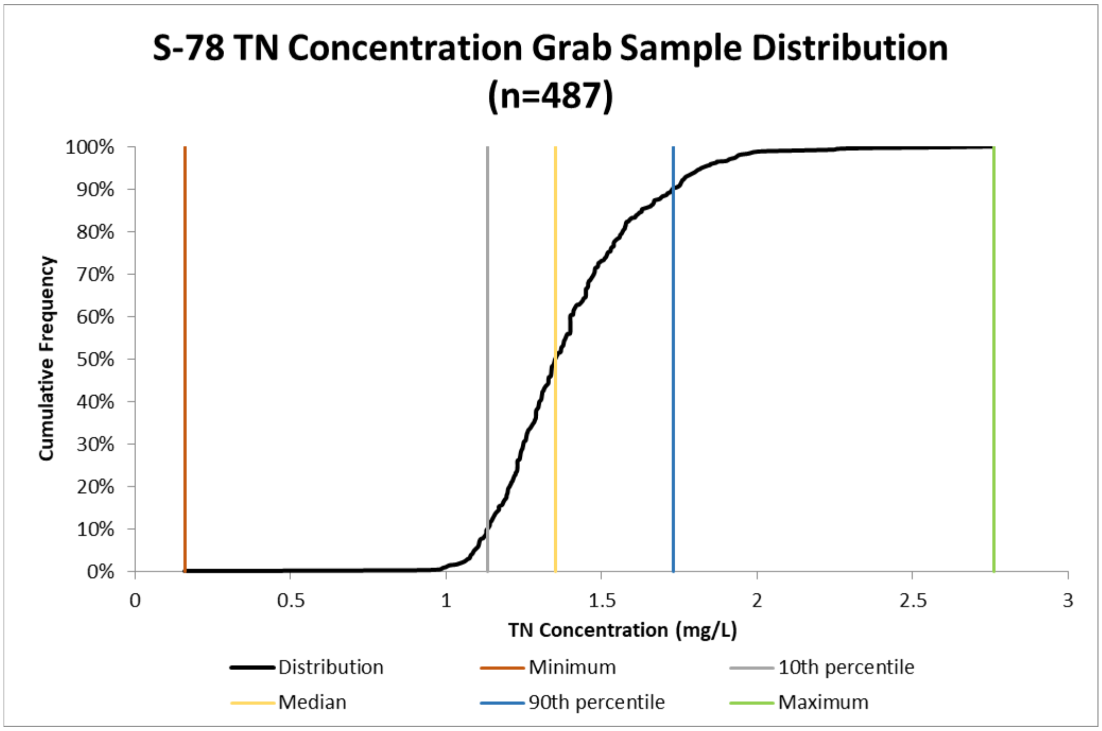


Figure 2-1. Cumulative Frequency Distribution for the TN Concentrations at S-78

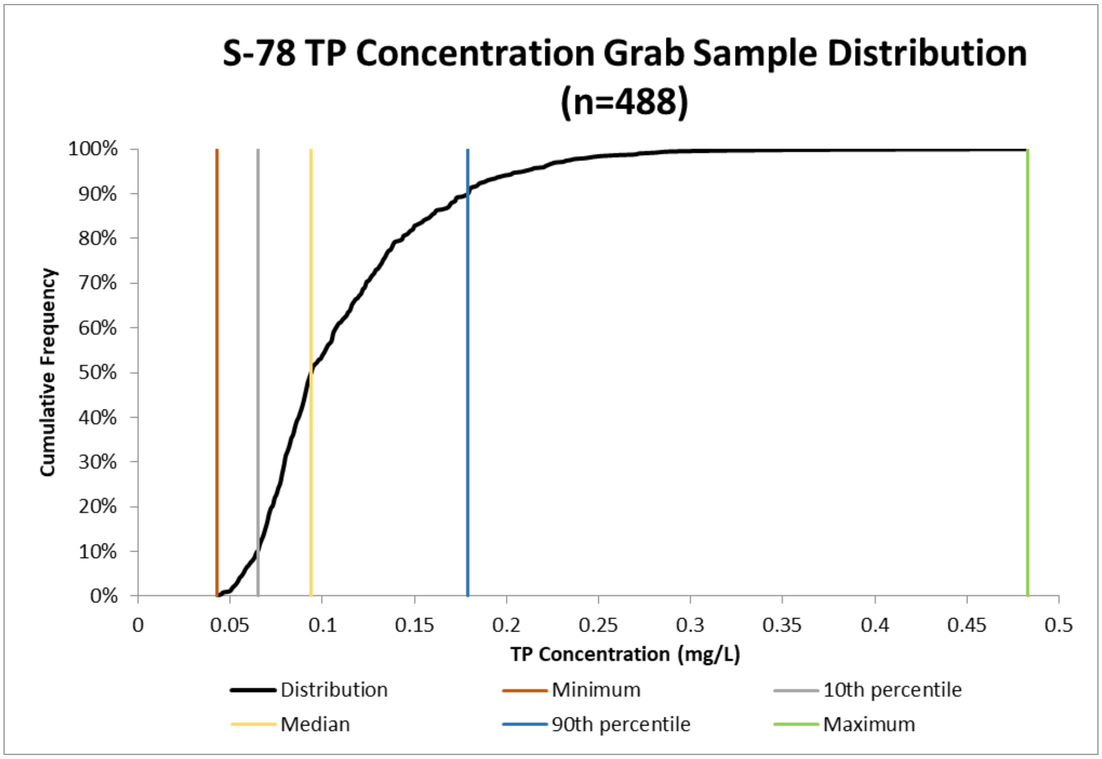


Figure 2-2. Cumulative Frequency Distribution for the TP Concentrations at S-78

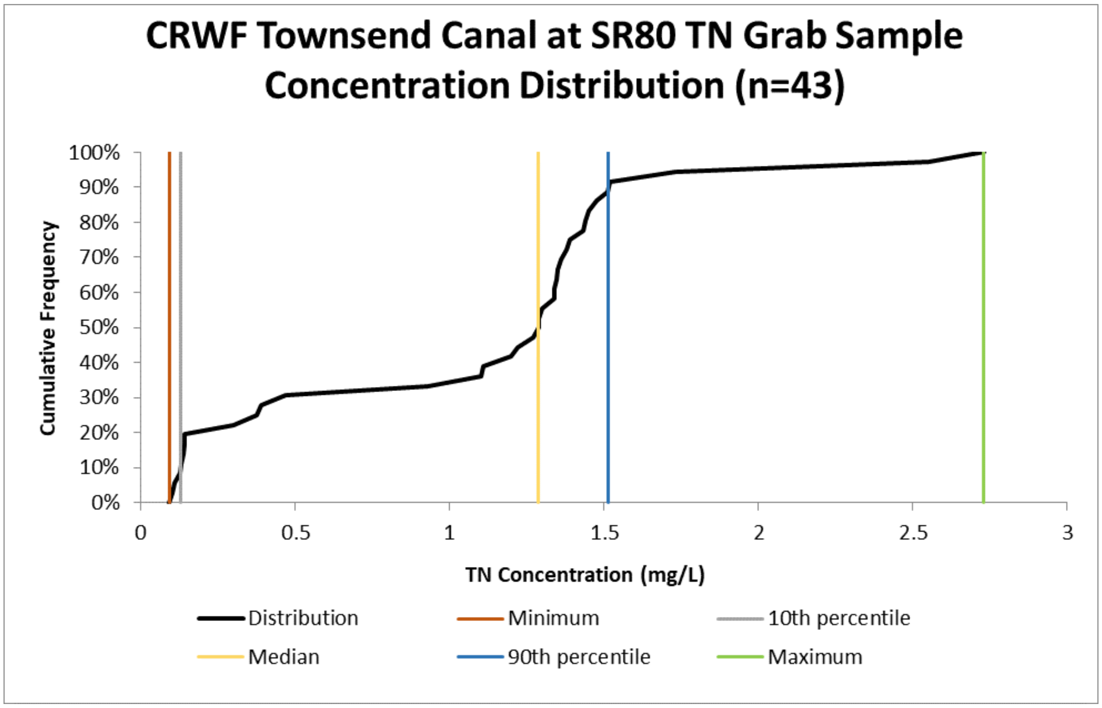


Figure 2-3. Cumulative Frequency Distribution for the TN Concentrations at Townsend Canal

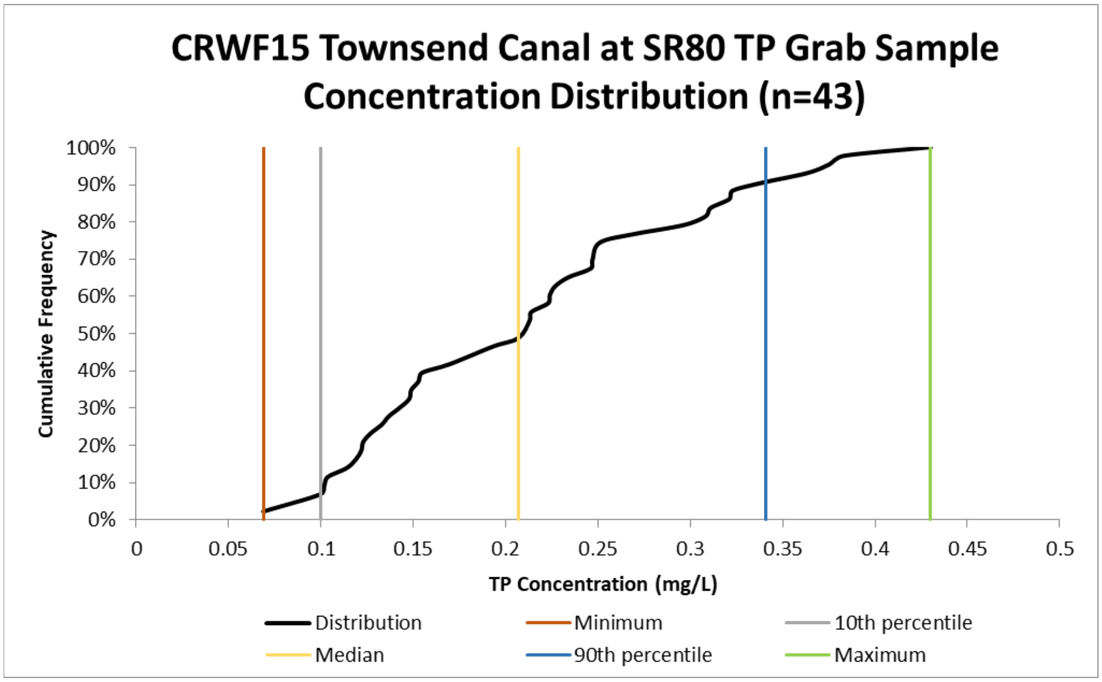


Figure 2-4. Cumulative Frequency Distribution for the TP Concentrations at Townsend Canal

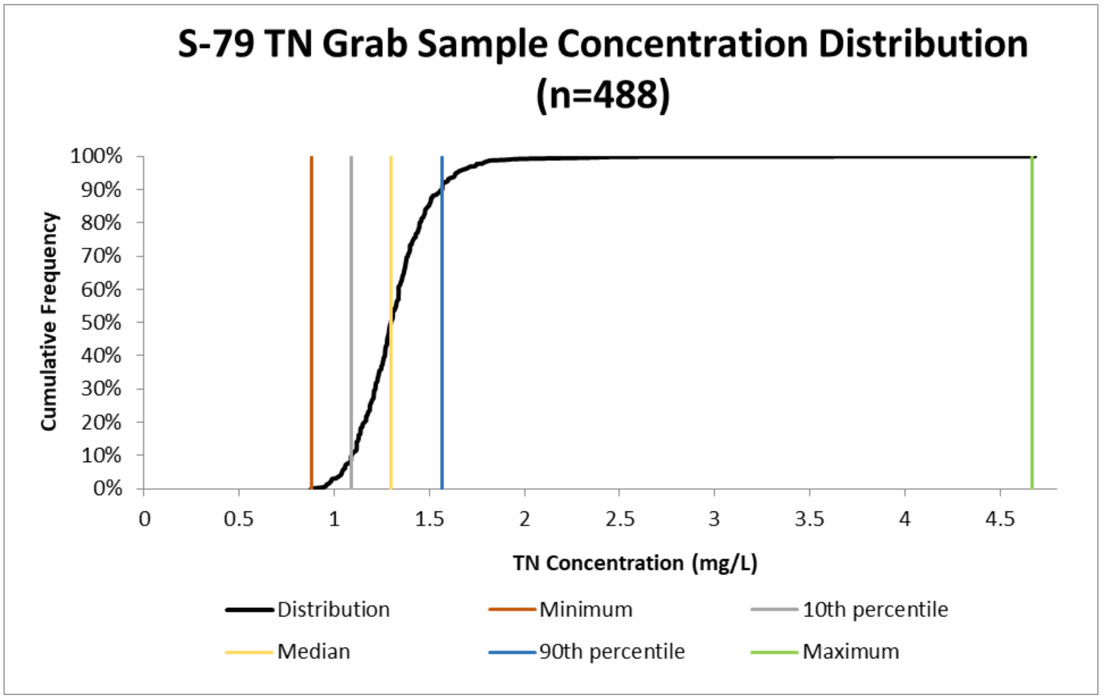


Figure 2-5. Cumulative Frequency Distribution for the TN Concentrations at S-79

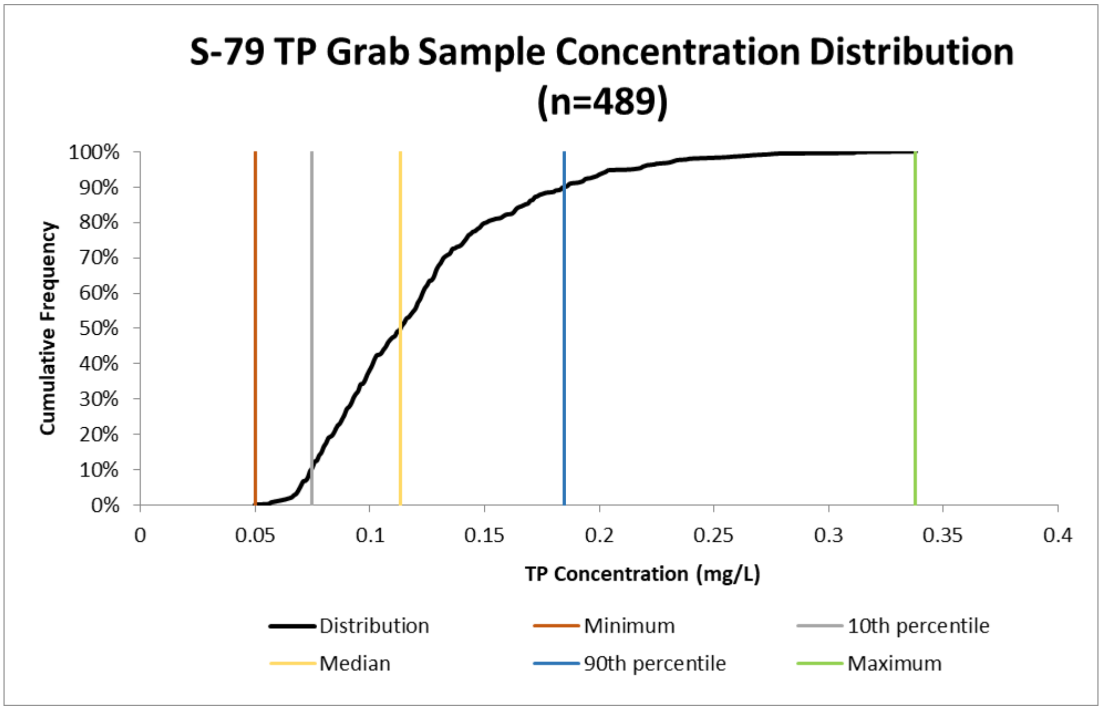


Figure 2-6. Cumulative Frequency Distribution for the TP Concentrations at S-79

These measured data were used to evaluate each technology's ability to treat the concentrations expected at the C-43 WBSR. Based on the data analysis, the average values from the upstream stations at S-78 and Townsend Canal were used to estimate the inflow concentrations to the treatment system. The average values of 1.5 mg/L (± 0.5 mg/L) of TN and 0.16 mg/L (± 0.05 mg/L) of TP were given to the vendors to assist in estimating a cost for their treatment system. Vendors were asked to estimate the cost to achieve an average TN concentration of 1.0 mg/L (± 0.5 mg/L) and an average TP concentration of 0.08 mg/L (± 0.05 mg/L), which correspond with the 10th percentile of measured data from the downstream station at S-79. The 10th percentile represents the lower 10% of the concentrations that were observed at S-79. **Figure 2-7** and **Figure 2-8** show the typical range of TN and TP values during the period of record used for this analysis. The 10th percentile values correspond to concentrations typically observed during the February through April. As the reservoir will generally be discharging during this time, this target was selected for the comparison to ensure that the water quality in the reservoir discharges would be at least the same as, if not better than, the ambient water quality concentrations in the river. These targets are based on the measured water quality in the river and were not intended to set criteria for the future water quality project. The information received from this request allowed for a direct comparison between the technologies.

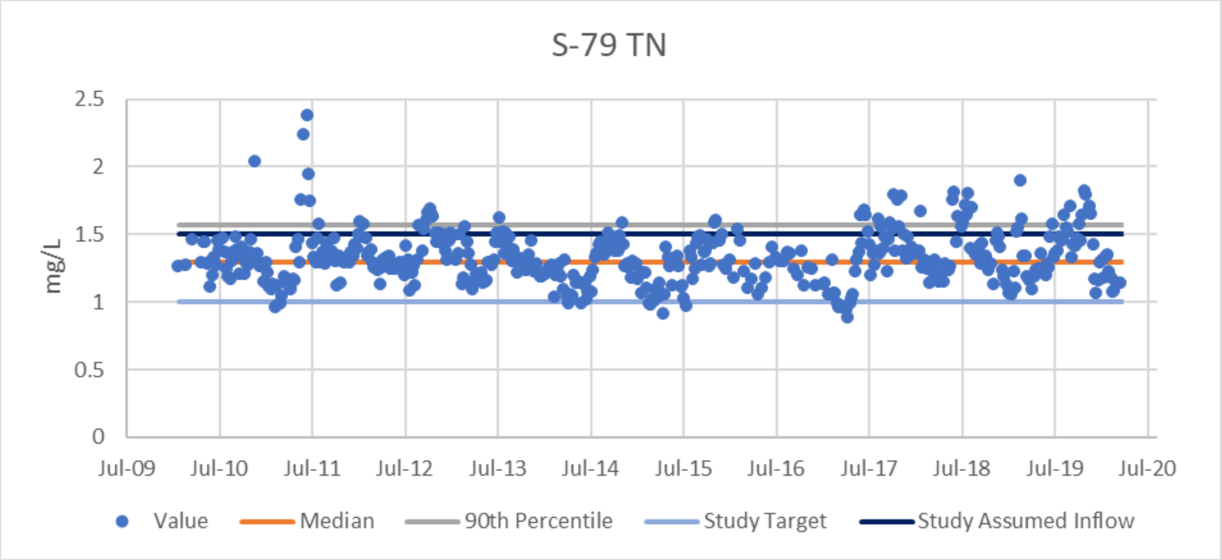


Figure 2-7. Time Series for TN Concentrations at S-79

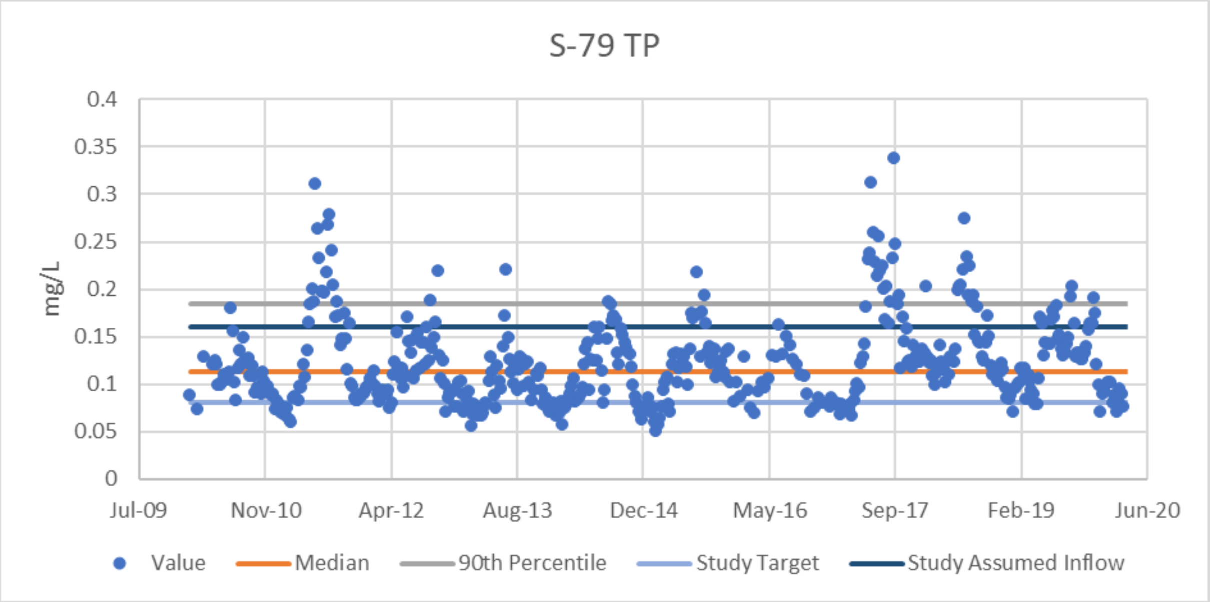


Figure 2-8. Time Series for TP Concentrations at S-79

2.2 Reservoir Constraints

When the Study was initiated in July 2019, J-Tech identified several constraints that would limit the flexibility of establishing a water quality treatment facility associated with the C-43 WBSR. These constraints include location in the landscape, available public lands, existing infrastructure surrounding the C-43 WBSR, and the limitations related to the federally authorized CERP project. These constraints are important to understand as the alternatives were being developed.

2.2.1 CERP – Infrastructure, Operation, and Construction

The C-43 WBSR is part of the congressionally authorized CERP project, with SFWMD as the local sponsor. SFWMD has moved forward with construction of the reservoir, which is scheduled for completion in 2023. Because the project is part of CERP, the selected water quality treatment component cannot affect the congressionally approved C-43 WBSR project purposes, infrastructure, construction schedule, or operation.

Effectively this means that the water quality treatment features may not impact or change any of the infrastructure that has already been designed as part of the C-43 WBSR including the earthen dams, pump stations, water control structures, ditches, conveyance canals, or other structures associated with the facility. Additionally, the implementation of a water quality treatment system cannot affect the operations of the reservoir or planned recreation at the site. A draft operational plan was developed as part of the Project Implementation Report in 2008 (**Appendix D**). As the operational plan for the reservoir is further developed, the operational intent of providing minimum flows to the Caloosahatchee Estuary and storing excess water to attenuate flows must remain intact (see **Section 2.2.2**). Lastly, the addition of the water quality feature must not affect the construction schedule of the reservoir that is currently underway. The Study evaluates the technologies based on the ability to implement the technology prior to completion of construction of the reservoir (see **Section 3.2**).

2.2.2 Water Balance

SFWMD has adopted a minimum flows and minimum water levels (MFL) rule for the Caloosahatchee River. An MFL can be defined as a flow rate or water level and is intended to identify the point at which further withdrawals or reductions in flow or level cause significant harm to the water resources or ecology of the resource. The MFL for the Caloosahatchee is the 30-day moving average flow of 457 cubic feet per second (cfs) at S-79 (the structure just downstream of the C-43 WBSR). An MFL exceedance occurs during a 365-day period when the 30-day moving average flow at S-79 is below 457 cfs. An MFL violation occurs when an MFL exceedance occurs more than once in a 5-year period. The flow, combined with tributary contributions below S-79, shall be sufficient to maintain a salinity gradient that prevents significant harm to mobile and immobile indicator species within the Caloosahatchee River. If significant harm occurs once the Caloosahatchee MFL recovery strategy is fully implemented and operational, the recovery strategy and MFL will be reviewed in accordance with Rule 40E-8.421, Florida Administrative Code. Mobile and immobile species shall be monitored as described in the recovery strategy (Chapter 40E-8.22, Florida Administrative Code).

Accordingly, the selection of a treatment technology for the C-43 WBSR must consider potential effects on the MFL that could result from construction and operation of the treatment system. Depending on the type of treatment system that is implemented, effects on the MFL, while anticipated to be small, could be either negative (water losses) or positive (water gains). Water losses from a treatment system could include evapotranspiration from open water or vegetated impoundments, seepage from unlined impoundments, or losses associated with residuals processing (passive or active drying or hauling of wet material). Water gains could primarily result from the accumulation of direct rainfall over the treatment facility infrastructure. Basin runoff will not directly enter the treatment facility and is not anticipated to affect the system capacity.

A water budget approach, which is an accounting of the various gains and losses, can be used to estimate the net effects of the various technologies on the MFL. It should be noted that some losses, such as seepage, may not ultimately have a measurable impact on the MFL. For example, if an unlined impoundment loses water through its banks or bottom area, the normal direction of groundwater flow is toward the Caloosahatchee River and the shallow groundwater flow is intercepted by the river channel; therefore, at least a portion of the water that appears to be lost from the treatment facility is not removed from the river system and may be partially treated before it returns to the system. On an annual basis, regional rainfall normally slightly exceeds or balances evapotranspiration (Zhao and Piccone, 2020). Further, the current land use of the property used for construction of these larger treatment systems must be considered. Most of the land would likely be in some form of agriculture use that would have existing irrigation demands and evapotranspiration losses that affect the local water budget. The net effect of converting these lands to a treatment system with a large wet footprint, such as a treatment wetland or HWTT, would likely not have a negative effect to flows measured at S-79, and direct rainfall captured is treated and not further enriched with nutrients as run off.

The impact of the water budget for the selected treatment technology on the MFL depends on the system boundary that is being considered. If the “system” includes the Caloosahatchee River between S-78 and S-79, the C-43 WBSR, and the selected treatment technology footprint, then the placement of the treatment facility upstream or downstream from the C-43 WBSR (to treat either C-43 WBSR inflows or outflows) does not change the net effect of the treatment technology on the ability to meet the MFL. To maximize the opportunity to meet the MFL, the selected technology would be constructed with the ability to be bypassed. As implied above, implementation of a treatment technology is not expected to reduce the ability to meet the MFL and may result in a net increase in flow.

2.3 Available Lands

The focus of the Study is to evaluate water quality treatment technologies that have the capacity to improve water quality leaving the C-43 WBSR. At the onset of the Study, it was determined that availability of public lands within the project vicinity should not direct the results of the Study, but rather the Study should proceed independent of available lands. J-Tech coordinated with the Working Group and has included relative land requirements in the attribute ranking evaluation described in **Section 3.3** to reflect that land acquisition would be required for some technologies, such as treatment wetlands, but not for others that offer a smaller footprint. Therefore, project lands have not been specifically identified for the Study and technologies have been evaluated independent of land availability and cost.

Although available lands and land costs are not included in the technology evaluation, it is important to recognize that a siting study will need to be included in the next phase of evaluation of the top recommended alternatives from this Study to select an alternative as the Water Quality Component (WQC) Plan for detailed design. SFWMD owns approximately 1,900 ac immediately north of the C-43 WBSR footprint and south of State Road 80 (see **Figure 2-7**). For the purpose of the conveyance assessment, J-Tech assumed that these lands could be used in part or in whole for the potential alternatives, while land for larger projects and infrastructure may require the purchase, or lease, of additional land. The land value for agricultural lands within the vicinity of the reservoir is estimated at $10,000 per acre while commercial lands are estimated up to $150,000 per ac (LandAndFarm.com, 2020).

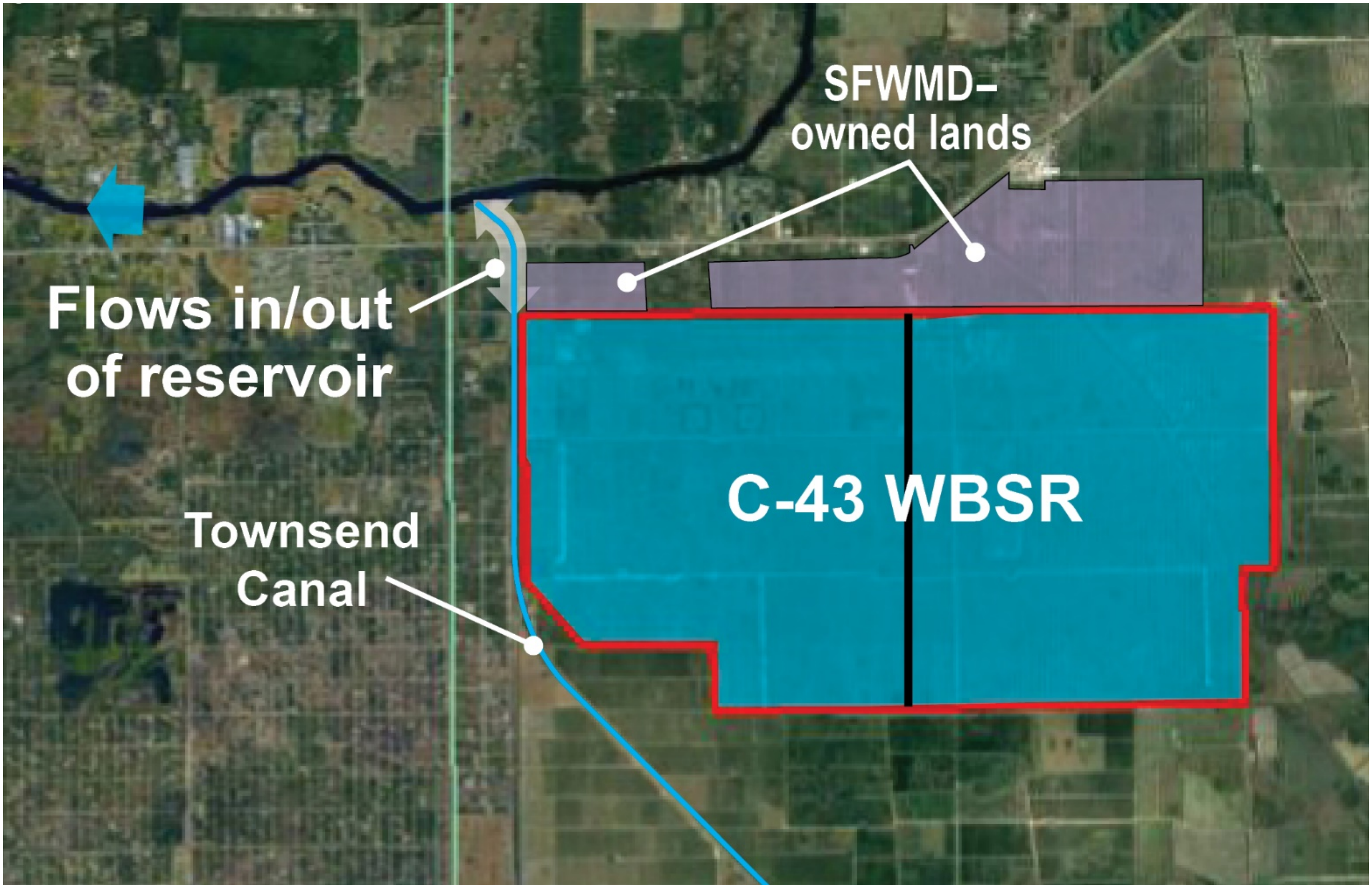


Figure 2-9. Caloosahatchee River (C-43) West Basin Storage Reservoir Available Lands Parcel Map

2.4 Conveyance and Connectivity

J-Tech evaluated how a water quality treatment component could be integrated with the C-43 WBSR to ensure that flow volumes could be delivered to a water quality treatment facility and eventually returned to the Townsend Canal or Caloosahatchee River. Additional evaluation of the future project location, water deliveries, and discharges will need to be performed for the final selected alternative and to evaluate the potential to maximize water quality improvements. However, for the purposes of this Study, J-Tech evaluated the need for additional conveyance features, pump stations, and access roads to confirm the feasibility of a treatment facility within and adjacent to the existing infrastructure, as closely as possible to the C-43 WBSR. The estimated costs associated with this infrastructure were used in the evaluation of the water quality treatment alternatives (see **Section 5.0**).

The Townsend Canal is an irrigation supply canal that runs north-south along the western side of the reservoir. The reservoir project is connected to Townsend Canal, and the S-470 pump station (1,500 cfs, currently under construction) will pump water into the reservoir. The reservoir project also consists of a perimeter canal system to direct reservoir discharges back to the Townsend Canal. As indicated earlier, direct structural connections to the reservoir structure and dam embankments are not consistent with the authorized CERP project and therefore not permitted.

Conveyance of water to a water quality treatment system, operational requirements of the system, and the final selected discharge location will need to be further evaluated and must consider multiple factors including available lands, topography, subsurface conditions, other legal users, etc. The project location will need to be selected in order to evaluate opportunities and constraints related to conveyance and connectivity. Depending on the water quality treatment system that is selected, different operational opportunities will need to be evaluated. Connection of the selected water quality component to the reservoir and discharge location will be dependent on feasibility of new infrastructure requirements in relation to existing features of the reservoir and other existing land use. These details will be further evaluated in the siting and design phase of the project to optimize water quality improvements. In addition, there is an opportunity to add an in-reservoir water quality treatment component to manage water quality during storage.

In the next phase of evaluation of the top recommended alternatives from this Study to select an alternative as the WQC Plan, various flow configurations will be analyzed so that the most effective delivery of treated water to the river can occur while maintaining water availability from the canal for permitted users. This may include separating the treated water flows from the Townsend Canal, as the canal water is multipurpose and used for agricultural water supply in the dry season. The WQC Plan and detailed design must also ensure that the overall intent of sending treated water to the Caloosahatchee River and Estuary is maintained without interfering with the designated purpose or construction schedule of the reservoir.

2.5 Pre-storage , Post-storage, and In-reservoir Treatment

The J-Tech team was tasked with evaluating three different forms of treatment: pre-storage, post-storage, and in-reservoir. Pre-storage treatment includes treating the water from the Townsend Canal or Caloosahatchee River prior to being stored within the reservoir. The advantage of this option is that pre-treatment will help to reduce nutrient concentrations, which would reduce the potential for algae blooms within the reservoir during the summer months. In-reservoir treatment includes technologies that will reduce nutrients and suspended solids in the water that is stored within the reservoir. While there are advantages to this method of treatment, the operations of the reservoir cannot be affected by the selected alternative and, therefore, structural considerations excluded some technologies. Additionally, there is a general understanding that as the water is stored, particulates and nutrients will settle out of the water column providing some amount of water quality improvement; however, that cannot be quantified at this early stage of the evaluation. Post-storage treatment would treat water flows leaving the reservoir and prior to discharge back to the Caloosahatchee River. This scenario provides the most control of the water quality being returned as the system could be closely monitored at the point of discharge.

Table 2-1 summarizes which of the 10 technologies can be used either pre-/post-storage or in-reservoir for treatment. The potential location of each technology and the connection to the reservoir were considered when developing the alternatives evaluated in this Study.

Table 2-1. List of Technology Connectivity with the C-43 WBSR

Technology	Treatment Location		
	Pre-Storage	In-Reservoir	Post-Storage
Treatment Wetlands	X	-	X
Sand Filtration	X	-	X
Air Diffusion System	-	X	-
MPC-Buoy	-	X	-
Alum Treatment	X	X	X
HWTT	X	-	X
ElectroCoagulation	X	-	X
AquaLutions®™	X	-	X
Bold & Gold®	X	-	X
NutriGone™	X	-	X

3.0 Alternative Formulation

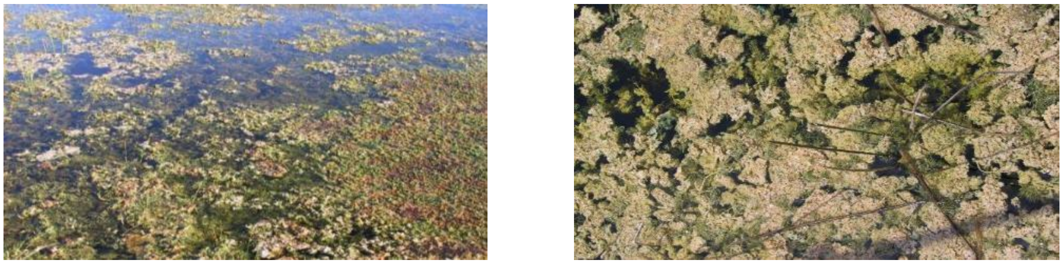
3.1 Highest Ranking Technologies (10)

Additional information about the highest ranking (10) technologies was developed by J-Tech and gathered from the vendors. J-Tech sent an email request to the vendors to collect additional information about technology sizing and performance for a system that treats flows within a range of 300-600 cfs, reducing TN from 1.5 mg/L to 1.0 mg/L, TP from 0.16 mg/L to 0.08 mg/L, and TSS from 20 mg/L to 10 mg/L (see **Section 2.1** for additional details on water quality). The information received from this request allowed a direct comparison between the technologies. A summary of the additional technology information is included in the sections below, and the detailed responses from the vendors are attached in **Appendix E**.

3.1.1 Treatment Wetlands

Treatment wetlands have been used throughout Florida to reduce nutrient concentrations in reclaimed water, industrial wastewater, stormwater runoff, and surface water. Treatment wetland projects are sometimes referred to as marsh flow-ways, filter marshes, or stormwater treatment areas (STAs). In south Florida, treatment wetland projects have most often been employed to reduce the concentration of phosphorus in agricultural runoff (such as the Everglades Agricultural Area [EAA] STAs) but have also been implemented more generally to reduce nitrogen, phosphorus, TSS, and algal biomass. In general, treatment wetland plant communities (**Figure 3-1**) have been installed in a hierarchical manner, based on inflow nutrient concentrations, beginning with floating aquatic vegetation (FAV) at the highest inflow concentrations and progressing through EAV, submerged aquatic vegetation (SAV), and an attached algal community, called periphyton, for the lowest concentrations as inflow concentrations are reduced by each successive treatment compartment.

Floating Aquatic Vegetation (FAV) Emergent Aquatic Vegetation (EAV)



Submerged Aquatic Vegetation (SAV) Periphyton

Figure 3-1. Treatment Wetland Vegetation Community Types

As part of earlier efforts to select treatment technologies for the C-43 basin, Wetland Solutions, Inc. (WSI) (2012) analyzed data from a variety of Florida treatment wetlands and summarized key findings and performance drivers. The primary objective of that effort was to evaluate whether there were correlations between lower nutrient concentrations and specific vegetation or soil types. There is considerable evidence that TP is most effectively removed by SAV-dominated wetlands at intermediate TP concentrations in the range between 50 and 300 parts per billion (ppb; Walker, 2010). Emergent wetlands were found to likely be more effective for TP removal at higher inlet concentrations (greater than 300 ppb) and periphyton-dominated wetlands were more effective than SAV systems at lower inlet TP concentrations (less than 50 ppb).

Of particular importance for the C-43 basin, where nitrogen is the primary nutrient of concern, the lowest TN concentrations occurred at wetland sites with EAV and sandy soils and in open water systems over sandy soils (the C-43 Storage Reservoir Test Cells). The C-43 Water Quality Treatment and Testing Project – Phase I Mesocosm Study confirmed that EAV wetlands on sandy soils could achieve low TN outlet concentrations with C-43 inflow water and that similar performance was achievable using SAV over sandy soils (J-Tech and WSI, 2019).

The lowest TSS concentration typically attained by Florida treatment wetlands was about 1 mg/L. For TSS reduction, periphyton and EAV were the most effective plant communities, followed by SAV, with open water and FAV least favorable. There was essentially no observed effect of substrate type on TSS reduction effectiveness (WSI, 2012). Details for the wetland treatment sites summarized by WSI (2012) are provided in **Appendix A**, Section 3.2.

3.1.1.1 Facility Details and Project Costs

As further described in **Section 4.2.1**, it has been estimated that a 5,000-ac treatment wetland will be required to meet the nutrient reduction goals, set for the purpose of this Study and technology comparison, at an average design flow of 457 cfs. A system of this scale was estimated to cost $121.4 million for construction and about $1.1 million to operate and monitor annually. The net present value (NPV) cost was estimated to be $136 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimate. Combining the estimated performance with the NPV cost yields cost-effectiveness values of approximately $20.69 per pound of TN, $128.03 per pound of TP, and $1.02 per pound of TSS.

3.1.2 Sand Filtration

Sand filters have been used for treatment of wastewater beginning in the 1800s. Sand filters are multi-chamber structures, composed of a sediment forebay, a sand bed, and typically an underdrain collection system. The mechanisms for pollution removal are dominated by filtration with gravitational settling and adsorption providing additional treatment. Microbial communities in the upper depths of a sand filter provide additional assimilation of nitrogen and phosphorus beyond simply physical filtration. Reported reductions for sand filters are 48% for TP, 51% for TN, and 84% for TSS. Treatment capacity can be affected with continuous operation requiring a drying period. One aspect of a sand filter that may be favorable to the C-43 WBSR application is the potential for water treatment during the discharge from the reservoir and then allowing it to remain dry for storage and filling periods (Bays et al., 2019).

Case studies for large-scale sand filters include water treatment of phosphate mines in Florida. One case study located in Hardee County treated phosphorus mine water for 2–3 years. The sand filter was operated following constructed wetland treatment and received up to 2 MGD. The demonstration system was approximately 4 ac in size (Bays et al., 2019). **Figure 3-2** shows the phosphorus mine wastewater sand filter treatment system. Inflow TP concentrations ranged from 0.14 mg/L to 1.1 mg/L, averaging 0.45 mg/L. The outflow concentrations averaged 0.23 mg/L with an average TP reduction of 48%. Inflow turbidity averaged 30 nephelometric turbidity units (NTU) and outflow turbidity averaged 4.5 NTU. The average reduction was 85% for turbidity. It was determined that a 2-ac sand filter is needed to treat 1 MGD (Bays et al., 2019).

Based on monitoring of sand filter capacity, replacement of the top layer every 3 to 5 years is recommended. Maintenance of the top layer requires periodic scarification to overcome biological clogging of the pore spaces. Sand removed from the system requires collection and handling, which may include hauling and disposal (Bays et al., 2019). Sand filtration is a passive treatment of TSS and TP that does not require any external energy for the treatment process, other than power and pumping cost to convey water to and from a site (Bays et al., 2019).

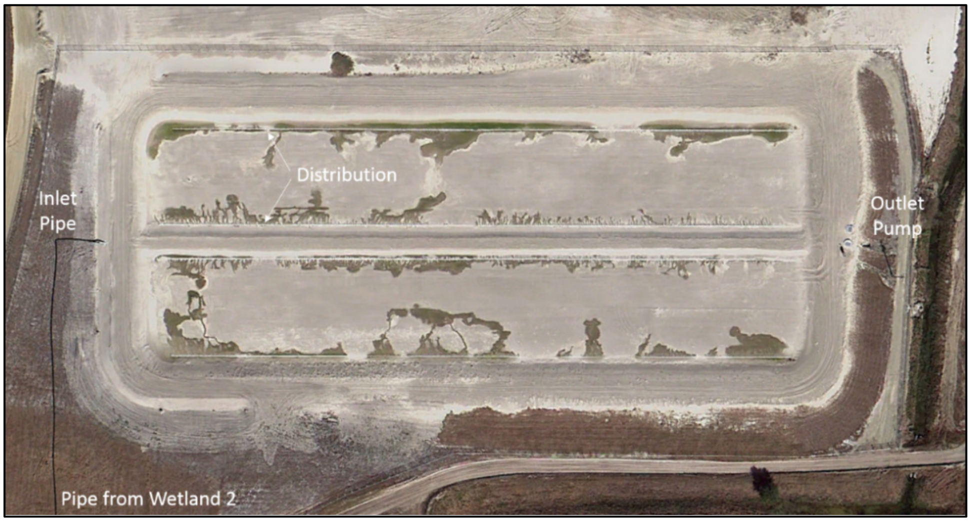


Figure 3-2. Sand Filters for Treatment of Phosphorus Mine Wastewater (Bays et al., 2019)

3.1.2.1 Facility Details and Project Costs

A 1,000-ac sand filter was estimated to be required to meet the nutrient reduction goals set for this Study at an average design flow of 457 cfs. A system of this scale was estimated to cost $210 million for construction and about $2.7 million to operate and monitor annually. The NPV cost was estimated to be $247 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Combining the estimated performance with the NPV cost yields cost-effectiveness values of approximately $37.19 per pound of TN, $232.42 per pound of TP, and $1.86 per pound of TSS.

3.1.3 Air Diffusion System

Air Diffusion Systems' (ADS) technology includes a fine bubble aeration system designed for domestic and industrial installations. Information from ADS states that they have a clog-free design that requires minimal power input to provide aeration within the reservoir with little maintenance required. The fine bubble aerators create mixing and oxygen diffusion within the reservoir (ADS, 2020a). ADS case studies include applications in Havana, Florida and proposals for work in the St. Lucie River, Florida. Large reservoir system studies include Wisconsin, Massachusetts, Delaware, Maine, Illinois, and Colorado, with international work in India and Samoa.

Performance data provided by ADS indicate a 90% biochemical oxygen demand (BOD) reduction and 50% to 75% reduction of TN and TP. Aeration is a well-established technology with a long history of application treating reservoirs at many scales. **Figure 3-3** shows the proposed layout to treat the C-43 WBSR.

3.1.3.1 Facility Details and Project Costs

ADS technology is best designed for in-reservoir treatment and does not produce residuals. System lifespan is estimated at 20 years, and some systems have been fully functioning after 40 years of operation. ADS also reported successfully retrofitting legacy systems to improve performance and reduce electricity costs with minimal capital re-investment, implying future optimizations for the C-43 WBSR. Maintenance includes checks of compressors, air leak testing of supply piping, and visual inspection of disk modules (ADS, 2020b). System operation is automated, and there are also monthly onsite maintenance inspections and water quality sampling to monitor system performance.

ADS proposed a system (**Appendix E**) incorporating the use of 128 disk modules for fine bubble aeration of the C-43 WBSR, which would mix approximately 3,963 MGD with a turnover of approximately 15 days (ADS, 2020b). The 128 disks are paired with eight 30-horsepower (hp) compressors (ADS, 2020b). Assuming the 30-hp compressors are working 24-hours a day, the yearly cost of running eight 30-hp compressors would be approximately $120,000 a year for electricity with a motor efficiency of 95% and a cost of $0.10 per kilowatt-hour (kWh). Cost of an aeration system designed for the C-43 WBSR is approximately $6.75 million including aeration disks, feeder tubing, compressors and all other hardware, delivery, installation, and 5 years of O&M (ADS, 2020b). It will cost about $124,000 to operate and monitor annually. The NPV cost was estimated to be $8.44 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. The ADS proposal does not provide a quantitative projection of TP or TSS reduction. ADS estimated a reduction in TN consistent with the requested performance criterion, assuming all nitrogen present is in the form of ammonia-nitrogen that is nitrified within the aerated water column. This performance projection may be optimistic given the predominance of organic nitrogen.

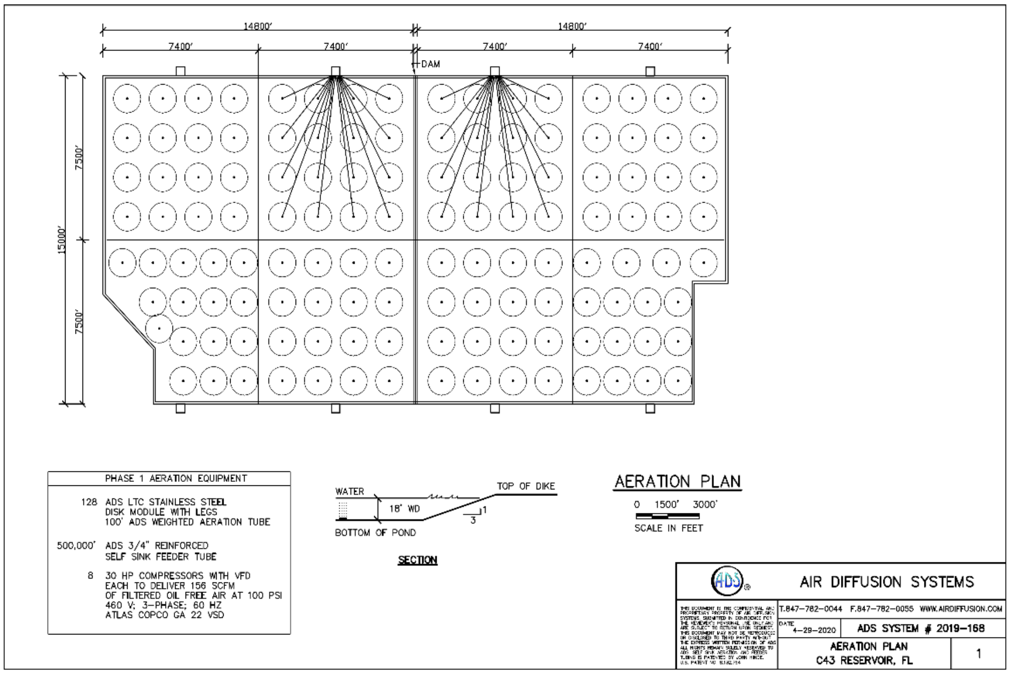


Figure 3-3. ADS Proposed System to Treat C-43 WBSR

3.1.4 MPC-Buoy

The MPC-Buoy is a solar-powered floating system that emits various ultrasonic frequencies to treat algae. The MPC-Buoy uses a three-step process to control algae. The first step involves monitoring of water quality by collecting water quality parameters every 10 minutes. Monitored parameters include chlorophyll *a* (green algae), phycocyanin (blue-green algae), pH, turbidity, dissolved oxygen, and temperature. The data are delivered to a web-based software that predicts algal blooms based on water quality parameters and maps algal distribution in large waterbodies. Based on the prediction, ultrasonic transmitters are activated to create a sound layer at the water's surface to prevent the algae from receiving sunlight (LG Sonic, 2020a). **Figure 3-4** provides a visual representation of the MPC-Buoy system. There are no documented case studies in Florida. However, a detailed study funded by DEP and administered through Florida Gulf Coast University began in 2020 and is expected to provide a full characterization of the benefits and effects of the technology on the development of algal blooms. Case studies include a drinking water reservoir in Dominican Republic that treated a 2.7-square-mile reservoir to reduce approximately 87% chlorophyll *a*. The MPC-Buoy has been used in New Jersey to reduce algae concentrations in a raw water reservoir (LG Sonic, 2020b).

Material provided by the vendor indicated that the MPC-Buoy suppresses algal growth, yielding a reduction of up 90% of algae with the use of specific ultrasonic sound waves and reduces TSS, BOD, and nutrients in the reservoir. MPC-Buoy is capable of treating areas up to 1,600 feet in diameter (approximately 46 ac) (LG Sonic, 2020a). This technology does not create additional residuals, which would reduce TSS in the reservoir discharge. Prior studies (e.g., Lürling and Tolman, 2014) have indicated that commercial ultrasonic treatment was lethal to zooplankton (Daphnia magna) but studies described by the vendor indicate that the technology is safe for wildlife (LG Sonic, 2018; LG Sonic, 2020b).

3.1.4.1 Facility Details and Project Costs

LG Sonic prepared a proposal (included in **Appendix E**) that proposes an array of 200 MPC-Buoys using solar-powered ultrasonic treatments to suppress phytoplankton and reduce algal TSS (LG Sonic, 2020c). MPC-Buoy technology is for in-reservoir treatment and does not produce additional residuals. The MPC-Buoy system is data-driven, using on-board real-time water quality monitoring to optimize the ultrasound treatment among all network-connected MPC-Buoys based on the water conditions. The vendor proposes that 40 MPC-Buoys be "Pro" models with the onboard water quality monitoring equipment, and the remaining 160 MPC-Buoys be "Lite" models without onboard water quality monitoring. The energy required to power each buoy is approximately 5 to 20 watts, which is supplied by the onboard solar panels. Technology includes three 195-watt peak solar panels and a 40-amp battery to provide power year-round, with an energy-saving program applied during periods of low sun radiation. Cost information provided by the vendor estimates a capital cost of $10.4 million to treat the entire C-43 WBSR (LG Sonic, 2020a). Annual O&M cost for the 200 MPC-Buoys is $441,500, plus up to $540,400 for annual replacement parts (estimated maximum). Water quality data collection at the buoys does not reflect conditions at the reservoir input and output, and additional monitoring may be needed to assess success in meeting treatment objectives at an approximate cost of $50,000 annually (LG Sonic, 2020c). The NPV cost was estimated to be $23.9 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. The proposal did not provide a specific projection that the system would meet the treatment objectives for phosphorus and nitrogen but because algal dry weight composition of nitrogen is approximately 1-7% nitrogen (Kadlec and Knight, 1996; Hampel, 2013) and 0.5-3% phosphorus (DeLaune and Reddy 2008), reductions in each would be expected through reduction in algal biomass.

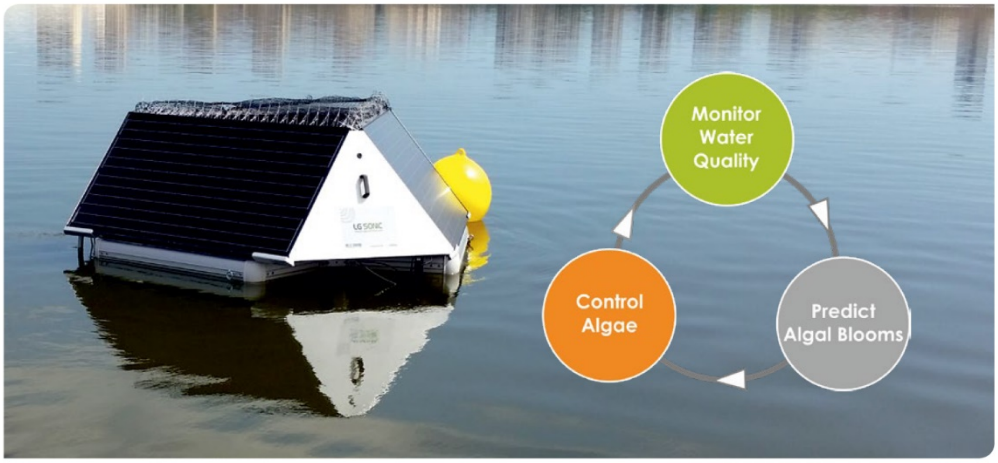


Figure 3-4. MPC-Buoy Technology and Three-Step Process (LG Sonic, 2020a)

3.1.5 Alum Treatment

Alum is a cationic flocculant (floc) used generally for coagulation treatment, especially in wastewater treatment plants, with applications in Florida for surface water treatment implemented since the 1980s (Harper, 2015). The technology has been investigated by SFWMD in Taylor Creek with the objective of confirming suitability for use in Class III freshwater systems. Watershed Technologies, LLC implemented the system (DEP, 2020). Alum addition is a process that has been used in many applications. Applications typically fall under one of three types of applications: sediment separation, injection into the inflow, and in-reservoir treatment.

One example of sediment separation is the Nutrient Reduction Facility, located in Lake County, which is a large-scale sediment separation facility that applies aluminum compounds for nutrient reduction. The process pumps water from Lake Apopka into the facility where alum is injected into the flow to bind with pollutants. The flow is then distributed into settling ponds where floc settles out of the flow. The clean water is collected at the opposite end of the settling ponds where it is returned to the lake. The Nutrient Reduction Facility has demonstrated the ability to treat up to 250 cfs while removing nearly two-thirds of the TP. The site requires extensive dewatering of the floc, which requires a large centrifuge to prepare the floc for transport off site. The estimated cost of the project was $7.3 million with an annual operating budget averaging approximately $1.5 million with alum as the primary expense (Florida Lake Management Society, 2010).

Other configurations of alum treatment systems inject alum into the flow based on a flow-proportioned basis. This ensures that the same dose of alum is added regardless of the discharge rate. A variable-speed chemical metering pump is used along with a flow meter to administer the dose of alum. Injection of alum is carefully monitored to ensure toxic concentrations of aluminum do not accumulate in the reservoir. Cost varies depending on the size of the metering pump and amount of alum needed for treatment (Bottcher et al., 2009).

Alum treatment is also achieved through in-reservoir application. This is usually preferred when a major source of phosphorus is from sediment phosphorus release within the reservoir. The longevity of in-reservoir treatment is important because legacy phosphorus release in the reservoir can lead to increased algal blooms. Longevity of phosphorus in the sediment is based on many water parameters, but the average for deeper, stratified lakes, which resemble the characteristics of the C-43 WBSR, is approximately 21 years (Huser et al., 2016). Since 2000, Florida lakes treated with alum for phosphorus concentration reduction include Anderson Lake, Gatlin Lake, and Tyler Lake (Huser et al., 2016). For the C-43 WBSR, given its large size, the primary objective of in-line treatment, for the purpose of this Study, is to provide a management tool to control algal growth within the reservoir. Alum treatment has been shown to reduce algal density and cyanobacteria blooms significantly with annual applications (e.g., Wagner et al., 2017).

3.1.5.1 Offline Alum Treatment System

Alum treatment, offline, is similar to the HWTT approach detailed below. Alum is a well-established chemical treatment approach shown to achieve more than 50% reductions of TP, TN, and TSS in Florida's surface waters (e.g., Harper, 2015). The footprint of the alum treatment trains would require approximately 50 ac, consisting of 28 ac of settling ponds and approximately 20 ac for mixing, centrifugation, chemical storage facilities, and related administrative and access infrastructure. Water conveyed by pump to the flocculation tanks and secondary clarifiers would be dosed with alum and discharged to the settling basins. Residuals would be pumped from settling ponds to centrifuge for dewatering and stored in above-ground drying basins.

The initial capital costs are approximately $25.1 million. Estimated annual O&M costs are approximately $4.34 million, and chemicals (mostly alum) represent the majority of that total. The NPV cost was estimated to be $84.1 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Cost-effectiveness estimates are approximately $12.67 per pound of TN, $79.17 per pound of TP, and $0.63 per pound TSS.

3.1.5.2 In-reservoir Alum Treatment System

In-reservoir alum treatment is a method that could be combined with other methods. In-reservoir treatment is usually preferred when a major source of phosphorus is from sediment phosphorus release within the reservoir. For the C-43 WBSR, alum could be injected directly into the formed suction intake of the inflow pump station (S-470) and mixing of the alum would occur with the discharge of the pump station into the reservoir. However, without rapid mix and flocculation basins, the mixing efficiency will be reduced by approximately 50%, and the alum dosing would be doubled relative to the offline system to achieve the same amount of nutrient removal. Furthermore, the amount of sludge produced will also double. It is assumed that the residuals would be captured and retained in the reservoir bottom without immediate need for removal. Given the estimated rate of sludge production for the offline alum treatment system of 0.12 MGD at 4% solids, and assuming that both a doubling of the sludge production rate as well as a 90-day reservoir filling duration, the annual deposition of alum within Cell 1 of the reservoir is on the order of 0.02 feet/year. At this rate, the time required to accumulate 1 foot of alum sludge over the reservoir bottom would be 50 years. For the purpose of this conceptual assessment, the reservoir will function as a settling basin for 50 years depending on inflow water quality.

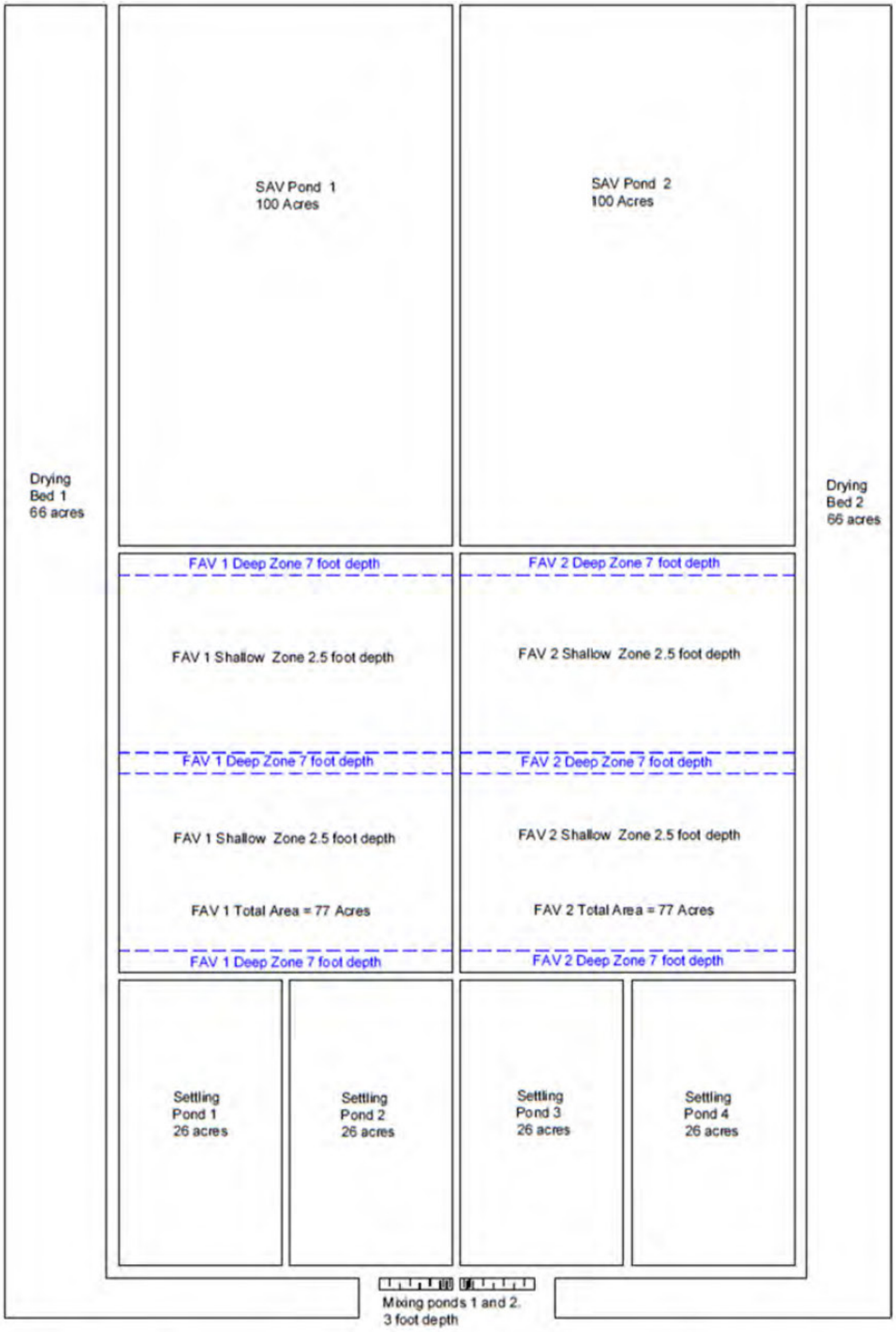
The capital cost for an alum storage and feed system including new electrical building, as well as non-construction costs (e.g., permitting, engineering, services during construction, and startup) is estimated to be $2.19 million. Annual O&M and monitoring costs are estimated to be $695,000. The NPV cost was estimated to be $11.63 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. This system is intended to provide a control on algal production in the reservoir. Twenty-year unit cost-effectiveness estimates for treating an average flow of 457 cfs during a reservoir filling period (assumed to be 90 days) are approximately $5.25 per pound of TN, $32.84 per pound of TP, and $0.26 per pound TSS.

3.1.6 Hybrid Wetland Treatment Technology

HWTT includes design, construction, and operation of a facility that combines wetland and chemical treatment approaches to reduce phosphorus (DeBusk, 2009). The treatment uses chemical coagulants added to the front end of a wetland treatment system, containing one or more deep-water zones to capture the resulting floc material. The passive treatment of the wetlands partnered with the active coagulant sorption results in the reduction of phosphorus. The coagulant used for the HWTT is alum (Watershed Technologies, 2014). Other forms of alum (e.g., polyaluminum chloride and sodium aluminate) were used in previous studies (Watershed Technologies, 2014). Additional features of the technology include pumped recirculation of alum floc or reusing floc to extend the functional life of the coagulant for reduction of phosphorus in the water column or to minimize phosphorus remobilization from sediment. The reuse of the dried, stable floc helps reduce the residual management efforts. Case studies of the technology have occurred at multiple locations in the Northern Everglades in basins S-65D, S-65E, S-154, and S-191. DeBusk (2009) states the HWTT is effective at removing phosphorus and improving water quality at each system. A key recommendation was to use FAV and SAV to reduce the nitrogen concentration. No specific flow rates were reported. Watershed Technologies (2014) characterized TN removal as effective at multiple sites, showing a range of TN reductions of 18% to 57%, depending upon inflow concentration, with systems achieving outflow concentrations ranging from 1.09 mg/L to 2.81 mg/L. The use of SAV was found to improve nitrogen removal.

3.1.6.1 Facility Details and Project Costs

An HWTT facility combines wetland and chemical treatments to achieve more than 50% reductions of TP, TN, and TSS. The combined footprint of two identical HWTT treatment trains requires approximately 668 ac, of which 198 ac should not be routinely flooded (the 132-ac drying beds and 66-ac supporting facilities). **Figure 3-5** provides a conceptual plan of the HWTT system. Residuals will be pumped from settling ponds to the drying beds. Residual management will be minimal given proper design, and opportunistically deposited within FAV cells during routine maintenance of ponds or within the reservoir if it sufficiently dries. This conceptual residual management can be considered given the continuing strong bond of alum with phosphate over time (Harper 2015)., Energy is needed to power the alum feed pump and other pumping requirements, but the total consumption for utilities and fuel is less than 1% of the operations budget. Alum addition, the major operating cost, is highly dependent on the concentration and flow into the HWTT (DeBusk, 2009). The vendor estimates initial capital costs of approximately $21.2 million (excluding contingency, engineering design, and post-construction surveys/certification). Estimated annual O&M costs are approximately $7.2 million, and chemicals (mostly alum) represent 92% of that total. The NPV cost was estimated to be $119 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Cost-effectiveness estimates are approximately $18.11 per pound of TN, $100.83 per pound of TP, and $0.90 per pound of TSS.



Component	Number of Ponds	Pond Area (each)	Pond Running Depth	Design Flow (each)	HRT at Design Flow
Mixing Area	2	0.5 acre	3 feet	180 cfs	6 minutes
Settling Pond	4	26 acre	12 feet	180 cfs	15 hours
FAV Pond	2	77 acre	2.5 & 7 feet	300 cfs	10 hours
SAV Pond	2	100 acre	2.5 feet	300 cfs	10 hours
Drying Bed	2	66 acre	4 feet		

Figure 3-5. Offline HWTT Process Flow Diagram Depicting Primary HWTT Facility Infrastructure

3.1.7 ElectroCoagulation

ElectroCoagulation removes contaminants from the water by passing an electrical current through the water between an anode and cathode plate. The plates release charged metal ions that neutralize suspended particles and create dense flocs that settle rapidly. ElectroCoagulation is capable of removing multiple contaminants, hardness, color, heavy metals, organics, suspended and colloidal solids, fats, oil, bacteria, viruses, and more. Water is passed between metal plates that transmit the electricity through the water before the coagulated contaminants are filtered and removed. In Florida, ElectroCoagulation has been evaluated at Lake Jesup for the removal of TP and proposed for the St. Lucie River and Lake Okeechobee (Gerber Pumps International, Inc., 2016). There are many industrial applications nationwide.

The Lake Jesup case study report showed a nutrient removal performance of approximately 64% to 91% for TN and 87% to 99% TP (Gerber Pumps International, Inc., 2016). Algae removal has been achieved with ElectroCoagulation at a rate of approximately 99% (Gerber Pumps International, Inc., 2020a). Residuals include TSS removed from the treated water with a 90% to 99% removal. The vendor states that the residuals are produced in a dry powder form, which simplifies removal and disposal (Gerber Pumps International, Inc., 2020a). Additionally, ElectroCoagulation produces approximately 83% less solids than alum treatment (Dole, 2019). The vendor suggests the residuals can be used for fertilizer or soil amendments (Gerber Pumps International, Inc., 2020a). Other researchers have found that ElectroCoagulation sludge can be incorporated into building block materials, providing suitable structural strength (Adyel et al., 2013). As with all coagulation technologies, residual disposal is a continuing concern. A favorable aspect of ElectroCoagulation application on this point is the relatively fewer residuals produced compared to alum treatment (Kabdasli et al., 2012).

3.1.7.1 Facility Details and Project Costs

ElectroCoagulation technology uses direct current to combine suspended particles and create dense flocs that settle rapidly. Removal of TP, TN, and TSS is generally greater than 90% with no added chemicals and no waste brine stream. Additionally, the method removes organics, color, pesticides, and many other contaminants. The facility footprint totals approximately 17 ac, spread among several units. The proposed ElectroCoagulation system will provide treatment to 53% of the average 457 cfs flow and blend the treated water with the balance of the of the untreated water to meet the target removal rates and discharge limits. The total capital cost is $148.4 million, which includes the cost of the 36 units, metal building, clarifier, thickeners and dewatering, electrical components, and site work and plumbing. The annual O&M cost is $3.16 million, which is mostly for power and for sacrificial plate replacement (Gerber Pumps International, Inc., 2020b). The NPV cost was estimated to be $191.4 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Cost-effectiveness estimates for treating an average flow of 457 cfs are approximately $28.81 per pound of TN, $180.08 per pound of TP, and $1.44 per pound TSS. It is noted for this Study that these costs are based on the initial submittal by the vendor. At the voluntary suggestion of the vendor, a subsequent round of tests by the vendor on water from Lake Jesup confirmed similar treatment performance with reduced residence times in the EC unit, which yielded a lower estimated number of EC units and associated costs by the vendor. The reduced capital and O&M costs yielded a 20-year NPV of $167.1 million. The unit costs were reduced proportionately but were insufficient to change the overall EC ranking in sixth place. This additional vendor information is provided in Appendix F.

3.1.8 AquaLutions®™

AquaLutions®™ is a water quality restoration technology designed to harvest algae and cyanobacteria from the water column at a commercial scale using a modified dissolved air flotation (DAF) system. By removing the algae and cyanobacteria, the nutrients and pollutants bound to the algae are also effectively and efficiently removed from the water column. DAF uses dissolved air bubbles to float the algae to the surface of the water column where they are collected and removed. The clean water is then returned to the source free of algae, with reduced nutrients and a heightened oxygen saturation (Eggers, 2019).

AquaLutions®™ has been deployed in Florida to improve water quality in several locations (Caloosahatchee River, St. Lucie Canal, and Banana River Lagoon). The prominent case study for AquaLutions®™ in Florida was at Lake Jesup where the DAF process was used to remove TP from the lake through a 5-year contract with the St. Johns River Water Management District. The project removed more than 6,500 pounds of TP, 90,000 pounds of TN, and 1.1-million pounds of dry weight algae from the lake (Eggers et al., 2014). **Figure 3-6** shows an overhead visual of an AquaFiber's®™ AquaLutions®™ project site.

Figure 3-6. Overhead View of an AquaFiber AquaLutions Project Site (Eggers, 2020)

AquaLutions®™ removes up to 90% TP, 65% TN, and 80% TSS (Eggers, 2019). AquaLutions®™ treatment produces residuals including algae and TSS. Collected algae is then made into fertilizer pellets or destroyed. Post-processing of the algae depends on the need for fertilizer in the surrounding communities. Providing fertilizer pellets to the farmers may reduce the transport of nutrients into the watershed by recycling nutrients that ran off the watershed. TSS removal would require dewatering and disposal (Eggers, 2019).

The AquaLutions®™ technology requires electricity to power the air blowers that produce the micro-air bubbles. The Lake Jesup project site required 0.9 to 1.0 kWh per 1,000 gallons (greater than 6-MGD facility), but the vendor suggests that a facility at the C-43 WBSR would require less energy depending on many factors including available head, pumps used to achieve the desired flow, and ability to create electricity onsite (e.g., renewable energy techniques, fluidized gas bed, vapor recovery) (Eggers, 2020).

3.1.8.1 Facility Details and Project Costs

AquaLutions®™ facilities are scalable based on the number of treatment basins. Each basin would be capable of flowing approximately 20 MGD (30 cfs) for a maximum system capacity of 20 basins flowing up to approximately 400 MGD (600 cfs). The influent flow rate necessary to produce the desired effluent concentration would determine the number of basins that are online at any one time, and the speed of bringing basins online can match the pace of forecasted flow dynamics into the C-43 WBSR. The overall footprint of the largest implementation would require approximately 227 ac, for an approximately 400 MGD (600 cfs) capacity. The proposed facility at C-43 WBSR would achieve a minimum 75% reduction in TP and a minimum 50% reduction in TN. Residuals would comprise mostly biomass, and this TSS removal would require dewatering and either disposal or beneficial re-use (Eggers, 2019).

The vendor proposed three system capacities for C-43 WBSR, and the costs and efficiencies are approximately linear among the options (e.g., the 300 cfs system is approximately half the 600 cfs system). Capital costs for the maximum approximately 400 MGD (600 cfs) AquaLutions®™ facility were projected to be approximately $98.0 million including design, permitting, and construction of the treatment plant. Estimated annual O&M costs are $27.3 million for the maximum 400 MGD (600 cfs) facility. Power consumption for the maximum facility is estimated to be 58,000,000 kWh/yr, totaling approximately $5,800,000 for electricity at $0.10 per kWh. The NPV cost was estimated to be $468.3 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Cost-effectiveness estimates are approximately $71.22 per pound of TN, $440.66 per pound of TP, and $3.53 per pound of TSS. Unit O&M costs are lower with increased flow and greater system capacity.

3.1.9 Bold & Gold®

Bold & Gold® is a biosorption activated media formulated to remove nitrogen species, phosphorus species, algal toxins, algal mass, Escherichia coli, and per- and poly-fluoroalkyl substances (University of Central Florida, 2019). The media can be used in many different applications including upflow filters, side-bank filters within wet detention ponds, dry detention systems, infiltration basins, rain gardens, pervious pavers, vegetated filter strips, drainfields, and rapid infiltration basins. Bold & Gold® is a mixture consisting of primarily mineral (Florida-based sand and Florida mined clay) and relatively slow degradable recycled materials (tire crumb) (Bogdan, 2020).

Bold & Gold® has been used in more than 200 locations across Florida with various applications for the reduction of both phosphorus and nitrogen. Recently, the University of Central Florida requested a grant to treat the water upstream of the St. Lucie River and Estuary. The project proposed building a filter with a size of approximately 2 ac to treat 0.05 gallons per minute per square foot (gpm/ft^2) flow with an average annual nitrogen concentration of about 1.5 mg/L. Target volume of flow was about 750 million gallons (MG) treated over 250 days (University of Central Florida, 2019).

In wastewater treatment with nitrate input of 3.61 mg/L, the removal of nitrate was approximately 83%. This application included a period where the filter was not saturated (University of Central Florida, 2019). The filters are estimated to be in service for 15 years with a treatment rate of 0.05 gpm/ft^2 (University of Central Florida, 2019).

Performance data in applications treating stormwater state a nitrogen removal rate of approximately 75% to 95%. For a recent stormwater application of Bold & Gold®, Valencia et al. (2017) observed a 60% TN reduction from 1.5 mg/L to 0.6 mg/L, with a reduction in dissolved organic nitrogen from 1.0 mg/L to 0.4 mg/L. The vendor indicates that 60% reduction is reasonably expected for the C-43 application (ECS 2020c).

3.1.9.1 Facility Details and Project Costs

A Bold & Gold® installation at C-43 WBSR is scalable based on the number of filter cells. A single 5-ac filter cell could treat approximately 12.2 cfs and the vendor proposes to construct 24 filter cells for a total maximum system capacity of approximately 292 cfs, which would be blended with untreated reservoir water to achieve the total target of 457 cfs (296 MGD), which is the flow needed to achieve the provided water quality treatment targets. The filter cells would occupy 120 ac, and additional supporting facilities bring the total land requirements to 175 ac. Bold & Gold® filter cells do not need to be co-located, or in any particular location relative to the reservoir or the river. Residuals are minimal, and the Bold & Gold® media is expected to have a 50-year service life, and the technology has continuous validation studies of 15-year lifespans (University of Central Florida, 2019). Capital costs for the Bold & Gold® facility were projected to be approximately $179 million. Estimated annual O&M costs are $540,000 between labor, electricity, and monitoring. The NPV cost was estimated to be $186.3 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Cost-effectiveness estimates are approximately $28.06 per pound of TN, $175.35 per pound of TP, and $1.40 per pound of TSS.

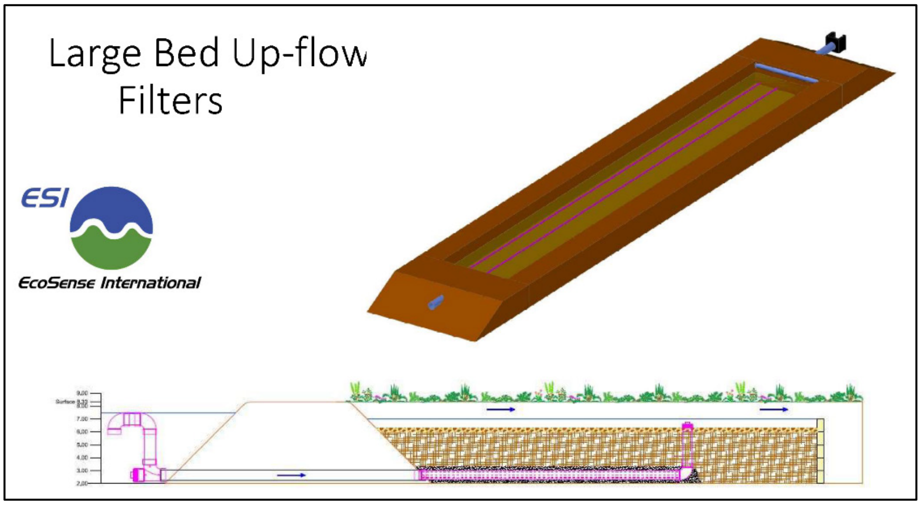
3.1.10 NutriGone™

NutriGone™, developed by EcoSense International, is a media mixture of inorganic carbon, organic carbon, and ion adsorption mineral. NutriGone™ is primarily used in the removal of nutrients from stormwater prior to discharge, intercepting groundwater near surface water interfaces and filtering surface water from ponds and swales. NutriGone™ is capable of being used in multiple different applications but EcoSense International has developed 2 technologies to house the media for stormwater filtration (EcoSense International, 2019).

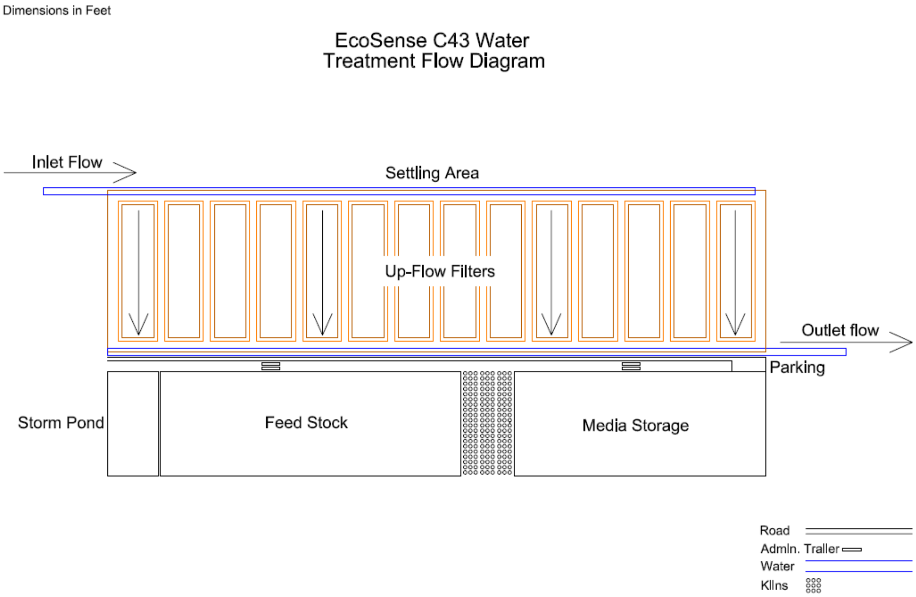
NutriGone™ has a stormwater project located in Brevard County, Florida. The Micco I Stormwater Improvement project researched the treatment efficiency of NutriGone™ as a best management practice (Schmidt and Housley, 2016). Data from the Micco I project indicated inflow concentrations of 1.17 mg/L TN, comprised of 0.91 mg/L total Kjeldahl nitrogen, 0.38 mg/L ammonia-nitrogen, and 0.21 mg/L oxidized nitrogen. Outflow nitrogen concentrations averaged 0.95 mg/L TN (19% reduction), comprising 0.8 mg/L total Kjeldahl nitrogen, 0.4 mg/L ammonia-nitrogen, and 0.21 mg/L oxidized nitrogen. Inflow TP averaged 0.11 mg/L and 0.08 mg/L, respectively. Monitoring of this site showed average TN and TP mass removal rates of 35% and 22 %, respectively.

NutriGone™ media sorbs the nutrients to the media. The vendor expects the media will last 353 days before being at maximum capacity for phosphorus. The media will need to be removed and new media added. The vendor suggests construction of a media production facility near the filter site. Vendor materials indicate that the media is capable of being sold as a soil amendment after being used in the filter at roughly 50% of the original price (Burden, 2020).

Figure 3-7 provides a visual representation of the suggested technology configuration to use NutriGone™.



a)



b)

Figure 3-7. (a) Example of NutriGone^{TM} Large Bed Up-Flow Filters (EcoSense International, 2019); (b) Proposed Implementation Diagram at C-43

3.1.10.1 Facility Details and Project Costs

A NutriGone™ installation at C-43 WBSR is scalable based on the number of filter cells. A single 1-ac filter cell could treat a maximum of approximately 43 cfs (approximately 28 MGD) and the vendor proposes to construct 14 filter cells for a total maximum system capacity of approximately 602 cfs (392 MGD). The filter cells would occupy 15 ac, and additional supporting facilities bring the total land requirements to 22 ac. Residuals processing includes removal and replacement of used filter media from the filter cell every 14-21 months (depending on loading as determined by monitoring), transported via dump truck or conveyor to the production facility where it would be allowed to dewater before transport to a secondary use facility. Preferred secondary use is a soil amendment at a livestock farming facility. Capital costs for the NutriGone™ media sorption installation were projected to be approximately $19.6 million. Estimated annual O&M costs are approximately $12.9 million. Approximately 94% of this O&M total is the materials cost of renewed filter media. The NPV cost was estimated to be $195.5 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates. Cost-effectiveness estimates are approximately $29.43 per pound of TN, $183.94 per pound of TP, and $1.47 per pound of TSS (Burden, 2020).

3.2 Technology Matrix

The information on each technology that was gathered from the vendors and described in **Section 3.1** was summarized in a matrix to assist with the technology evaluation and alternatives formulation. The matrix is presented in **Table 3-1**.

Table 3-1. Summary of the 10 Technologies for Water Quality Treatment

Technology	Florida Case Study/Data Quality[1]	Nutrient Reduction	General Land Area[2]	Operation & Maintenance	Residuals	Energy Requirements	Cost[3]	Potential Habitat and Ecosystem Services
Treatment Wetlands - Constructed wetlands for passive nutrient removal through sedimentation, biological uptake, sorption to organic and inorganic surfaces, and chemical precipitation.	- Multiple large-scale applications in Florida (e.g., STA, Orlando). - Data quality: Good	- Predicted reductions: ○ 32% TN ○ 47% TP ○ 85% TSS - Reported reductions: ○ 20-40% TN ○ 75-90% TP ○ >90% algae ○ >90% TSS	- 5,000 ac wetted area - 5,400 ac total site area	- Hydraulic structures and pump stations. - Water quality monitoring. - Vegetation management to maintain composition.	- Long-term residual accumulation (50-years)	- Pump station operation. - Electrical actuators for flow control structures. - Power for SCADA system, autosamplers, and control building.	- Capital cost: $121,400,000 - O&M cost: $1,077,800/yr - NPV cost: $136,000,000 - Cost-effectiveness: ○ TN = $20.69/lb ○ TP = $128.03/lb ○ TSS = $1.02/lb	- Semeraro et al. (2015): Sustain “wildlife habitats and biodiversity at local and global scales.” Potential role in recreational and educational opportunities. - Ghermandi and Fichtman (2015): Support educational tours and recreation, such as birdwatching. Provide environmental habitats.
Sand Filtration - Large-scale application of accepted sand filter technology to separate particles from liquid media through vertical filtration through a sand layer.	- Case studies include water treatment of phosphate mines in Florida. - Data quality: Moderate	- Predicted reductions: ○ 50% TP ○ 50% TN ○ 50% TSS - Reported reductions: ○ 48% TP ○ 51% TN ○ 84% TSS	- 1,000 ac technology area - Large infrastructure area	- Replacement of the top layer every 5 years. - Monthly scarification to prevent biological clogging and manage non-native plants.	- Sand requires collection and handling, which may include hauling and disposal. - Could be used for an agricultural soil amendment.	- No energy required to operate technology, using gravity.	- Capital cost: $210,385,000 - O&M cost: $2,692,000/yr - NPV cost: $246,972,000 - Cost-effectiveness: ○ TN = $37.19/lb ○ TP = $232.42/lb ○ TSS = $1.86/lb	- Large treatment area would be open and accessible for wildlife use year-round.
Air Diffusion System - Fine bubble aeration of water column delivered by 8, 30-hp Atlas Copco GA22VSD compressors. 0.10 parts per million of beneficial bacteria applied daily with automated liquid delivery system into the incoming flow.	- Applications in Florida with proposals to work in St. Lucie River. - Large reservoir studies in Wisconsin, Massachusetts, Delaware, Maine, Illinois and Colorado. - Data quality: Moderate	- Predicted reductions: ○ 50% TN ○ System sized for 1.5 mg/L TN (as ammonia) reduction - Reported reductions: ○ 90% BOD ○ 50–75% TN and TP	- 2,000 square feet technology area - Small infrastructure area - All diffusers, feeder tubes below water surface	- Weekly check of compressors. - Record discharge pressure and temperature. - Compressor filters visually inspected monthly. - Annual air leak testing. - Clean disk modules once a year.	- None.	- System will require 8, 30-hp compressors. - Estimated daily electrical costs are $452 per day.	- Capital cost: $6,752,000 - O&M cost: $124,000/yr for power, labor and maintenance costs not included - NPV cost: $8,437,200 - Cost-effectiveness ○ TN = $1.27/lb ○ TSS = $0.06/lb	- Aerated water column would minimize fish kills, especially in winter months, and increased stocking densities. - Improves overall reservoir water quality and prevents harmful algal blooms.
MPC-Buoy - Emits ultrasound wavelengths to disrupt algal buoyancy and maintain algae in deeper low light layers. 40 MPC-Buoy Pro and 60 MPC-Buoy Lite systems are proposed. Only the Pro systems have water quality monitoring systems.	- No documented applications in Florida (studies underway). - Data quality: Low–Moderate	- Predicted reductions: ○ 50% TSS ○ Reduces BOD - Examples: ○ 73% blue-green algae reduction ○ 50% chlorophyll reduction ○ 50% algae reduction within two months	- 100 square feet of technology area - Small infrastructure area - 100 square foot storage space	- Payment for water quality testing after first year. - 10-year lifespan.	- None.	- Each buoy is equipped with 3 solar panels of 195 Wp and 40-amp lithium batteries for autonomous power supply. - Power consumption of 5–20 watts. - Provides power year round. - Automatically powers off the ultrasonic transmitters during low battery charge. - Automatically switches to an energy-saving program during low sun radiation times.	- Capital cost: $10,432,500 - O&M cost: $989,900/yr - NPV Cost: $23,885,600 - Cost effectiveness: ○ TSS = $0.18/lb	- Improves overall reservoir water quality and prevents harmful algal blooms. - Website https://www.lgsonic.com/: “eliminates up to 90% of existing algae and prevents the growth of new algae. The cell wall of the algae remains intact, preventing the release of toxins from the algae into the water. The ultrasound used by LG Sonic is safe for fish, plants, zooplankton, and insects. Our devices use of low power (5–20 watts), wherefore no high voltage is transmitted into the water.”

Technology	Florida Case Study/Data Quality[1]	Nutrient Reduction	General Land Area[2]	Operation & Maintenance	Residuals	Energy Requirements	Cost[3]	Potential Habitat and Ecosystem Services
Alum Treatment • Lagoon-based alum application and solids retention for high rate nutrient removal.	• Nutrient Reduction Facility in Lake County, large-scale sediment separation Lake Lafayette, Tallahassee • Data quality: Good	• Predicted reductions: ○ 50% TP ○ 50% TN ○ 50% TSS • Reported reductions: ○ 66% TP ○ 51% TN ○ 84% TSS	• 500-ac technology area • Medium infrastructure area	• Remove floc from settling ponds. • Alum addition.	• Floc accumulated in settling pond, which requires drying and disposal.	• No information provided on energy requirement.	• Capital cost: $25,131,700 • O&M cost: $4,341,000/yr • NPV cost: $84,131,000 • Cost-effectiveness: ○ TN = $12.67/lb ○ TP = $79.17/lb ○ TSS = $0.63/lb	• Open settling basins and drying areas create wildlife habitat. • Ackerman (2018, article): Makes "swimming safer nationwide and could one day stem the red tide that plague's Florida's coast." • Harper (article): Dried alum floc is chemically inert and "has no restrictions for use as fill material or cover."
Hybrid Wetland Treatment Technology • Application of aluminum compounds to constructed wetlands designed for rapid nutrient coagulation and passive solids separation.	• Multiple projects in Northern Everglades that remove TP to improve water quality. • Data quality: Good	• Predicted reductions: ○ 50% TP ○ 50% TN ○ 50% TSS • Reported reductions: ○ Average TP removal of 86%. ○ Up to 96% of TP removal (with the larger sites). ○ Up to 68% of TN removal.	• 668-ac technology area • Large infrastructure area	• Alum injection system to ensure proper dosage.	• Residuals are captured within deep zones of wetland, so no residual management needed.	• Wetland is passive treatment. • Alum injection pump requires power, but no information was provided.	• Capital cost: $21,197,000 • O&M cost: $7,200,000/yr • NPV cost: $119,047,000 • Cost-effectiveness ○ TN = $18.11/lb ○ TP = $100.83/lb ○ TSS = $0.90/lb	• Wetland habitat created. • Open settling basins and drying areas create wildlife habitat. • Website (http://www.watershedtechnologiesllc.com/benefits/): "environmental benefits via wetland and wildlife habitat restoration and creation."
ElectroCoagulation • Application of a direct current to water through metal electrodes to neutralize particle charge, coagulate nutrient and metal ions, and sediment residuals.	• Lake Jesup case study. • Data quality: Good	• Predicted reductions: ○ 50% TP ○ 50% TN ○ 50% TSS • Reported reductions: ○ 95 – 99% TP ○ 60 – 80% TN ○ Algae cells (3–5 micron size) ○ Cyanotoxins ○ 53% of average flow (457 cfs) of treated water blended with untreated water will meet water quality targets.	• 10-ac technology area • Small infrastructure area • 6-ac metal building • 1-ac clarifier	• Removal of residuals and replacement of blades. • Estimated time for replacement of plates: 8.5 months (270 days).	• Used electrodes. • TSS and algae residuals.	• 0.6 kWh per 1,000 gal • 93,267 kWh per day for 155 MGD flow (53% blended to meet target design criteria) • KWh/yr: 34,042,548	• Capital cost: $148,355,00 • O&M: $3,164,000/yr • NPV cost: $191,357,000 • Cost-effectiveness ○ TN = $28.81/lb ○ TP = $180.08/lb ○ TSS = $1.44/lb	• Solids drying bed creates some habitat.
AquaLutions®™ • Combines chemical coagulation with fine-bubble dissolved air flotation for nutrient reduction and solids separation to harvestable and reusable biological solid.	• Several Florida locations (St. Lucie River, Caloosahatchee River). • Data quality: Good	• 65% TN • 90% TP • 80% TSS • Removes algae • 75% TP (minimum) • 50% TN (minimum)	• Technology area: ○ 168 ac for 300 cfs ○ 188 ac for 457 ac ○ 227 ac for 600 cfs • Medium infrastructure area	• Periodic maintenance of blowers is needed. • Facility operated 24 hours for 7 days each week except for routine maintenance and power outages	• Residuals include algae biomass and TSS. • Algae is collected and made into fertilizer pellets or destroyed. • TSS removal would require dewatering and disposal	• Energy required to power air blowers for flotation. ○ 0.9–1.0 kWh per 1,000 gal. ○ 30,000,000 kWh/yr (300 cfs) ○ 45,000,000 kWh/yr (457 cfs) ○ 58,000,000 kWh/yr (600 cfs)	• Capital cost: $97,967,000 • O&M costs: $27,247,000 • NPV cost: $468,262,500 • Cost-effectiveness ○ TN = $71.22/lb ○ TP = $440.66/lb ○ TSS = $3.53/lb	• Open treatment basins and drying areas create wildlife habitat. • Website (http://www.aquafiber.com/florida.html), the technology cleans "surface waters to support healthy aquatic ecosystems. Recreational fishing provides a good example of the potential economic threat from water quality decline."
Bold & Gold® • Sorption media comprised of proprietary mix of inorganic sand, clay, and tire crumbs for passive chemical bonding of phosphate and ammonia to media surface and enhanced denitrification.	• More than 200 locations across Florida. • Data quality: Good	• 64% of flow treated and then blended to meet water quality target	• 130-ac technology area • Medium infrastructure area	• Filters estimated to be in service for 15 years with treatment rate of 0.05 gpm/square foot. • Filter Bold & Gold® media is expected to have a service life of 50 years.	• Media will need to be disposed of after 50-year service lifetime. • Filter material is mainly sand and may even be left on site after 50 years.	• Materials discuss need to run pumps and aeration of top sand layer. • No detailed information provided.	• Capital cost: $179,000,000 • O&M cost: $540,000/yr for labor • NPV cost: $186,336,000 • Cost-effectiveness: ○ TN = $28.06/lb ○ TP = $175.35/lb ○ TSS = $1.40/lb	• Open treatment basins and drying areas create wildlife habitat. • Website (https://ecs-water.com/bold-and-gold-frequently-asked-questions/): "Bold & Gold Filtration Media is an inert material with no biological toxic effects." • Removes algal toxin and perfluoroalkyl and polyfluoroalkyl substances.

Notes:

[1] Data quality definition – Good data quality includes availability of peer-reviewed papers and reports prepared for water management districts or public utilities. Moderate quality includes data provided by vendor but reported by outside or third-party laboratory. This characteristic differs from confidence in performance estimates, which is meant to capture a cumulative assessment of data quality, case histories, and similarity to C-43 site conditions.

[2] Estimated area based on nutrient reduction criteria set for the purpose of this Study comparison.

[3] Cost effectiveness calculated based upon NPV/total mass removed.

3.3 Methodology for Alternatives Formulation

Each of the 10 technologies was evaluated and ranked against a series of attributes and for cost effectiveness to determine which technologies would work best to provide water quality treatment for the C-43 WBSR.

The first step in the ranking process was to evaluate the technologies based on key attributes. **Table 3-2** summarizes these attributes, the weight assigned, and the justification for that weight. In the table, attributes are grouped by color, i.e., cells with attributes of the highest importance are green, cells with attributes of medium importance are yellow, and cells with attributes of low importance are orange. Attributes that are more important to the success of the project were given a greater weight. The highest weight, which indicates the most important attribute, is a 5. The lowest weight, which indicates the least important attribute, is a 1. Attributes evaluated, in order of weight, include:

- **Scalable** – This attribute was given the highest weight, and it evaluates whether the technology has been used and proven at a similar scale. Technologies were assessed for their ability to handle the expected flows and nutrient concentrations at the C-43 WBSR (e.g., 457 cfs flows and a 10,000-ac reservoir). Lower scores were assigned to technologies without examples of large-scale implementation comparable to the C-43 WBSR.
- **Confidence in performance estimates** – This attribute evaluates whether reliable and reasonable performance data are available for nutrient and algae removal efficiencies. Technologies with peer-reviewed nutrient removal data or studies prepared for water management districts or public utilities were preferred.
- **Available Florida case study** – This attribute assesses whether Florida case studies existed for the reviewed technologies and whether these case studies demonstrated favorable results for studies conducted in Florida. Technologies with multiple Florida case studies were ranked higher than those with few or no Florida case studies.
- **Residuals production** – Residuals are the waste product, typically in a solid form, that remain after a treatment process has occurred. For chemical treatment, this is typically a precipitate, while for biological treatment, this is typically an organic solid produced by plant or microbial growth. This attribute assesses whether residuals are produced and how they are handled as a result of the use of the technology. Handling, treatment, and storage of residuals is costly and time intensive and requires permitting and additional infrastructure.
- **Habitat** – This attribute evaluates the benefits and potential harm to fish and wildlife as a result of the technology. Technologies that provide habitat for fish and wildlife, such as treatment wetlands that create valuable habitat for wading and nesting birds as well as fish and other aquatic species, receive a higher score than technologies that do not provide habitat benefits.
- **Ecosystem services** – This attribute assess ecosystem services, which are the benefits that ecosystems provide to people. These services can be divided into four inter-related categories. (1) Provisioning services, which provide goods such as food; freshwater; timber, fiber, fuel, and other raw materials; genetic materials for resistance to plant pathogens; biochemical products and medicinal resources; ornamental species and/or resources for direct human use; (2) Regulating services, which include air quality regulation, climate regulation, natural hazard regulation, disease regulation, erosion protection, soil formation and regeneration, biological

regulation, and water purification; (3) Cultural services, which provide opportunities and inspiration for education, science, recreation, spiritual, religious, and aesthetic activities; and (4) Supporting services, which include nutrient cycling, nursery habitat, soil formation, and primary production (Brauman et al., 2007; de Groot et al., 2010).

- **Energy efficiency** – This attribute focuses on the energy requirements for the reviewed technologies. The use of more environmentally friendly energy with lower carbon footprint is preferred, and therefore ranked higher, than more energy intensive technologies. The energy costs are not included in this attribute but are included in the cost-effectiveness evaluation.
- **Land requirements** – This attribute assesses the relative amount of land needed to properly implement the reviewed technologies. For ranking, the land requirements were grouped into three categories—low (small, less than 100 ac), medium (greater than 100 ac and less than 1,000 ac), and large (greater than 1,000 ac). Higher ranking was assigned to technologies with smaller land requirements. As noted in **Section 2.3**, some technologies may fit on available land while others, such as a full-scale treatment wetland, will require the acquisition of additional property. This attribute partially accounts for potential land availability challenges without requiring the completion of a siting evaluation.
- **O&M** – This attribute assesses the day-to-day complexity of operations and staff involvement needed to keep the technology functioning properly. Higher ranking was assigned to technologies with less complexity and human resource needs. The O&M costs are not included in this attribute but are included in the cost-effectiveness evaluation.
- **Schedule of implementation** – This attribute was given the lowest weight with regards to importance. The timeline associated with implementation and completion of the technologies were assessed, and a higher score was given to technologies that could be implemented by 2023 when reservoir construction is complete.

Table 3-2. Ranking Attributes and Assigned Weights

Attribute	Weight	Justification
Scalable	5	Experience with technology at a similar scale
Confidence in Performance Estimates	5	Must have a high confidence in removal estimates provided
Available Florida Case Study	4	Reduced risk based on reliability of data with Florida case studies; however, this Study supports innovation
Residuals Production	4	Preference for technology that does not produce residuals or require management
Habitat	3	Ancillary benefits to fish and wildlife by providing habitat
Ecosystem Services	2	Ancillary benefits to humans by provisioning services, regulating services, cultural services, and supporting services
Energy Efficiency	2	Preference for technology with lower carbon footprint
Land Requirements	2	Relative footprint area needed to provide for water quality treatment
O&M	2	Preference for technologies with less complexity of operations and less operator involvement
Schedule of Implementation	1	Time needed to construct and implement the treatment technology

As discussed above, each of these attributes was scored for each technology. Assigned scores were 0, 1, or 2, with a higher score being better. The criteria used to assign the score for each attribute are summarized in **Table 3-3**. The scores were multiplied by the weight for each attribute and then added together to determine a total score. The technologies were then ranked from 1 to 10 with 1 assigned to the highest (best) score and 10 assigned to the lowest (worst) score. The scoring and rank for each attribute are shown in **Table 3-4**.

The formula to calculate the total attribute score for each technology is:

> Technology total score = (Scalable score x 5) + (Confidence in Performance Estimates score x 5) + (Available Florida Case Studies score x 4) + (Residuals Production score x 4) + (Habitat Value score x 3) + (Ecosystem Services score x 2) + (Energy Efficiency score x 2) + (Land Requirements score x 2) + (O&M score x 2) + (Schedule of Implementation score x 1).

The next step in the process was to evaluate cost-effectiveness. The capital and O&M costs were either developed by J-Tech or provided by the vendors. The O&M costs include items such as power consumption, replaceable parts, and water quality monitoring. These costs were used to calculate the NPV costs over a 20-year period. The NPV was estimated using the Microsoft Excel spreadsheet function for NPV. The mathematical formula for calculating the NPV of an individual cash flow is:

> NPV = F/[(1 + i)^n], where
>
> F = Future payment (cash flow)
>
> i = Discount rate (or interest rate)
>
> n = the number of periods in the future the cash flow is projected

The NPV was estimated for each year for a 20-year series of future O&M values (representing cash flow). The capital cost was added to the NPV to represent the total investment in the project over the 20-year period. The NPV costs were then divided by the TN, TP, and TSS (used to represent algae) removals to determine the cost effectiveness. The ADS vendor did not provide a TP efficiency and the MPC-Buoy vendor did not provide TP or TN efficiencies; therefore, for these parameters, these technologies received a score of 10, which is the lowest score.

Table 3-3. Scoring for Each Attribute

Technology Scoring	Scalable	Confidence in Performance Estimates	Available Florida Case Studies	Residuals Production	Habitat Value	Ecosystem Services	Energy Efficiency	Land Requirements	O&M	Schedule of Implementation
2	Proven at similar scale	High	More than 5	No residual management	High	High	High	Low	Low	Short
1	Proven at moderate scale	Medium	Between 1 and 5	Moderate residual management	Medium	Medium	Moderate	Moderate	Moderate	Moderate
0	Proven at small scale	Low	None	Large residual management	Low or None	Low or None	Low	High	Intensive	Long

Table 3-4. Technology Ranking by Attribute

Technology Scoring	Attribute										Total Score	Rank
	Scalable	Confidence in Performance Estimates	Available Florida Case Studies	Residuals Production	Habitat Value	Ecosystem Services	Energy Efficiency	Land Requirements	O&M	Schedule of Implementation		
Weight -->	**5**	**5**	**4**	**4**	**3**	**2**	**2**	**2**	**2**	**1**		
Treatment Wetland	2	2	2	2	2	2	2	0	2	0	54	1
Sand Filtration	1	1	1	2	1	0	2	0	2	1	34	4
Air Diffusion System	1	0	1	2	0	0	1	2	2	2	29	6
MPC-Buoy	1	0	0	2	0	0	2	2	2	2	27	8
Alum Treatment	1	2	2	0	1	0	1	2	1	1	35	2
HWTT	0	2	2	1	1	2	1	1	1	0	35	2
ElectroCoagulation	0	2	1	2	0	0	0	2	0	1	27	8
AquaLutions	1	2	1	1	0	0	1	1	0	1	28	7
Bold & Gold®	0	1	2	2	0	0	1	1	2	1	30	5
NutriGone™	0	0	1	2	0	0	1	1	0	1	17	10

Note: The score times the weight for each attribute were added together to determine a total score for each technology. The highest total score received a rank of 1, which is the highest (best) ranking. The lowest total score received a rank of 10, which is the lowest (worst) ranking.

The scores were assigned on a scaled metric. For each cost category, the technology with the lowest cost received a score of 1, and the technology with the highest cost received a score of 10. The other technologies received a scaled score based on their costs in comparison to the lowest and highest cost technologies. For each cost-effectiveness category, the most cost-effective technology received a score of 1, and the least cost-effective technology received a score of 10. The other technologies received a scaled score based on their cost-effectiveness in comparison to the most and least cost-effective technologies. The rankings by cost and cost-effectiveness are shown in **Table 3-5**.

The final step was to determine composite ranking using the scores by attribute and cost-effectiveness. Of the total weight, 50% was assigned to the attributes scoring from **Table 3-4** and 50% was assigned to the cost-effectiveness scoring from **Table 3-5**. For the cost-effectiveness scores, a higher weight was applied to the TP and TN cost-effectiveness values than to the TSS values, given the understanding that a technology designed for nutrient reduction will be expected to reduce solids within the same system. This higher weight was intended to reflect the importance of nutrient reduction for protection of downstream estuarine resources. A summary of the process used to determine the treatment technologies ranking is shown in **Figure 3-8**. The final score and ranking are summarized in **Table 3-6**, and are shown in **Figure 3-9** through **Figure 3-11** for TN, TP, and TSS, respectively. The formula for calculating the final score is:

Final score = (Attribute Score x 50%) + (Cost-effectiveness Score x 50%), where

Cost-effectiveness score = (TN score x 40%) + (TP score x 40%) + (TSS score x 20%)

Based on this evaluation, the highest ranked technologies are treatment wetlands, alum treatment, and HWTT. The next highest ranked technologies include Bold & Gold®, sand filtration, ADS, and ElectroCoagulation. The lowest ranked technologies were NutriGone^{TM}, AquaLutions, and MPC-Buoy. The lowest ranked technologies were removed from further consideration in identifying alternatives.

Adjusting the weight to emphasize TN or TP removal does not significantly affect the rank of the technologies. **Table 3-7** compares the rankings of four alternative weighting scenarios: baseline (with 40% weight for TP and TN removal each and 20% TSS removal), 100% weight on TN removal, 100% weight on TP removal, and 100% weight on TSS removal. The top three alternatives consisted of treatment wetlands, alum treatment, and HWTT, which were the same in all scenarios. Bold & Gold® and ADS were each ranked fourth in at least one of the four scenarios. J-Tech conducted additional sensitivity analysis of the ranking weights, and the results of this analysis are summarized in **Appendix F**. Results support the same general conclusion that treatment wetlands, alum treatment, and HWTT remain the top three ranked technologies, with sand filtration and Bold & Gold® providing fourth and fifth ranked alternatives.

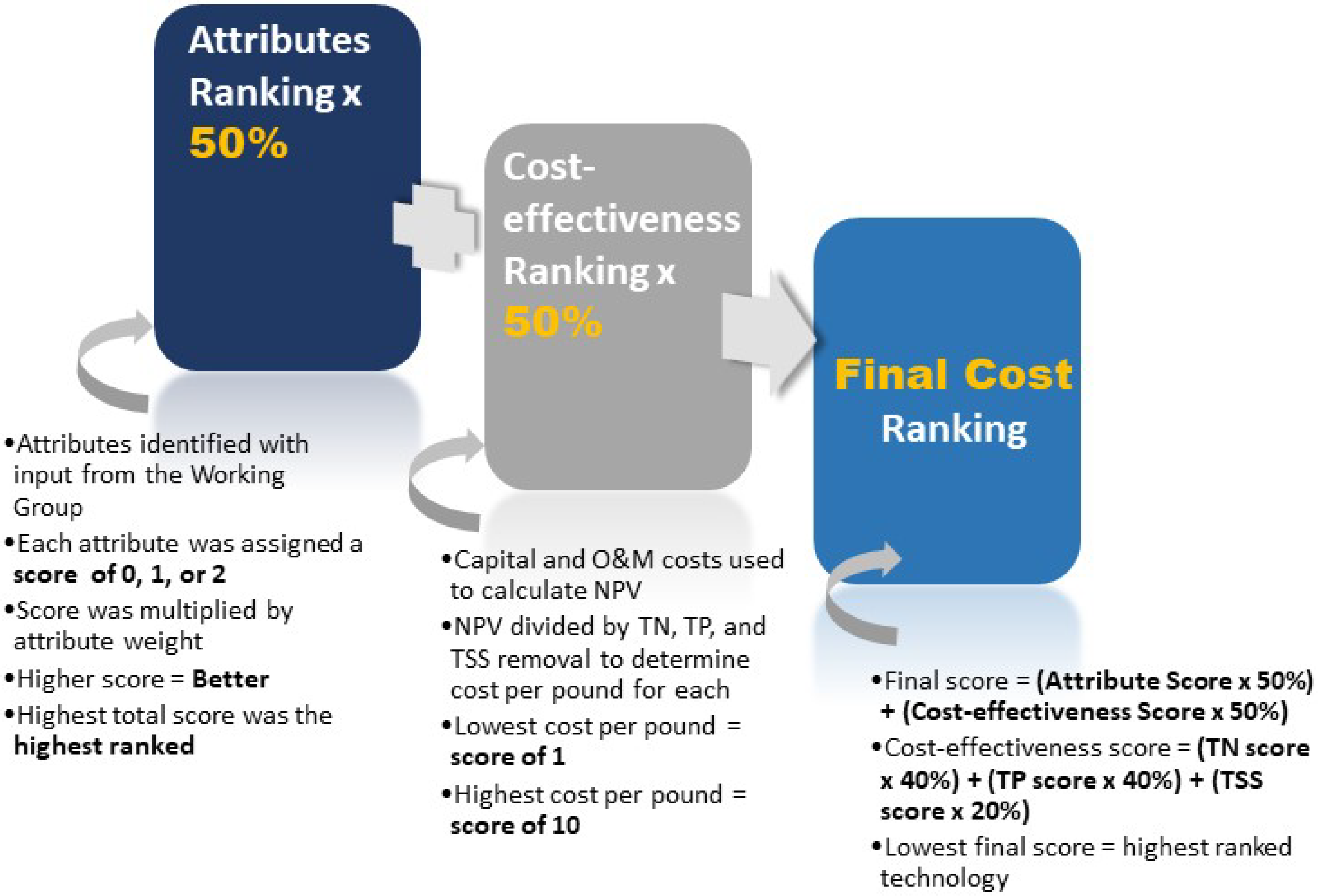
Table 3-5. Ranking by Cost and Removal Effectiveness

Technology	Cost Summary (Technology Only, $ millions)			Cost Effectiveness ($/lb)			Cost Effectiveness Ranking		
	Capital	O&M	NPV	TP	TN	TSS	TP	TN	TSS
Treatment Wetland	$121.40	$1.08	$136.05	$128.03	$20.69	$1.02	1.95	3.22	3.50
Sand Filtration	$210.39	$2.69	$246.97	$232.42	$37.19	$1.86	3.97	5.11	5.67
Air Diffusion System	$6.75	$0.12	$8.44	-	$1.27	$0.06	10.00*	1.00	1.00
MPC-Buoy	$10.43	$0.99	$23.89	-	-	$0.18	10.00*	10.00*	1.30
Alum Treatment	$25.13	$4.34	$84.13	$79.17	$12.67	$0.63	1.00	2.30	2.48
HWTT	$21.20	$7.20	$119.05	$100.83	$18.11	$0.90	1.42	2.93	3.16
ElectroCoagulation	$148.36	$3.16	$191.36	$180.08	$28.81	$1.44	2.95	4.15	4.58
AquaLutions	$97.97	$27.25	$468.26	$440.66	$71.22	$3.53	8.00	9.00	10.00
Bold & Gold®	$179.10	$0.54	$186.34	$175.35	$28.06	$1.40	2.86	4.06	4.48
NutriGone™	$19.60	$12.94	$195.46	$183.94	$29.43	$1.47	3.03	4.22	4.66

* TP and TN reductions were not provided by the vendor; therefore, the TP and TN cost-effectiveness was given the lowest score.

Table 3-6. Final Composite Ranking

Technology	Cost Effectiveness Ranking			Attribute Ranking	Weighted Score	Final Ranking Based on Weighed Score
	TP	TN	TSS			
Weight -->	0.4	0.4	0.2	1.0		
Alum Treatment	1.0	2.3	2.5	2	1.9	1
Treatment Wetland	2.1	3.3	3.6	1	1.9	2
HWTT	1.4	2.9	3.2	2	2.2	3
Bold & Gold	2.9	4.1	4.5	5	4.3	4
Sand Filtration	4.0	5.1	5.7	4	4.4	5
Air Diffusion	10.0	1.0	1.0	6	5.3	6
Electrocoagulation	3.0	4.2	4.6	8	5.9	7
NutriGone™	3.0	4.2	4.7	10	6.9	8
AquaLutions	8.0	9.0	10.0	7	7.9	9
MPC Buoy	10.0	10.0	1.3	8	8.1	10



Attributes Ranking x 50%

- Attributes identified with input from the Working Group
- Each attribute was assigned a **score of 0, 1, or 2**
- Score was multiplied by attribute weight
- Higher score = **Better**
- Highest total score was the **highest ranked**

Cost-effectiveness Ranking x 50%

- Capital and O&M costs used to calculate NPV
- NPV divided by TN, TP, and TSS removal to determine cost per pound for each
- Lowest cost per pound = **score of 1**
- Highest cost per pound = **score of 10**

Final Cost Ranking

- Final score = **(Attribute Score x 50%) + (Cost-effectiveness Score x 50%)**
- Cost-effectiveness score = **(TN score x 40%) + (TP score x 40%) + (TSS score x 20%)**
- Lowest final score = highest ranked technology

Figure 3-8. Process Used to Rank the Treatment Technologies

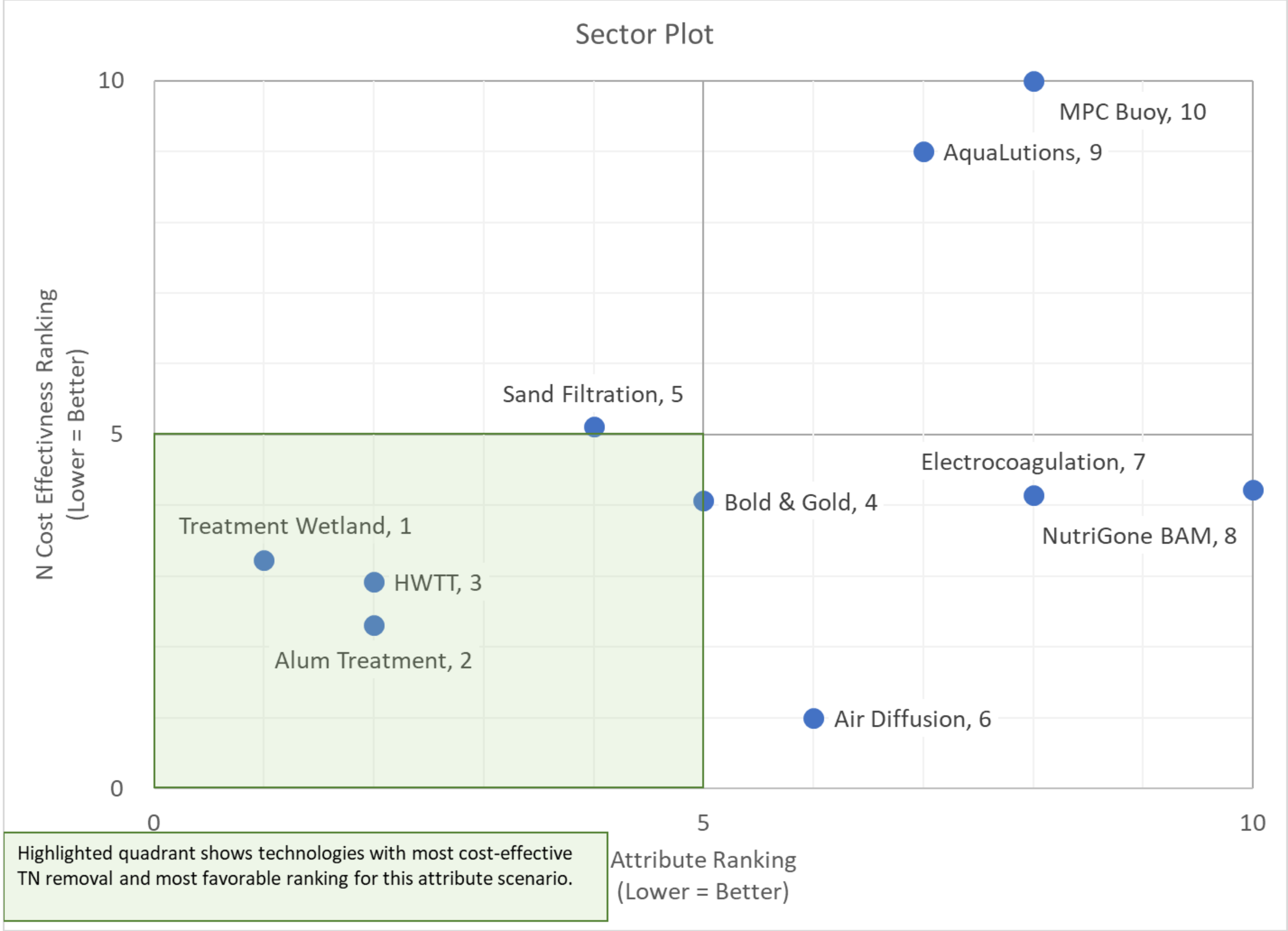
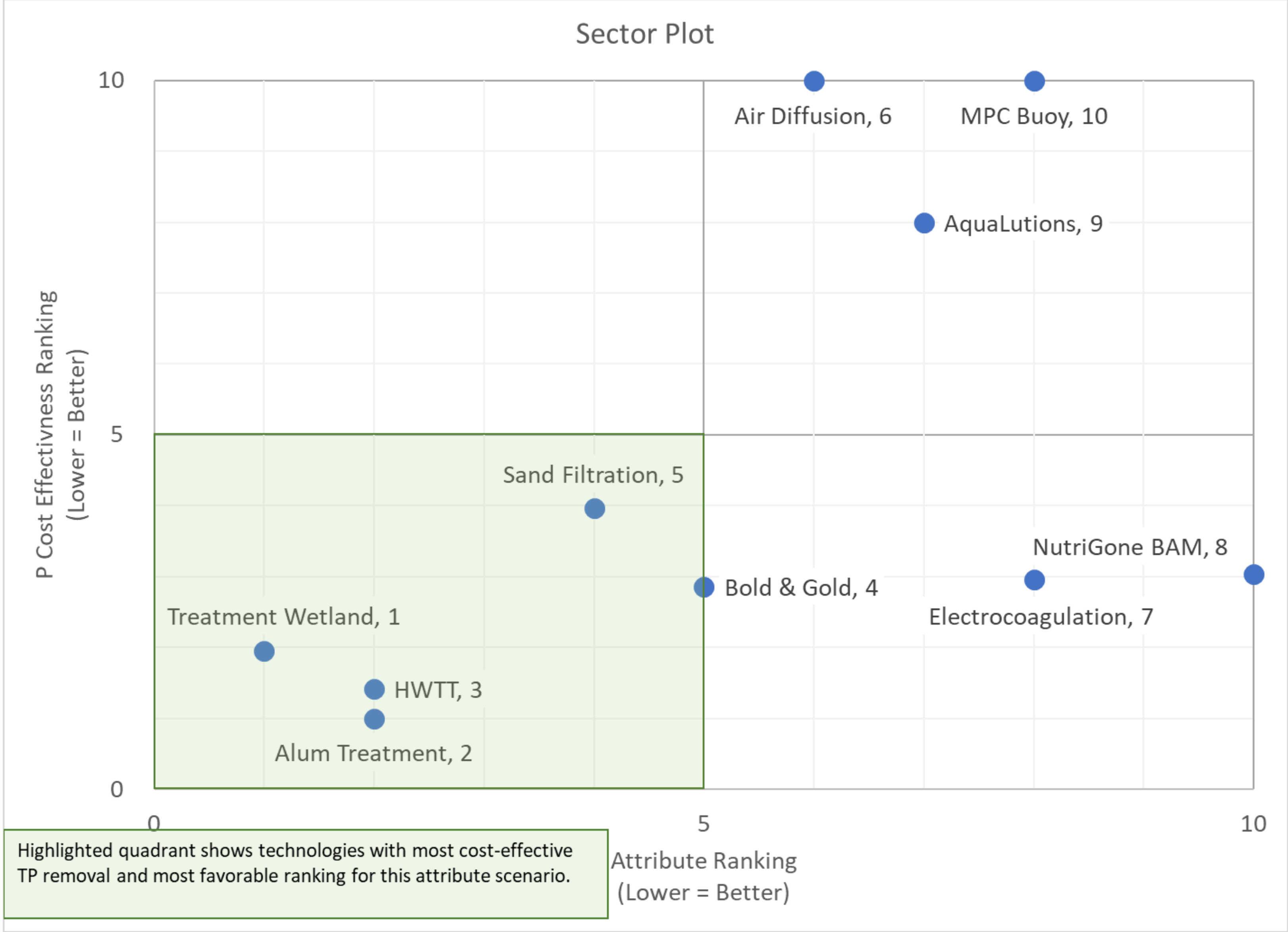
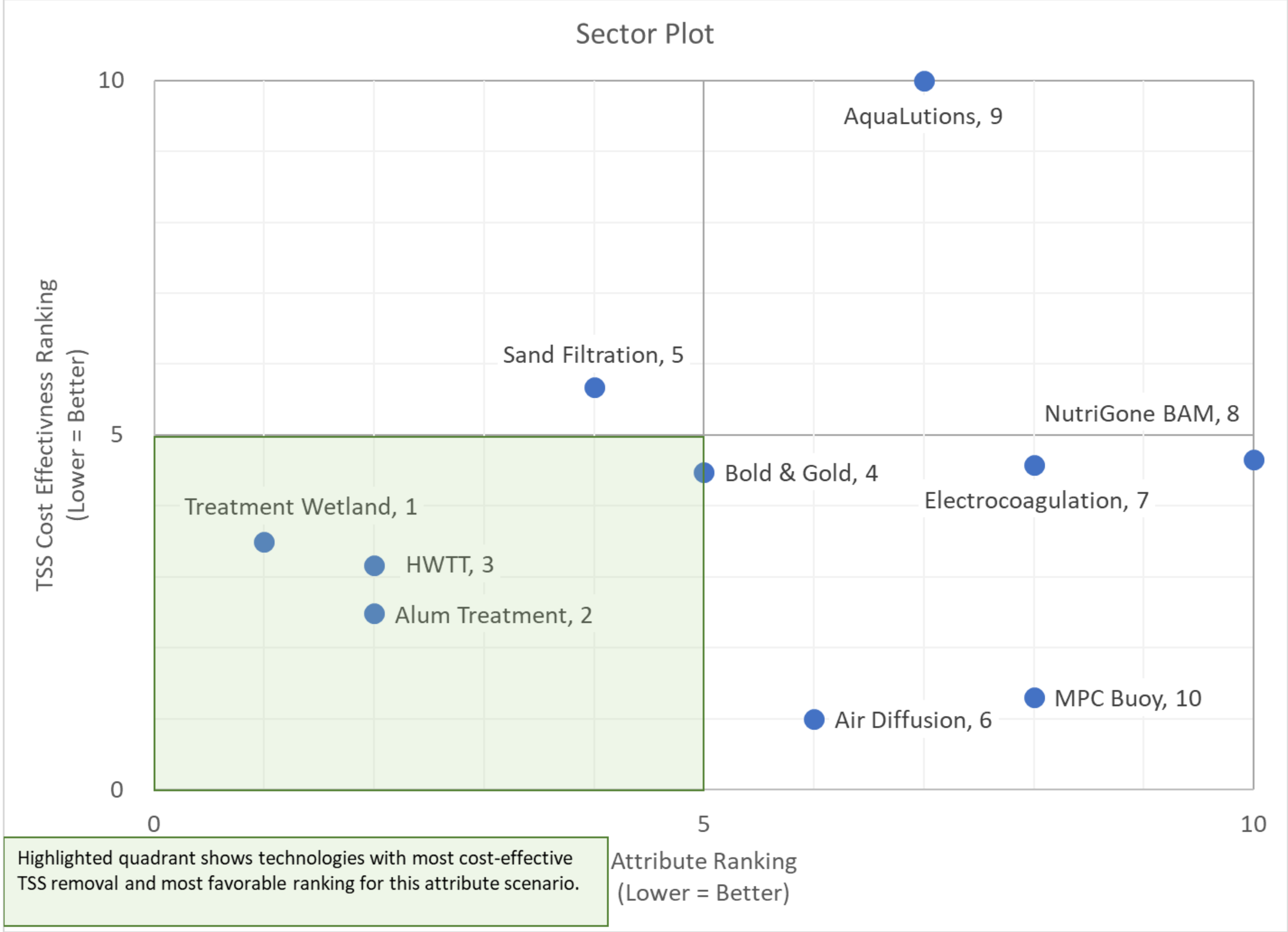


Figure 3-9. Comparative Plot for the TN Effectiveness Ranking


Sector Plot

Highlighted quadrant shows technologies with most cost-effective TP removal and most favorable ranking for this attribute scenario.

Figure 3-10. Comparative Plot for the TP Effectiveness Ranking



Highlighted quadrant shows technologies with most cost-effective TSS removal and most favorable ranking for this attribute scenario.

Figure 3-11. Comparative Plot for the TSS Effectiveness Ranking

Table 3-7. Comparison of Composite Ranking by Weighting Scenario

Technology	4-4-2	0-10-0	10-0-0	0-0-10
Alum Treatment	1	1	1	1
Treatment Wetland	2	2	2	2
HWTT	3	3	3	3
Bold & Gold®	4	5	4	6
Sand Filtration	5	6	5	7
Air Diffusion	6	4	9	4
Electrocoagulation	7	7	6	8
NutriGone™	8	8	7	9
AquaLutions	9	9	8	10
MPC Buoy	10	10	10	5

Scenario Notes:

- 4-4-2: Baseline scenario, with ranking consisting of 40%, 40% and 20% preference for removal of TP, TN and TSS, respectively.
- 0-10-0: 100% weight on TN removal effectiveness.
- 10-0-0: 100% weight on TP removal effectiveness
- 0-0-10: 100% weight on TSS removal effectiveness

4.0 Evaluate and Compare Alternatives

4.1 Selection and Identification of Project Alternatives

The ranking of the technologies provided in **Section 3.3** identifies treatment wetlands, alum, and HWTT as having the highest scores (1–3, respectively). These three technologies will be evaluated for further consideration. Additionally, Bold & Gold®, sand filtration, ADS, and ElectroCoagulation ranked next highest in the evaluation (4–7, respectively) and should be evaluated as potential alternatives, or as part of a project in combination with other technologies or treatment trains.

4.1.1 Treatment Trains and Combinations

Each technology was initially sized to achieve a prescribed level of water quality improvement target set for the purpose of this Study. This approach was taken to facilitate the direct technology-to-technology comparisons described in **Sections 3.1.10.1** and **3.3**. However, there may be performance or cost benefits to implementing a project that combines one or more technologies, particularly when land areas are limited. Technologies could be combined for series or parallel operation (**Figure 4-1**). In a series mode of operation, the inflow passes through one technology and then through the next. In parallel operation, the inflow splits between two technologies and the outflows combine again. A series configuration might be considered if two technologies excel at reducing concentrations of different water quality parameters of interest. A parallel configuration might be considered if there are clear benefits to using one type of treatment system for low flows and another type of treatment system for higher flows.

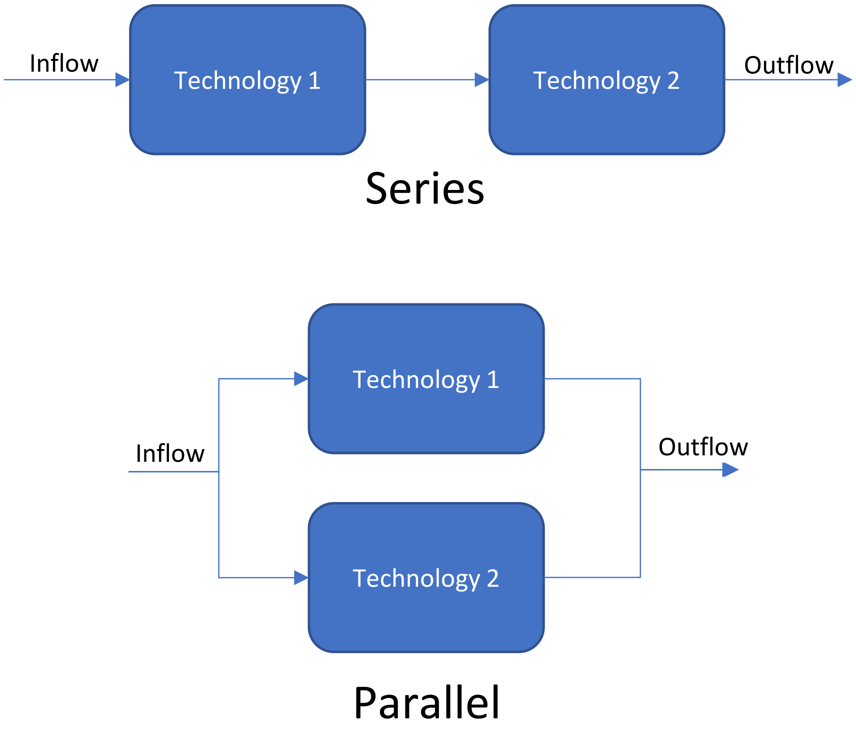


Figure 4-1. Conceptual Flow Diagram for Series and Parallel Technology Configurations

In combining technologies, the following factors should be considered:

- The removal efficiency for a unit process or technology is dependent upon the inflow concentration and flow rate. Most technologies have a lowest achievable concentration (limits of the technology) that can be attained, which is independent of the inflow concentration or loading rate. Accordingly, as the inflow concentration decreases, the removal efficiency typically decreases. For instance, a technology that can reduce an inflow TN concentration of 1.5 mg/L by 30% will likely not be able to reduce an inflow TN concentration of 1.0 mg/L by 30%.
- Treatment efficiencies for units in a treatment train (series configuration) are likely not additive. If each of two technologies can remove TN with an efficiency of 30%, placing those technologies in series will likely not yield a combined removal efficiency of 60%.
- The overall treatment efficiency for parallel technologies is calculated as the flow-weighted average of the individual treatment efficiencies.
- Technologies operated in series must be complementary. The first process cannot produce an effluent that negatively impacts the second process. Preferably, the first process provides an improvement in water quality for one parameter (TN, for example) while the second treats another parameter (TP, for example). Ideally, the first process also transforms (pre-treats) compounds from their form at the system inflow to an altered form that is more readily removed by the second process.

The ranking methodology described in **Section 3.3** identified the MPC-Buoy, AquaLutions®™, and NutriGone™ as the lowest scoring technologies; therefore, these technologies were not evaluated for treatment trains or combinations. The remaining technologies, in order of ranking, include:

1. Treatment Wetlands
2. Alum Treatment
3. HWTT
4. Bold & Gold®
5. Sand Filtration
6. ADS
7. ElectroCoagulation

Any of these technologies could be implemented as parallel systems without creating significant technical or water quality compatibility issues associated with the comingling of the effluents. The same is not necessarily the case for series operation of combined treatment systems. For example, if alum floc settled poorly in either the alum or HWTT systems and that effluent was routed to a sand filter or Bold & Gold® filter, it would be possible to blind the surface of the filter and cause that process to fail. Some technologies may be better suited as either the upstream or downstream process. **Table 4-1** shows the ways pairs of the seven remaining technologies could be combined and indicates whether any given pair produces compatible intermediate effluent quality.

Table 4-1. Compatibility of Seven Technologies for Series Operation

Downstream Technology	Upstream Technology						
	Treatment Wetland	**Sand Filtration**	**Alum Treatment**	**HWTT**	**Bold & Gold®**	**ADS**	**ElectroCoagulation**
Treatment Wetland	--	N	Y	Y	Y	Y	N
Sand Filtration	Y	--	N	N	Y	Y	N
Alum Treatment	N	N	--	N	Y	Y	N
HWTT	N	N	Y	--	Y	Y	N
Bold & Gold®	Y	Y	N	N	--	Y	N
ADS	N	N	N	N	N	--	N
ElectroCoagulation	Y	Y	Y	Y	Y	Y	--

N = No (not compatible); Y = Yes (compatible)

Treatment wetlands could be used as an upstream process and be followed by sand filtration, Bold & Gold®, or ElectroCoagulation. While either alum or the HWTT could provide additional water quality benefits, they would more likely be constructed as the upstream system when combined with treatment wetlands. ADS would not be expected to provide any additional improvement to post-treatment wetland effluent. Treatment wetlands could follow Bold & Gold® or ADS as a downstream technology.

Sand filtration could be followed by Bold & Gold® or ElectroCoagulation as it may provide pretreatment for particulate pollutants with the downstream technologies providing treatment for dissolved pollutants. Sand filtration could also serve as a polishing process for treatment wetlands, Bold & Gold®, or ADS by removing particulate pollutants that may not be removed by the upstream units.

As an upstream process, alum could be followed by treatment wetlands, HWTT, or ElectroCoagulation. Alum followed by treatment wetlands is essentially the same process as HWTT. ElectroCoagulation would remove remaining TN and TP that might not be fully removed by the alum application process. Alum should not be followed by filtration processes such as sand filtration or Bold & Gold® as the media effectiveness could be impacted if alum floc settling is not consistently effective, unless additional routine maintenance is included to scrape the surface layers. An alum process could be placed downstream of either Bold & Gold® or ADS.

Similar to the alum system, HWTT could be followed by treatment wetlands or ElectroCoagulation. Both downstream systems would be expected to provide additional polishing for the HWTT effluent. HWTT should not precede sand filtration or Bold & Gold® for the same reasons (media blinding) that conventional alum treatment is not recommended before filtration systems. HWTT could be used as a downstream process to polish the effluents from alum, Bold & Gold®, or ADS.

Bold & Gold® is marketed primarily for denitrification (removal of oxidized nitrogen) and phosphorus adsorption. As such, it could be used as a pretreatment process prior to any of the remaining processes except ADS, which would nitrify organic nitrogen to the oxidized form that would then require removal. However, there may be some potential for a treatment wetland to fix nitrogen following pretreatment by Bold & Gold®. As a downstream unit, Bold & Gold® could follow treatment wetlands, sand filtration, or ADS as it may provide additional nutrient removal. Bold & Gold® would not be recommended to follow either the alum or HWTT systems due to the risk of unsettled floc blinding the media.

ADS was reported to provide treatment for oxidized nitrogen, but not for other forms of nitrogen or phosphorus. Accordingly, ADS could be used as an upstream process for any of the remaining technologies. The other processes are all expected to provide adequate treatment for oxidized nitrogen as well as other constituents so air diffusion may not be expected to provide any added benefit if placed as a downstream unit behind another process. Therefore, due to this fact and the relative lack of information provided for TN, TP, and TSS removal, ADS was removed from further consideration when developing alternatives.

The performance data indicate that ElectroCoagulation is highly effective at reducing both TN and TP to very low levels, so there would not be a strong reason to follow it with any other technology, except perhaps sand filtration as a mechanism to capture the solids generated by the ElectroCoagulation process. However, ElectroCoagulation could follow any of the other technologies and be expected to provide additional water quality improvement.

4.2 Results of the Alternatives Analysis

4.2.1 Treatment Wetland

As noted in **Section 3.1.1**, treatment wetlands, or STAs, are a proven technology for nutrient removal in southwest Florida. A treatment wetland system was sized to treat inflows or outflows from the C-43 WBSR based on relevant, regional operational performance data. To meet the performance objectives set for the purpose of this Study (reducing TN by 33% from 1. 5 mg/L to 1.0 mg/L, reducing TP by 50% from 0.16 mg/L to 0.08 mg/L, and reducing TSS by 50% from 20 mg/L to 10 mg/L) at flow rates consistent with the MFL (457 cfs), a treatment wetland area of approximately 5,000 ac was determined to be necessary. The area requirement was estimated based on recent performance of the SFWMD's C-43 Water Quality and Treatment Testing Project (C-43 WQTTP) (J-Tech and WSI, 2019), other treatment wetlands in Florida (**Appendix A**, Section 3.2), and analysis using wetland performance modeling techniques described by Kadlec and Wallace (2009). It is assumed that the 5,000-ac system would be constructed at a site with predominantly sandy soils. The 5,000-ac system results in an average hydraulic loading rate of about 5.5 centimeters per day (cm/d) at the MFL flow of 457 cfs, which is consistent with operational experience at the C-43 WQTTP that saw TN concentrations reduced from about 1.5 mg/L to 1.1 mg/L and TP from 0.16 mg/L to less than 0.04 mg/L at loading rates up to 6 cm/d (J-Tech and WSI, 2019).

A conceptual layout for a 5,000-ac treatment wetland is shown on **Figure 4-2**. For planning purposes, it was assumed that the wetland would be compartmentalized into three cells, each with an effective treatment area of about 1,667 ac. The construction of cell embankments and supply and discharge canals would increase the total project footprint to about 5,400 ac. Estimated performance of the 5,000-ac system at an average flow of 457 cfs is summarized in **Table 4-2**. Over a 20-year planning period, the wetland system was estimated to remove over 8.6 million pounds of TN, 1.3 million pounds of TP, and 305 million pounds of TSS.

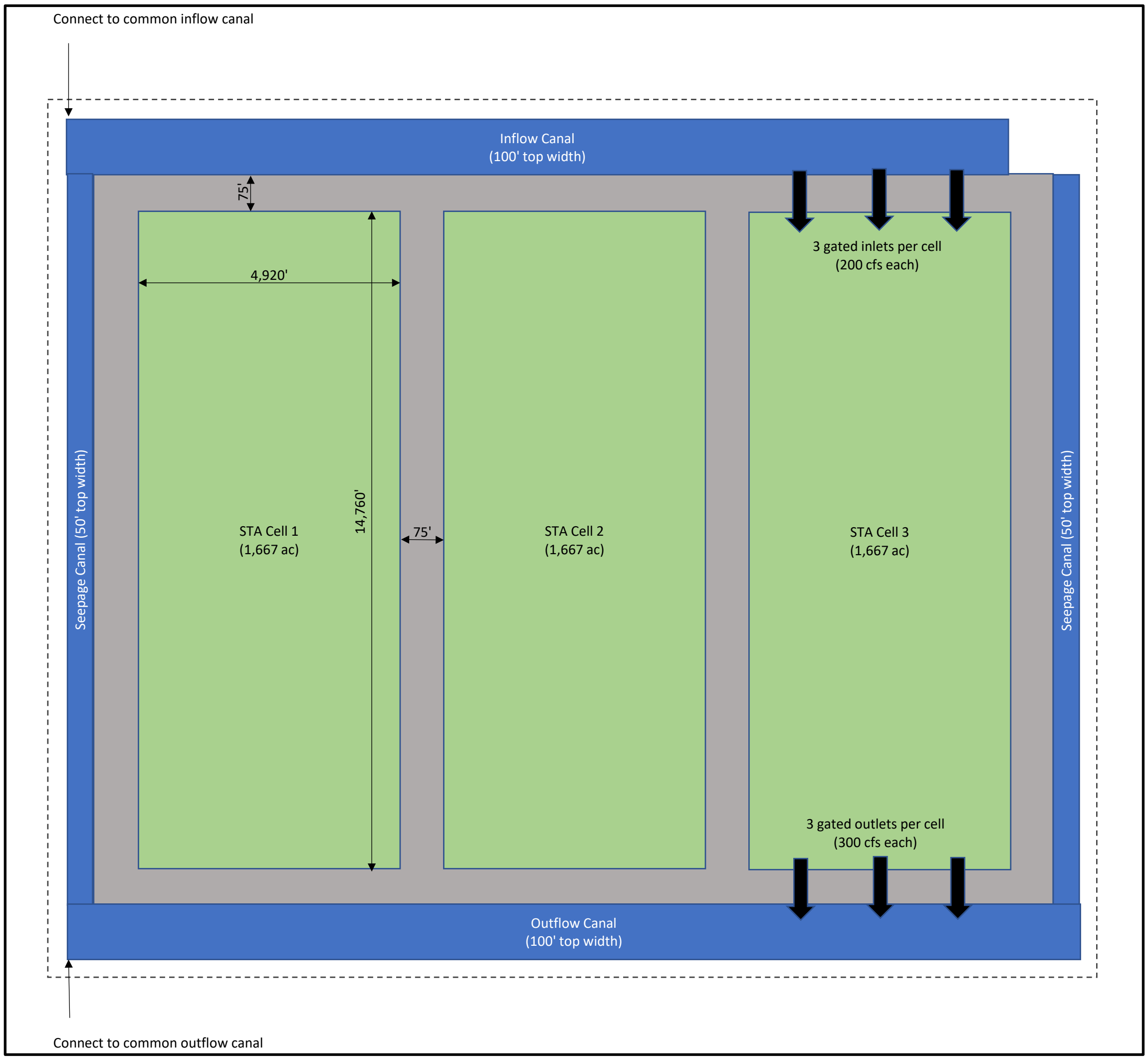


Figure 4-2. Conceptual Layout for C-43 WBSR Treatment Wetland System

Table 4-2. Estimated Performance for a 5,000-ac Treatment Wetland System

Parameter	TN	TP	TSS
Inflow Concentration (mg/L)	1.5	0.16	20
Outflow Concentration (mg/L)	1.02	0.085	3
Reduction (mg/L)	0.48	0.075	17
Efficiency	32%	47%	85%
Mass Removal (lbs/yr)	431,644	67,444	15,287,403
20-yr Mass Removal (lbs)	8,632,887	1,348,889	305,748,066

For cost-estimating purposes, it was assumed that embankments and canals would be constructed to typical SFWMD standards, similar to the existing STAs that have been constructed in the EAA and northern Lake Okeechobee watershed. Estimated capital costs were dominated by earthwork (cell grading, embankment construction, canal excavation) and were assumed to be $15/cubic yard of material. Costs for annual O&M were estimated from data provided by SFWMD for operation of the EAA STAs in 2017 and 2018. Non-pumping O&M costs averaged $215.57 per acre and included approximately $440,000/year for compliance monitoring. These O&M costs do not include pumping which is discussed in **Section 5.1**. Estimated capital and O&M costs are summarized in **Table 4-3**. The total estimated capital cost was $121.4 million, and the estimated annual O&M cost was $1.08 million. The NPV cost was estimated to be $136.0 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates.

Table 4-3. Estimated Capital and O&M Costs for a 5,000-ac Treatment Wetland

Activity/Element	Units	Quantity	Unit Cost	Extended Cost	Notes
Clearing and Grubbing	AC	5,400	$1,500	$8,100,000	
STA Grading	AC	5,000	$5,000	$25,000,000	Move 1 foot of material at $3/cy
STA Embankment	LF	90,000	$250	$22,500,000	440 ft^2 xsec = 16 cy/LF @ $15/cy
Inflow Canal	LF	15,000	$360	$5,400,000	640 ft^2 xsec = 24 cy/LF @ $15/cy
Outflow Canal	LF	15,000	$360	$5,400,000	640 ft^2 xsec = 24 cy/LF @ $15/cy
Seepage Canal	LF	30,000	$110	$3,300,000	200 ft^2 xsec = 7.5 cy/LF @ $15/cy
Gated Structures (200 cfs)	EA	9	$600,000	$5,400,000	$3,000/cfs
Gated Structures (300 cfs)	EA	9	$1,000,000	$9,000,000	$3,000/cfs
SCADA	LS	1	$1,000,000	$1,000,000	
Control Building	LS	1	$1,000,000	$1,000,000	
Construction Subtotal				***$86,100,000***	
Engineering	%	15		$12,915,000	
Permitting	%	1		$861,000	
Contingency	%	25		$21,525,000	
Total				**$121,401,000.00**	
Capital Cost per Acre				$24,280.20	
O&M	AC	5,000	$215.57	$1,077,835.00	
Net Present Worth				$136,048,124.00	

LF = linear foot; AC = acre; LS = lump sum; cy = cubic yard

4.2.2 Alum Treatment

Two alum treatment conceptual alternatives are proposed for treating C-43 WBSR water: an offline system to treat discharge from the WBSR and an online system designed to inject alum into the reservoir inlet during loading cycles. This section provides a brief overview of the components and costs of each.

4.2.2.1 Offline Alum Treatment System

A conceptual alternative for an offline alum treatment system is shown in **Figure 4-3**. Water from the WBSR would be pumped at an average flow of 457 cfs from the reservoir's north perimeter canal to an inflow canal of approximately 1,100 linear feet (LF) and then flow by gravity to a treatment area of approximately 50 ac. Alum for nutrient removal would be fed to the facilities inflow canal via a liquid alum feed system from a storage tank yard. The liquid alum feed system would consist of three 8,000-gallon exterior alum storage tanks with ultraviolet (UV) protection and secondary containment and two metering pumps with a control panel that a canopy protects from UV exposure.

Water from the inflow canal would then be split to flow to two parallel concrete rapid mix basins to provide flash mixing of the alum with paddle mixers. Each rapid mix basin holds approximately 102,000 gallons. The water from the rapid mix basins flows by gravity to two parallel earthen flocculation basins with high-density polyethylene (HDPE) liners via a conveyance canal of approximately 608 LF. The flocculation basins will be approximately 3 MG each and the entire flocculation zone will be aerated with a diffused air system via two 200 hp blowers to provide an airflow of approximately 6,500 standard cubic feet per minute. After the flocculation basins, flow will be directed over a submerged weir, 250 feet in length, in each basin to provide hydraulic separation between the flocculation basins and sedimentation basins. The earthen sedimentation basins will be HDPE lined and hold approximately 25 MG each.

The sedimentation basins are designed based on a surface loading rate of 0.40 gpm/ft^2 to settle out solids created by the alum treatment system during peak flow conditions. After sedimentation, the final treated effluent flow is discharged by gravity to a collection canal of approximately 457 LF that sends flow to the Townsend Canal. The alum treatment system has been sized to yield average outflow concentrations of 0.08 mg TP/L and 1.0 mg TN/L. These concentrations have been shown to be achievable at other full-scale alum facilities in Florida. For example, similar ranges of performance have been noted for the Upper Lake Lafayette Nutrient Reduction Facility in Tallahassee, where the inflow TP range of 0.05-0.3 mg/L is reduced by 74% to a range of less than 0.01-0.1 mg/L (City of Tallahassee, 2018). Similarly, a 68% reduction in TN was measured, where inflow TN is reduced from a range of 0.3-0.8 mg/L to 0.05-0.4 mg/L.

Settled solids that accumulate in the sedimentation basins will be pumped to a centrifuge dewatering facility. The following assumptions were applied to develop a conceptual plan for the dewatering facility:

1. 0.12 MGD of sludge flow (alum floc, algae, and biological matter) = 120,000 gallons per day (given)
2. 120,000 gallons per day @ 4% solids = 40,057 dry lb/day
3. From a centrifuge manufacturer (Alfa Laval), the maximum capacity of G3-125 centrifuge for this type of WTP alum sludge is 4,000 pounds per hour or 200 gpm.
4. Operating 5 days per week, 13 hours per day, two operating units would be needed. If operated 7 days per week, 16 hours per day, 1 operating and 1 standby = 2 units would be assumed to save significant amount of money for equipment and dewatering building space.
5. One standby redundant centrifuge unit (a typical practice) for a total of three installed centrifuge units
6. Three (3) centrifuge sludge feed pumps

7. Three (3) emulsion polymer systems
8. Three (3) cake screw conveyor systems
9. 67-foot X 60-foot dewatering building with centrifuges on mezzanine above cake conveyors that includes footprint for electrical room

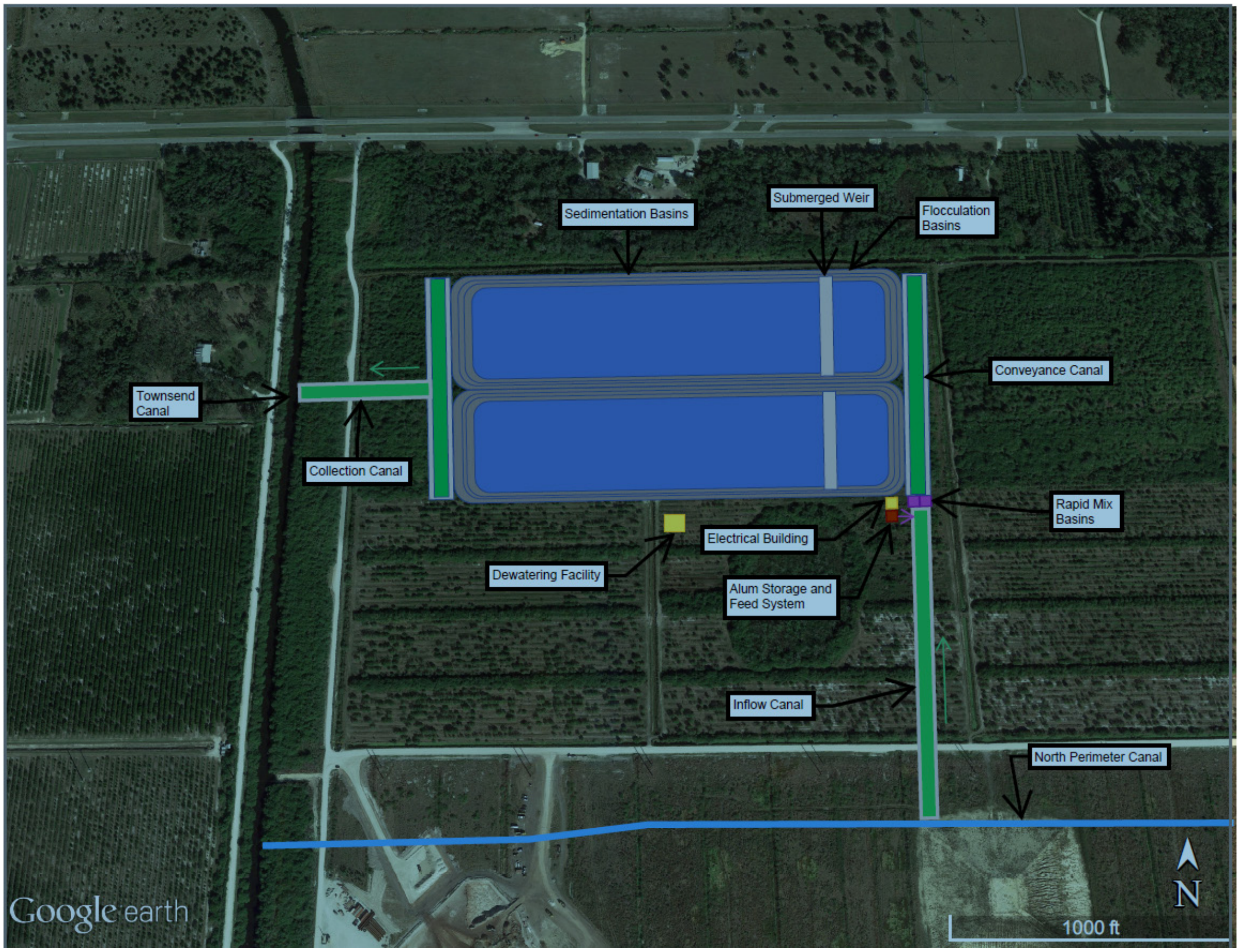


Figure 4-3. Conceptual Layout for C-43 WBSR Offline Alum Treatment System

For cost-estimating purposes, capital costs were estimated for the alum injection system, including rapid mixing chamber, flocculation basin, and settling basins, as well as the dewatering and solids management system. Annual operating costs for the alum injection system totaled $1,310,000 and $1,400,000 for the dewatering system. Floc pumping was estimated to cost $1,200,000 and compliance monitoring was $440,000. The total estimated capital cost was $25.13 million, and the estimated annual O&M cost was $4.34 million. The NPV cost was estimated to be $84.13 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates.

4.2.2.2 Online Alum Injection System

As a more simplistic treatment alternative for adding liquid alum for phosphorus removal treatment, alum can be injected directly into the formed suction intake of the inflow pump station to the C-43 reservoir and some mixing of the alum will occur with the discharge of the pump station to the reservoir. The mixing of this type of alum introduction would operate at a 50% efficiency compared to the rapid mix basins for the offline system and alum dosing rates would have to be doubled to achieve the same amount of phosphorus removal. Furthermore, the amount of sludge produced will also double. Given the size of the reservoir, the assumption is that the floc would be retained in the sediments without need for removal for at least 50 years or longer.

Although the liquid alum storage and feed system would be sized to treat up to the peak inflow to the reservoir of 1,500 cfs, the liquid alum storage and feed system will on average dose to treat 457 cfs of inflow to conserve on the average alum consumption and is sufficient to maintain control on algal growth in the reservoir. The liquid alum feed system consists of six 30,000-gallon exterior alum storage tanks with UV protection and secondary containment and two metering pumps with a control panel that a canopy protects from UV exposure. A small electrical building that has a footprint 102 square feet is also included to house the motor control centers and variable frequency drives for the alum feed pumps.

The capital cost is estimated to be $2,187,000 and annual operating costs are estimated to be $695,000. The NPV cost was estimated to be $11.63 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates.

4.2.3 HWTT

As summarized in **Section 3.1.6**, the HWTT treatment area uses 459 ac, consisting of two treatment trains with multiple treatment ponds in series. The mixing pond where alum is mixed with water from the reservoir will require approximately 1 ac of land in total (two 0.5-ac ponds). The water will move through four settling ponds to allow for floc (alum and nutrients) to settle out to the bottom of the cell. The wetland treatment facility will include FAV and SAV ponds. The estimated total acreage for the settling, FAV, and SAV ponds is 104 ac, 154 ac, and 200 ac, respectively, for a total pond treatment land area of 459 ac.

Supporting facilities are considered to be the areas required for access (internal access roads, perimeter access road, and embankments), chemical storage/dosing facilities, and miscellaneous areas such as those used for storage, parking, pump station pads, and other similar uses. The total land area for supporting facilities for the HWTT alternative is anticipated to be approximately 77 ac.

Solids will be pumped to the drying beds after accumulating in the settling ponds. The drying beds allow for passive dewatering of the solids material that is a byproduct of the treatment process through evapotranspiration and seepage. The drying beds are sized based on an assumed solids accumulation rate in the settling ponds. Based on the anticipated flows to be treated, two beds will be required sized at 66 ac each. The total land area for residuals handling and solids storage is therefore 132 ac. The total project area needed is 668 ac and would treat the 457 cfs needed to meet the MFL.

The vendor estimates initial capital costs of approximately $21,197,000 (excluding contingency, engineering design, and post-construction surveys/certification). Estimated annual O&M costs are approximately $7,200,000, and chemicals (mostly alum) represent 92% of that total. The NPV cost was estimated to be $119 million for a 20-year period using a discount rate of 4%. It should be noted that land acquisition costs were not included in the estimates.

Additional details provided by Watershed Technologies, LLC regarding this alternative can be found in **Appendix E.**

4.2.4 Treatment Wetland with Bold & Gold®

A potential combined system could include a 1,000-ac treatment wetland with a 104-ac Bold & Gold® media filtration system. The individual areas were derived under the assumption that the land area available would support a 1,000-ac wetland, which would be expected to provide consistent treatment for 20% of the average flow (about 91 cfs), commensurate with the reduction in area from a full-scale 5,000-ac STA. A 104-ac Bold & Gold® filter would treat 235 cfs, with the expectation that the water would be treated to lower concentrations than specified. The outflow from the treatment wetland and Bold & Gold® filter would be blended with untreated water in the reservoir discharge and still meet the water quality objective set for the purpose of this Study. The total flow treated by the combined technologies would be 325 cfs.

The capital, O&M, and NPV costs were estimated by proportion to the flow treated. The total capital cost was estimated to be $115.9 million, with annual O&M costs of $0.65 million. The 20-year NPV cost was estimated to be $124.7 million. It should be noted that land acquisition costs were not included in the estimates.

4.2.5 Sand Filtration with Bold & Gold®

As a conceptual alternative for treatment of the C-43 WBSR discharge, the combination of a full-scale sand filter and a parallel media filtration facility was investigated and is described in this section. The sand filter would provide a sustainable alternative to implementing a full-scale treatment wetland but at a reduced area. The sand filter hydraulic loading rate appropriate for the range of TP and TN reduction required for this application is on the order of one foot/day. Similarly, the media filtration beds using Bold & Gold® media are capable of a significantly greater hydraulic throughput of 5 inches/hour (Environmental Conservation Solutions, 2020). Both systems offer the benefit of a simpler operational approach consisting primarily of hydraulic flow maintenance and site vegetation management.

As a system with a total reduced footprint, the key working assumption for the sand filter and Bold & Gold® facility is that, on average, 20% (91 cfs) of the average daily flow of 457 cfs would be routed to a 200-ac sand filter. As detailed in the Bold and Gold® submittal (Environmental Conservation Solutions, 2020), because the media is expected to treat to lower concentrations than the study objectives, 64% (234 cfs) of the remaining 80% of the average daily flow would be treated through the media filtration beds. As a result, the total flow treated by the sand filter and media system would be 325 cfs. The combined flows from both components would yield average outflow concentrations of 0.08 mg/L of TP and 1.0 mg/L of TN.

The total Bold & Gold® treatment area is estimated to be 104 ac, based upon the proportion (80%) of total system flow treated and the projected full-scale Bold & Gold® treatment area of 130 ac. Of this total area, 60 ac would consist of twelve 5-ac ponds. Access roads and drainage infrastructure and stormwater management would comprise the remaining 44 ac.

Water from the C-43 WBSR would be pumped from the perimeter canal to the sand filter through an open distribution channel. Water would flow by gravity through parallel discharges to the distribution channel of the sand filter and the distributed piping of the Bold & Gold® system. Water filtering through the sand filter and the Bold & Gold® beds would be collected by underdrains and be routed by gravity to collector channels and then to the discharge channel for an outflow to the C-43.

The capital, O&M, and NPV costs were estimated by proportion to the flow treated. The total capital cost was estimated to be $133.7 million with an O&M cost of $0.97 million. The 20-year NPV cost was estimated to be $146.9 million. It should be noted that land acquisition costs were not included in the estimates.

4.2.6 ElectroCoagulation

The ElectroCoagulation vendor proposed a full-scale system sized to treat the average flow of 457 cfs by blending 53% of treated water with untreated water to arrive at the desired reduction target for TP, TN, and TSS for this Study. This would be implemented with a 10-second hydraulic retention time in the ElectroCoagulation chamber. The facility would receive pumped flow from the C-43 WBSR through the inlet conveyance channel.

The equipment sizing and number of units required was based on a 20-hour per day operating cycle for each ElectroCoagulation unit to allow for tank acid cleaning and periodic plate replacement. Thirty-six of the units would treat 240.5 cfs. The 36 units would be housed in a hurricane rated covered metal building approximately 1,850 feet in length by 140 feet in width and approximately 24 feet in height. Each unit is mounted on 18-foot by 17-foot skids. The units would be elevated on a structural steel mezzanine to allow for gravity flow for cleaning and free flow of the treated water to the next process phase of solids separation.

Each ElectroCoagulation unit would include the following equipment:

1. Atmospheric reaction chamber up to 140 degrees Fahrenheit
2. 1/8-inch screen filter (customer must prescreen to 1/32 of an inch)
3. System supply pump
4. Air purge
5. 480-volt alternating current to direct current power supply with current control, programmable logic controller, and polarity reversing
6. Steel and aluminum 217 blade set with 2,229,000 square inches per set
7. Automated drain back cleaning

For solids handling, the facility would include a 250-foot-diameter clarifier, gravity belt thickeners, and dewatering centrifuges. The facility would include access roads, power, and electrical supply. A slurry of solids would be pumped to the dewatering facility. Treated water would overflow by gravity to the outlet channel for blending and conveyance to the C-43.

The capital, O&M, and 20-year NPV costs are $148.4 million, $3.16 million, and $191.4 million, respectively.

5.0 Cost-Benefit Analysis for Alternatives

Cost-benefit analysis is a tool used to examine the net economic benefits of a project or policy decision (Boardman et al., 1996). It has been widely used to examine the economic feasibility of public investments in a variety of areas including water resources, transportation, agriculture, and energy projects. The cost-benefit analysis is performed by comparing in present dollar terms the value of the total costs of a project to the value of its total benefits (Eisen-Hecht and Kramer, 2002). For this Study, the cost-benefit analysis indicates which alternative yields the highest water quality improvements and ancillary benefits to the affected stakeholders as compared to the total project costs that would be incurred. This section summarizes the costs of water conveyance infrastructure, treatment system capital and O&M costs, and the water quality benefits of each of the six project alternatives to support selection of the top treatment technology alternatives that will be further evaluated during the next phase of the project. Because this section is intended to provide a conceptual comparison of alternatives, it does not address the location and costs of highly specific project features, such as land parcels, intake or discharge locations, and site-specific infrastructure. The top recommended alternatives from this Study will be evaluated as viable alternatives based on maximum water quality treatment efficiencies, preliminary cost optimization, and a project siting study to select an alternative as the WQC Plan. The WQC Plan will be the basis for the Statement of Work for detailed design.

5.1 Infrastructure Costs

The costs presented in **Section 3.1** did not include delivery of water to each technology because the specific locations where the technologies might be implemented have not been fully identified. Some technologies proposed treating side-stream flows that would reduce their water delivery infrastructure needs when compared to systems that treat 457 cfs. For this Study, three facility sizes are being considered to identify an approximate estimate of costs needed for infrastructure including canals, roads, and pump station capacity. The final alternatives identified above have been designated small, medium, and large based on flow capacity and land requirements.

A small site was assumed to consist of a 50-ac area used to construct a technology-based water treatment system, which could be located near the northwest corner of the C-43 WBSR adjacent to the Townsend Canal. Water would be pumped using a new 250 cfs pump station, from the C-43 WBSR's north perimeter canal into a 1,100 LF inflow canal. Water from this inflow canal would be treated within the facility and then discharged by gravity into the adjacent Townsend Canal via a 400 LF discharge canal. The infrastructure required for this concept includes a pump station, 1,600 LF of canals, a single-barrel gravity discharge structure, and 1,600 LF of access/ maintenance base-rock roads (see **Figure 5-1**).

A medium sized project site was assumed to consist of a 1,000-ac area used for a HWTT facility. This area would be situated just north of the C-43 WBSR's northeast boundary and would receive inflows from the perimeter canal via a newly constructed 300 cfs pump station and 800 LF canal. Once the water has been successfully treated, it would be released into an 800 LF discharge canal ultimately discharging back into the perimeter canal. The infrastructure required for this concept would include a 300 cfs pump station, 1,600 LF of canals, a single-barrel gravity discharge structure, and 1,600 LF of access/maintenance road paralleling both sides of the inflow and discharge canals (see **Figure 5-2**).

The large project option was assumed to consist of a 5,000-ac area that would be used as a series of treatment wetland cells. Inflows would be provided by a 450 cfs pump station and 800 LF canal located on the east side of the C-43 WBSR. Discharge would be provided by a 400 LF outflow canal with a gravity discharge structure draining back into the perimeter canal. The infrastructure required for this system would include a 450 cfs pump station, 1,200 LF of canals, a single barrel gravity discharge structure, and 1,200 LF of access/maintenance roads on both sides of the inflow and outflow canals (see **Figure 5-3**).

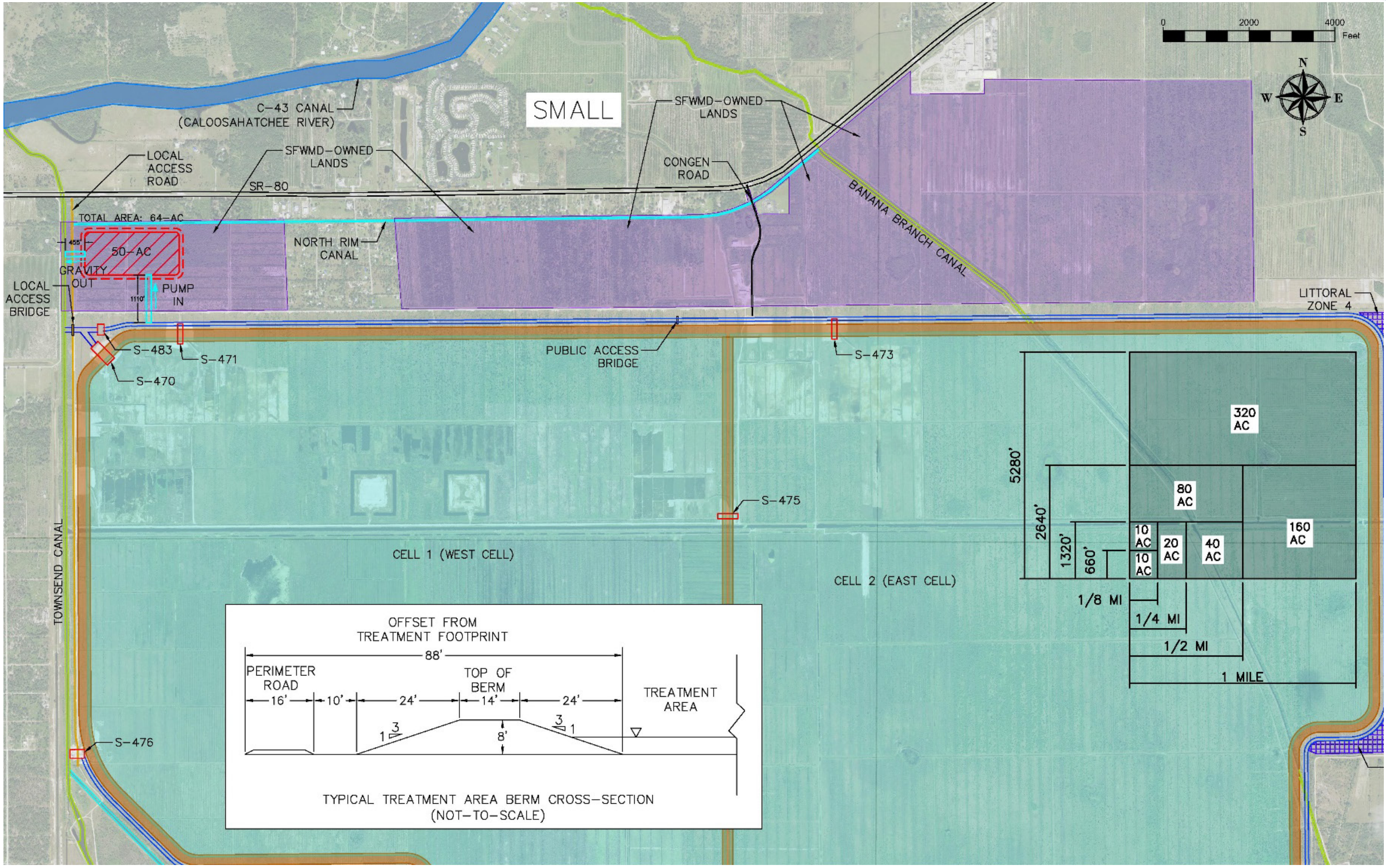


Figure 5-1. Example Infrastructure for a Small Treatment Facility

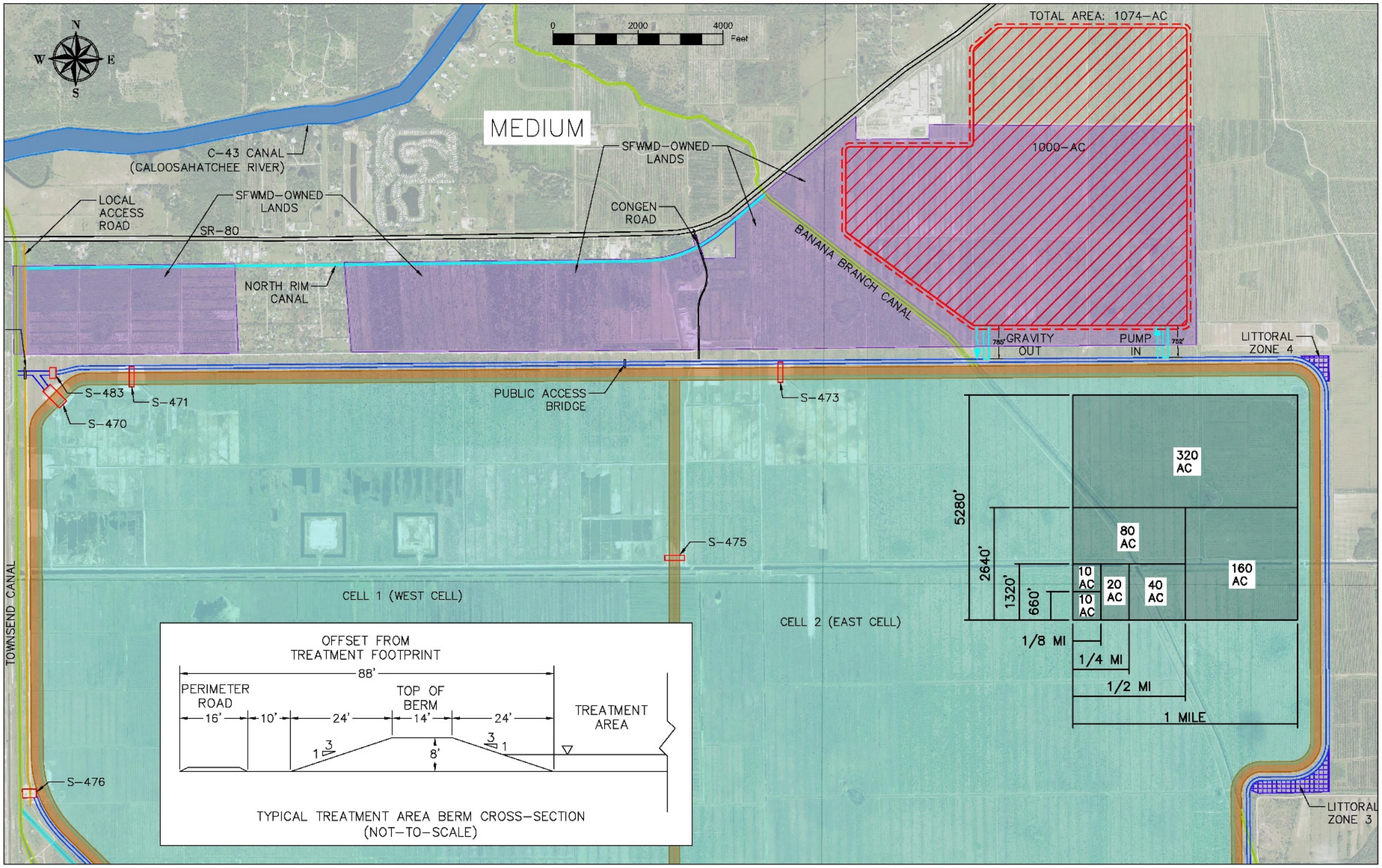


Figure 5-2. Example Infrastructure for a Medium Treatment Facility

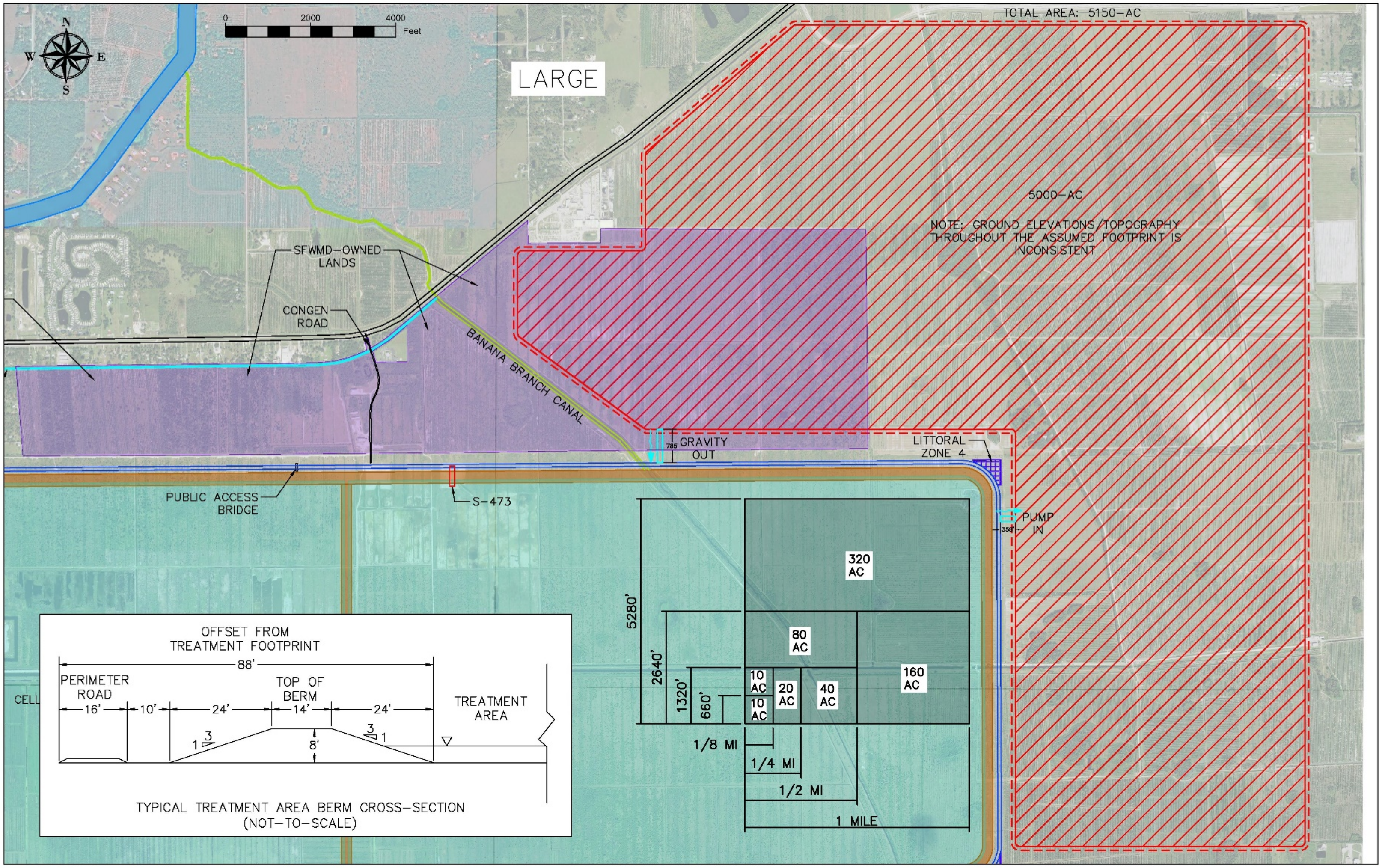


Figure 5-3. Example Infrastructure for a Large Treatment Facility

These preliminary infrastructure cost estimates are intended to be used for comparative purposes only (**Table 5-1**). Design constraints based on site-specific conditions will ultimately define the final infrastructure costs. These estimates are based on average prices for similar types of work extrapolated to accommodate the facilities sizes shown in these preliminary sketches. They use the same unit costs for each item of work. The only changes from small, medium, and large are the size of the proposed pump station and the approximate length of inflow and outflow facilities. Canal and road widths are assumed to be the same for all three conditions. The discharge structure is assumed to be a single bay for all three project sizes.

Table 5-1. Preliminary Estimate of Infrastructure Costs

SMALL				
Feature	**No.**	**Unit**	**Unit Cost**	**Total**
Pump Station	250	cfs	55,000	13,750,000
Canals & Roads	1,600	LF	750	1,200,000
Discharge Structure	1	EA	1,000,000	1,000,000
			Total:	**$15,950,000**
MEDIUM				
Feature	**No.**	**Unit**	**Unit Cost**	**Total**
Pump Station	300	cfs	55,000	16,500,000
Canals & Roads	1,600	LF	750	1,200,000
Discharge Structure	1	EA	1,000,000	1,000,000
			Total:	**$18,700,000**
LARGE				
Feature	**No.**	**Unit**	**Unit Cost**	**Total**
Pump Station	450	cfs	55,000	24,750,000
Canals & Roads	1,200	LF	750	900,000
Discharge Structure	1	EA	1,000,000	1,000,000
			Total:	**$26,650,000**

5.2 Capital and O&M Costs

The capital and O&M costs for HWTT, Bold & Gold®, and ElectroCoagulation were provided by the vendors. The construction and O&M costs for the treatment wetland, sand filtration, and alum treatment were developed by J-Tech. The annual O&M cost for the conveyance infrastructure was assumed to be 5% of the construction cost. This assumption captures the replacement maintenance and power cost for the pump station, maintenance of the hydraulic control structures, and maintenance of the conveyance channels. The total capital and O&M costs were combined to derive a project life cycle cost for 20 years for each alternative. The capital, O&M, and NPV costs are summarized in **Table 5-2**.

Table 5-2. Summary of Capital, O&M, and NPV Costs for the Alternatives

Alternative	Capital Cost ($ millions)	Annual O&M Costs ($ millions/yr)	NPV 20-year ($ millions)
Treatment Wetland	$148.1	$2.41	$180.8
Alum Treatment	$51.8	$5.67	$115.5
HWTT	$47.8	$8.53	$163.8
Treatment Wetland with Bold & Gold®	$134.6	$1.58	$156.1
Sand Filtration with Bold & Gold®	$152.4	$1.91	$178.3
ElectroCoagulation	$164.3	$3.96	$218.1

5.3 Monitoring Costs

Monitoring falls into two general categories: (1) compliance monitoring and (2) process control monitoring. For purposes of this Study, it is assumed that the water quality performance of the selected technology would be routinely measured to demonstrate a net improvement in water quality. The requirements of the compliance monitoring program are not currently known, but it can be assumed that they will be independent of the size or complexity of the selected technology. Compliance monitoring costs are anticipated to be low in comparison to capital and other O&M costs. Process control monitoring includes the testing and instrumentation needed to operate each technology successfully and efficiently. The monitoring costs are built into the construction and O&M costs described above in **Sections 3.1** and **4.2**, respectively.

5.4 Project Benefits by Alternative

For this Study, the benefits evaluated include water quality improvement including TN and TP removal, as well as algal suspended solids (TSS, which was also used as proxy for algae removal). It is recognized that some water quality benefits are expected to occur during water storage within the C-43 WBSR. TN and TP would be retained and buried in sediments, and TSS would settle out of the water column. The Study focuses on additional nutrient and TSS removal technologies to ensure that the water returning to the C-43 and ultimately to the CRE has improved water quality compared to the ambient condition. Water quality monitoring to be performed during operation of the water quality treatment system would be used to characterize the quality of water from the WBSR and to the C-43 . Additional monitoring during reservoir filling and storage could characterize the quality of water being sent to and stored in the reservoir.

Each of the final technologies has been evaluated for its ability to treat flows and improve water quality. The benefits provided by each alternative are described in **Table 5-3** and shown in **Figure 5-4**.

Table 5-3. Water Quality Treatment Alternatives: Unit Cost by Parameter Removed

Alternative	Area (ac)[1]	Treated Flow (cfs)	Unit Cost TN Removed (20-year)	Unit Cost TP Removed (20-year)	Unit Cost TSS Removed (20-year)
Treatment Wetland	5,000	457	\$27.22	\$170.15	\$1.36
Alum Treatment (offline)	50	457	\$17.40	\$108.73	\$0.87
HWTT	668	457	\$24.66	\$154.15	\$1.23
Treatment Wetland with Bold & Gold®	1,000 Wetland 104 Bold & Gold®	91 Wetland 234 Bold & Gold® 325 Total	\$23.51	\$146.93	\$1.18
Sand Filtration with Bold & Gold®	200 Sand Filter 104 Bold & Gold®	91 Sand Filter 234 Bold & Gold® 325 Total	\$26.85	\$167.81	\$1.34
ElectroCoagulation	150	229	\$32.85	\$205.29	\$1.64

[1] Based on nutrient removals set for the purpose of this study.

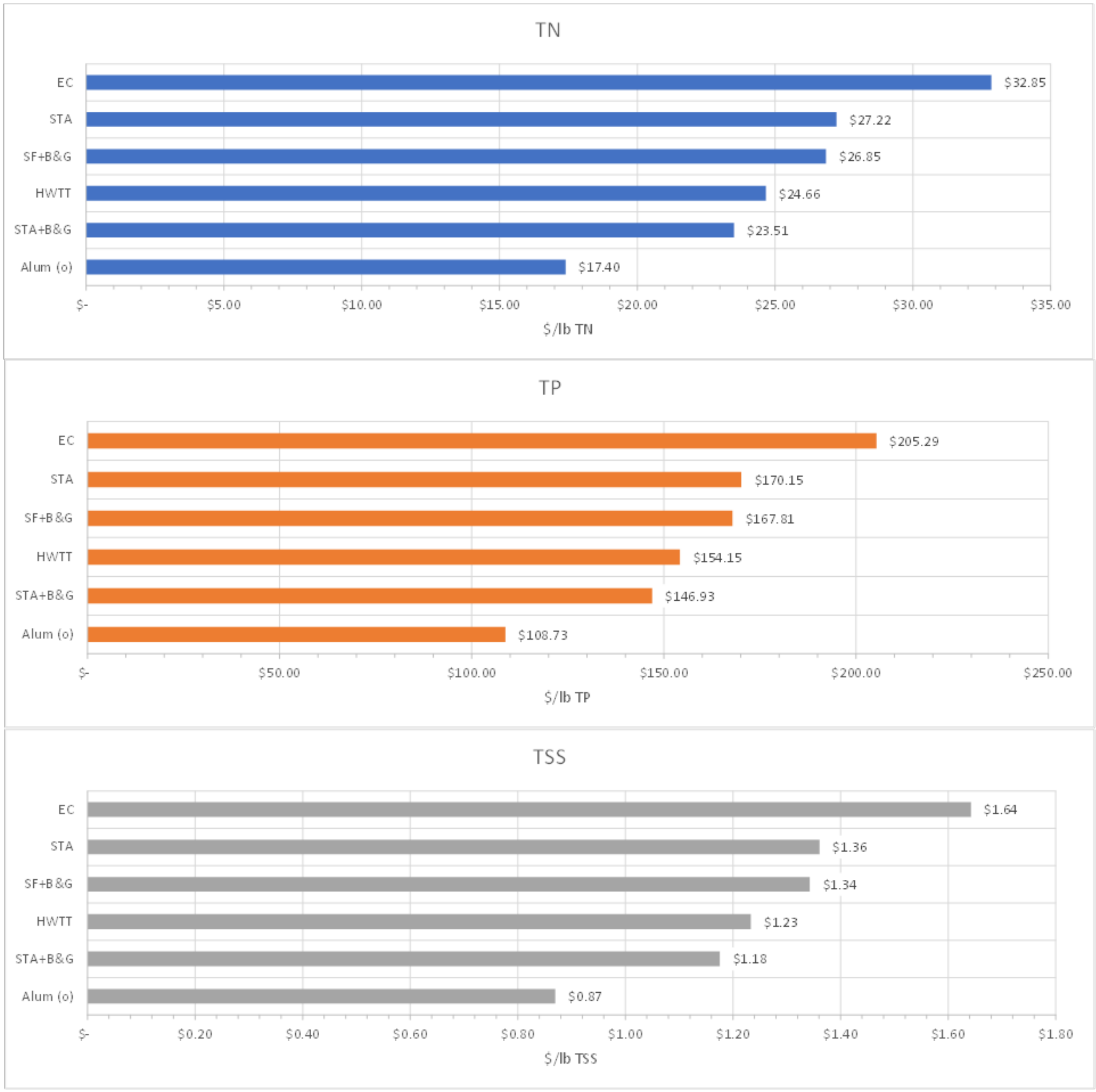


Figure 5-4. **Unit Costs of Alternatives by Water Quality Benefits for TN (top), TP (middle), and TSS (bottom)**

The results of this conceptual comparative analysis indicate that alum treatment technologies afford the most cost-effective nutrient reduction relative to other alternatives. The estimated unit cost by offline alum treatment is estimated to be $17 per pound of TN removed and $109 per pound of TP removed. These estimates agree well with reported unit cost ranges of $6-$32 per pound of TN and $40-$115 per pound of TP for full-scale alum injection facilities in Florida (Bottcher et al., 2009). The HWTT unit costs are also within range of these observed unit costs, given the preliminary nature of all costs presented here, while including the ancillary benefit of significant wetland habitat and flexibility in adjusting alum dose based upon seasonal variation in nutrient concentration or flow rate.

The treatment wetland and Bold & Gold® and sand filter and Bold & Gold® would each create a significant area of wetland habitat and associated ecological benefits. The treatment wetland alternative land area is large relative to existing SFWMD land holdings but would not require the use of chemicals to achieve the objectives. The ElectroCoagulation alternative may offer the greatest adjustable control over outflow concentration of all technologies.

One beneficial aspect of the offline alum treatment system alternative, as well as the HWTT alternative (Watershed Technologies, 2020b), is the potential to include an online system to inject alum directly into the reservoir for algal bloom control and enhanced nutrient retention. Based upon the preliminary evaluation in this Study, the unit costs of this mode of operation are significantly lower than the offline facility (**Table 5-4**).

Table 5-4. Unit Cost Comparison of Online and Offline Alum Treatment Alternatives

Alternative	TN (cost per pound)	TP (cost per pound)	TSS (cost per pound)
Online	$5.25	$32.84	$0.26
Offline	$17.40	$108.73	$0.87

6.0 Recommendations and Next Steps

The next phase of the project will be the C- 43 WBSR WQC Siting Evaluation. The top recommended alternatives from this Study will be evaluated as viable alternatives based on maximum water quality treatment efficiencies, preliminary cost optimization, and a project siting study to select an alternative as the WQC Plan. The WQC Plan will be the basis for the Statement of Work for detailed design. J-Tech recommends that the final WQC Plan include both in-reservoir treatment with alum to help prevent algal blooms within the reservoir itself, as well as a post-storage water quality component to treat reservoir discharges that can be closely monitored prior to being returned to the Caloosahatchee River and Estuary. The technologies identified are cost-effective options that reduce the discharge of nutrients that may contribute to algal blooms to the downstream CRE. It is imperative that the current C-43 WBSR construction schedule and all project purposes are not impacted by the recommendations ultimately provided in the Study. Based on the technologies reviewed in the Information Collection Summary Report (**Appendix A**), the attribute ranking evaluation, alternatives formulation and analysis, and the cost-benefit analysis, the final recommendations are presented in **Section 6.1**.

6.1 Recommended Alternatives

With input from the Working Group and feedback from four public meetings, including two virtual meetings, the following alternatives are recommended for further evaluation for project implementation in the next phase:

- Alum treatment – both as an offline treatment facility and online, in-reservoir injection system
- Smaller treatment wetland with parallel Bold & Gold® treatment
- HWTT
- Sand filter with parallel Bold & Gold® treatment

Based on the cost benefit analysis, the offline alum treatment system resulted in the lowest cost per pound for nutrient removal, as well as the smallest land requirements. In-reservoir alum treatment was also evaluated and found to be even more cost effective with no additional land requirements. For these reasons, online alum injection is recommended to be included as a component of the ultimate C-43 water quality treatment system. However, while alum injection provides a measure of control over nutrient concentrations and algal production within the reservoir, the duration of storage may lead to changes in the water quality in the WBSR. Additional treatment of the reservoir discharge is recommended, given the primary objective of the C-43 water quality treatment system to ensure that water discharged to the canal does not contribute to impairments of downstream water quality compared to existing conditions in the Caloosahatchee River Basin. The parallel treatment system that combines a smaller STA or sand filter with Bold & Gold®, either as a pre-treatment or post-treatment system, was the next most cost-effective technology. The parallel treatments provide flexibility in the volumes of flows that can be treated prior to discharge, where one technology is used for lower flows and the other is on standby for higher flow conditions. For example, the STA may be sized to receive a continuous baseflow during discharge while media filtration may be sized to treat the remainder of flow, which is expected to vary. Further technology evaluation may determine that a smaller and less expensive system could treat similar flow volumes. The HWTT system, the third most cost-effective alternative, is well studied in Florida systems and this Study confirmed that it is cost effective for removing nutrients. The parallel treatment system that combines a smaller sand filter with Bold & Gold® was the fourth most cost-effective alternative.

The full-scale (5,000-ac) treatment wetland alternative ranked fifth based on water quality cost-effectiveness; however, the capital cost used for the analysis did not include the acquisition of additional land that would be needed for project implementation. With land costs considered, the cost per pound for nutrient removal for the full-scale treatment wetland would further increase the separation between the wetland alternative and higher ranked alternatives. Despite the higher total cost that would be expected for the treatment wetland alternative, J-Tech and the Working Group received several stakeholder comments supporting the continued consideration of this alternative based on the proven history of success across South Florida, magnitude of ancillary benefits these systems offer to humans and wildlife, provision of additional storage volume, and avoidance of chemical application to meet water quality improvement objectives. It should be noted that a full-scale treatment wetland was not considered in conjunction with the design of the C-43 WBSR, which may add complications related to topographic variations between the C-43 WBSR and a potential treatment wetland site. A thorough investigation to identify potential land acquisition opportunities that would supplement the approximately 1,900 acres owned by SFWMD located directly adjacent to the C-43 WBSR and south of State Road 80 may result in a revised total cost for the treatment wetland alternative that is lower than currently anticipated. For these reasons, SFWMD may choose to retain the treatment wetland alternative for further evaluation.

6.2 Next Steps

The next phase of the project will be the C- 43 WBSR WQC Siting Evaluation. The top recommended alternatives from this Study will be evaluated as viable alternatives based on a more in-depth analysis of expected water quality and chemistry to more specifically evaluate project performance and identify target TN, TP, and TSS removal rates; maximum water quality treatment efficiencies; conceptual cost optimization; and a siting study to determine land availability and specific infrastructure needs to select an alternative as the WQC Plan. The WQC Plan will be the basis for the Statement of Work for detailed design with the goal of project construction to be completed and online concurrently with full operation of the reservoir.

J-Tech currently recommends that the final WQC Plan include both in-reservoir treatment with alum to help prevent algal blooms within the reservoir itself, as well as a post-storage water quality component to treat reservoir discharges that can be closely monitored prior to being returned to the Caloosahatchee River.

6.3 C-43 Water Quality Alternative Treatment Technology Pilot Study

As noted in **Section 6.1**, the top four alternatives include either alum treatment or Bold & Gold® media. The Working Group and public raised some questions about the efficiency of these technologies to treat the chemical composition of the water found within the C-43 basin. To help address these questions, SFWMD initiated the C-43 Water Quality Alternative Treatment Technology (WQATT) Pilot Study. The preliminary results from the first month of the Pilot Study are attached in **Appendix G**. SFWMD is extending the study to evaluate the treatment efficiencies during the wet and dry seasons and to allow the Bold & Gold® media to reach its full treatment capacity. The results from both the preliminary and expanded pilot studies will be used in the WQC Siting Evaluation to assist in analyzing the alternatives in greater detail.

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Appendix A: Information Collection Summary Report

C-43 West Basin Storage Reservoir Water Quality Feasibility Study

Deliverable 2.2: *Final* Information Collection Summary Report

Prepared for

South Florida Water Management District

Date

April 3, 2020

Prepared by

J-Tech, an Alliance between Jacobs Engineering and Tetra Tech, Inc.

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Appendix

Acronyms and Abbreviations

10^6 ac-ft/yr	Million acre-feet per year
µg/L	Microgram per liter
ac-ft	Acre-feet
ADS	Air diffusion system
Alum	Aluminum sulfate
BDON	Bio-available dissolved organic nitrogen
BMAP	Basin management action plan
BMP	Best management practice
BOD	Biochemical oxygen demand
CERP	Comprehensive Everglades Restoration Plan
chl *a*	Chlorophyll *a*
cfs	Cubic feet per second
cm/d	Centimeter per day
CDOM	Carbonaceous organic matter
Coordinating Agencies	SFWMD, DEP, and FDACS
COD	Chemical oxygen demand
CRE	Caloosahatchee River Estuary
CRWPP	Caloosahatchee River Watershed Protection Plan
DAF	Dissolved air flotation
DEP	Florida Department of Environmental Protection
DO	Dissolved oxygen
DON	Dissolve organic nitrogen
DSBB	Debris separating baffle box
EAA	Everglades Agricultural Area
EAV	Emergent aquatic vegetation
ENP	Everglades National Park
FAV	Floating aquatic vegetation
FDACS	Florida Department of Agriculture and Consumer Services
FTW	Floating treatment wetland
FWM	Flow-weighted mean
gpm/ft^2	Gallon per minute per square foot
HAB	Harmful algal bloom
hp	Horsepower
HWTT	Hybrid wetlands treatment technology
J-Tech	Jacobs Engineering and Tetra Tech, Inc.
kWH	Kilowatt-hour
lbs/yr	Pounds per year
LCDNR	Lee County Department of Natural Resources
mg/L	Milligrams per liter
MGD	Million gallons per day
mt	Metric ton
mt/yr	Metric tons/year
NEEPP	Northern Everglades and Estuaries Protection Program
NTU	Nephelometric turbidity units

PFWS	Phosphorus Free Water Solutions
ppb	Parts per billion
PSTA	Periphyton stormwater treatment areas
SAV	Submerged aquatic vegetation
SD	Standard deviation
SFWMD	South Florida Water Management District
SRP	Soluble reactive phosphorus
STA	Stormwater treatment area
Study	C-43 West Basin Storage Reservoir Water Quality Feasibility Study
TKN	Total Kjeldahl nitrogen
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WBSR	C-43 West Basin Storage Reservoir
WCA	Water Conservation Area
Working Group	C-43 Water Quality Feasibility Study Working Group
WQTTP	Water Quality Treatment and Testing Project
WSI	Wetland Solutions, Inc.
WY	Water year

Executive Summary

On January 10, 2019, Governor Ron DeSantis signed Executive Order 19-12, calling for greater protection of Florida's environment and water quality. The Executive Order directed the state's agencies to take a more aggressive approach to address some of the environmental issues plaguing the state, with a significant emphasis on south Florida and the harmful algal blooms (HABs) associated with blue-green algae. Specifically, the Executive Order directed the Florida Department of Environmental Protection (DEP) to "work with the South Florida Water Management District to add stormwater treatment to the C-43 Reservoir to provide additional treatment and improve the quality of water leaving this important storage component" of the Comprehensive Everglades Restoration Plan.

This Information Collection Summary Report is the preliminary document for the C-43 West Basin Storage Reservoir (WBSR) Water Quality Feasibility Study, which compiles pertinent information on the key topics of Caloosahatchee River Watershed water quality, blue-green algae ecology and management, and water quality improvement technologies. This report provides a summary of available, technically feasible, conventional, and innovative biological, chemical, and physical treatment technologies for water quality improvement for eventual pre-treatment, in-reservoir treatment, and/or post-treatment application to the C-43 WBSR. Conventional technologies evaluated include, but were not limited to, physical and chemical methods used in water treatment, wastewater treatment, and environmental remediation. Physical methods evaluated include separation of solids from water by use of filtration technologies. Chemical methods evaluated include removal of solids or nutrients by introducing a chemical compound to coalesce particles for enhanced settling or inactivation of nutrients. Natural treatment systems evaluated include, but were not limited to, ponds; treatment wetlands dominated by emergent aquatic vegetation, floating aquatic vegetation, submerged aquatic vegetation, periphyton, or mixed marsh; and media filtration systems, such as vertical downflow subsurface flow systems (managed and passive).

The conventional water quality treatment alternatives described in this report are predominantly gathered from the DEP Accepted Water Technologies Library (DEP, 2020) but also include information submitted directly to the Water Quality Feasibility Study consultant, J-Tech (Jacobs Engineering and Tetra Tech, Inc.), and the C-43 WBSR Water Quality Feasibility Study Working Group members from additional technology vendors. The summary of available conventional and natural treatment technologies described in this report indicates that a wide range of approaches are available. All technologies are constrained to varying degrees by limitations on the scale of operation that will be necessary to provide effective treatment for the C-43 WBSR, while not affecting the congressionally approved C-43 Reservoir project purposes, infrastructure, construction schedule, or operation. For this preliminary review, the list of potentially applicable technologies was evaluated and reduced to 25 technologies recommended for further evaluation. Key criteria to evaluate the technologies during this initial step included:

- General knowledge base.
- Performance within appropriate concentration ranges for the key water quality parameters.
- Scalable to flows within the project range.
- Available Florida case studies.

- Unit capital and operational cost information or preliminary estimates of full-scale cost.

Table ES-1 summarizes the list of 25 technologies recommended for further evaluation.

Table ES-1. List of 25 Technologies Recommended for Further Evaluation

Technology	Justification for Further Evaluation
Advanced Wastewater Treatment	▪ Long history of application treating wastewater ▪ Capable of achieving low total nitrogen (TN) and total phosphorous (TP) concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available
Air Diffusion Systems (ADS)	▪ Aeration is a well-established technology ▪ Capable of achieving low TN and TP concentrations ▪ Can be scaled to large volume reservoirs ▪ No Florida case study but multiple case studies available other states ▪ Vendor has provided plans and costs to treat C-43
Aluminum Chloride	▪ Long history of application treating wastewater, stormwater and surface water ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available
Aluminum Sulfate	▪ Long history of application treating wastewater, stormwater and surface water ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available
AquaLutions®™	▪ Recent application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Vendor confident of capacity to function at high flows ▪ Florida case studies ▪ Cost information available
Aqua-Swirl®	▪ Common application treating stormwater ▪ Capable of achieving high total suspended solids (TSS) (algae) removal ▪ Vendor confident of capacity to configure function at high flows ▪ No documented Florida case studies provided ▪ Cost will need to be estimated specific to application
Bold & Gold	▪ Recent history of application treating stormwater ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost information available
Ciba Krysalis FA/FC	▪ Used to treat Miami River, Port Manatee, and Tampa Bay ▪ Capable of achieving high TSS (algae) removal ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Denitrifying Bioreactor	▪ Long history of application treating stormwater and groundwater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Downstream Defender®	▪ Recent history of application treating stormwater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of treating a stream of the total flow to reduce overall concentration ▪ Florida case study not available ▪ Cost will need to be estimated specific to application

Technology	Justification for Further Evaluation
Dredgeclear 53	▪ Used to treat North Palm Beach Waterway and interior residential canals ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
ElectroCoagulation	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations and remove algae ▪ Vendor confident of capacity to configure function at high flows ▪ Florida case studies ▪ Vendor has provided plans and costs to treat C-43
Floating Treatment Wetlands (Biohaven)	▪ Increasing application in Florida waters ▪ Capable of achieving measurable TN and TP concentrations ▪ Scaling to large reservoir areas may be difficult ▪ Florida case studies ▪ Cost information available
FLOPAMTM EM 230	▪ Used before to treat the Gator Sand Mine ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost information available
Hybrid Wetlands Treatment Technology (HWTT)	▪ Recent history of application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Unit cost data available based on flow
Managed Recirculation	▪ Experimental approach but based on reservoir circulation studies ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired volume ▪ Florida case study information unavailable ▪ Cost information unavailable
Microbe-Lift	▪ Recent history of application treating surface water ▪ Capacity to achieve low TN and TP concentrations not demonstrated ▪ Capacity to function at similarly large volumes not demonstrated ▪ Florida case studies ▪ Unit cost information available
MPC-Buoy	▪ Recent history of application treating surface water ▪ Capable of treating algae populations ▪ Capacity to function at similarly large volumes not demonstrated ▪ Florida case studies just beginning ▪ Unit cost information available
NutriGone™	▪ Recent history of application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Optimer 7194 Plus	▪ Used before to treat eutrophic Lake Maggiore ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Sand Filtration	▪ Long history of application treating wastewater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Unit cost data available based on flow

Technology	Justification for Further Evaluation
SciCLONE™	▪ Recent history of stormwater treatment ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ No Florida case study information available ▪ Cost information available
Southern Algae Control	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies unavailable but Okeechobee applications investigated ▪ Vendor has provided plans and costs to treat C-43
StormPro®	▪ Long history of application treating wastewater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ No Florida case study information available
Treatment Wetlands	▪ Long history of application treating stormwater and groundwater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available

Note: Technologies are listed in alphabetical order

1.0 Background/Introduction

1.1 Overall Study Background

On January 10, 2019, Governor Ron DeSantis signed Executive Order 19-12, calling for greater protection of Florida's environment and water quality. The Executive Order directed the state agencies to take a more aggressive approach to address some of the environmental issues plaguing the state, with a significant emphasis on south Florida and the harmful algal blooms (HABs) associated with blue-green algae. Specifically, the Executive Order directed the Florida Department of Environmental Protection (DEP) to "work with the South Florida Water Management District (SFWMD) to add stormwater treatment to the C-43 Reservoir to provide additional treatment and improve the quality of water leaving this important storage component" of the Comprehensive Everglades Restoration Plan (CERP).

The C-43 West Basin Storage Reservoir (WBSR) project is designed to capture and store water from Lake Okeechobee and the C-43 Basin during Florida's rainy season. The reservoir is under construction on a 10,700-acre parcel owned by SFWMD in Hendry County (Figure 1-1) and is a 50-50 cost-share between SFWMD and the United States Army Corps of Engineers (USACE). Fully constructed, the C-43 WBSR will store approximately 57 billion gallons of water (approximately 170,000 acre-feet), for the congressionally authorized CERP project. The project, expected to be completed in 2023, will include construction of two 5,000-acre reservoir storage cells (Cells 1 and 2), two pump stations, a perimeter canal along with associated water control structures, and required improvements to the State Road 80 Bridge and the Townsend Canal, which ultimately connects to the Caloosahatchee River.

The C-43 WBSR project will work in conjunction with other regional projects and efforts to reduce the frequency and intensity of harmful freshwater discharges into the Caloosahatchee River Estuary (CRE). Once completed, the project will provide immediate environmental restoration benefits by:

- Capturing and storing stormwater runoff from the C-43 Basin, and regulatory discharges from Lake Okeechobee, thus reducing excess freshwater flows to the estuary.
- Helping to maintain a desirable salinity balance by controlling peak flows during the wet season and providing essential freshwater flows during the dry season.
- Helping to sustain a healthy estuarine nursery that supports recreational and commercial fisheries.
- Reducing nutrient loading to the CRE, an incidental benefit resulting from settling of nutrient rich particulate matter in the reservoir

Depending on storage needs, water depth in the reservoir will range from 15 to 25 feet. Water stored in the reservoir is protected by a water reservation rule and will be released on a regulated schedule to help achieve minimum flow requirements at the S-79 structure (Franklin Lock and Dam) during dry season low-flow conditions. The water reservations rule for the Caloosahatchee River (C-43) WBSR is defined in subsection 40E-10.041(3), Florida Administrative Code. This project is one component of a larger restoration project for the Caloosahatchee River and Estuary and will comprise a significant portion of the overall water storage requirement for the Caloosahatchee River Watershed.

The C-43 WBSR will serve multiple purposes. It is intended to support CRE restoration by attenuating peak stormwater flows during the wet season and providing additional base flow to the estuary during the dry season. The reservoir will capture and store a portion of the watershed runoff and regulatory releases from Lake Okeechobee, reducing the number and volume of discharges to the CRE during the wet season. In addition, it is envisioned to provide public access and recreational opportunities, and the perimeter canal is intended to maintain allocated water supply to the local agricultural areas adjacent to the reservoir.

It is imperative that releases from the C-43 WBSR do not contribute to impairments of downstream water quality constituents compared to existing conditions in the Caloosahatchee River Watershed. DEP identified the CRE to be impaired for total nitrogen (TN). DEP has not identified the CRE to be impaired for total phosphorus (TP); however, DEP has identified TP impairments in tributaries throughout the Caloosahatchee River Watershed. Therefore, this nutrient should be considered for reduction as well. The reduction of nutrient concentrations and loads to the CRE is required by the Northern Everglades and Estuary Protection Program (NEEPP) passed by the Florida Legislature and signed into law in 2007 and amended in 2016, and by the Caloosahatchee River and Estuary Basin Management Action Plan (BMAP), adopted in 2012 and amended in 2020.

Furthermore, it is imperative that treatment technologies identified during the development of the C-43 WBSR Water Quality Feasibility Study (Study) cannot affect the congressionally approved C-43 Reservoir project purposes, infrastructure, construction schedule, or operation.

To examine conventional and innovative biological, physical, and chemical technologies available and applicable to treating water entering and discharging from the C-43 WBSR or reducing potential algal biomass within the C-43 WBSR, SFWMD, DEP, and local governments have partnered to develop the Study. Collectively, representatives of SFWMD, DEP, Hendry County, Lee County, City of Cape Coral, City of Sanibel, and Lehigh Acres Municipal Services Improvement District make up the C-43 Study Working Group (Working Group). The Working Group provides guidance to the SFWMD Project Manager, who is responsible for administering the contract and acting as the liaison between the Working Group and C-43 Study consultant, J-Tech (Jacobs Engineering and Tetra Tech, Inc.), who was selected to complete the Study.

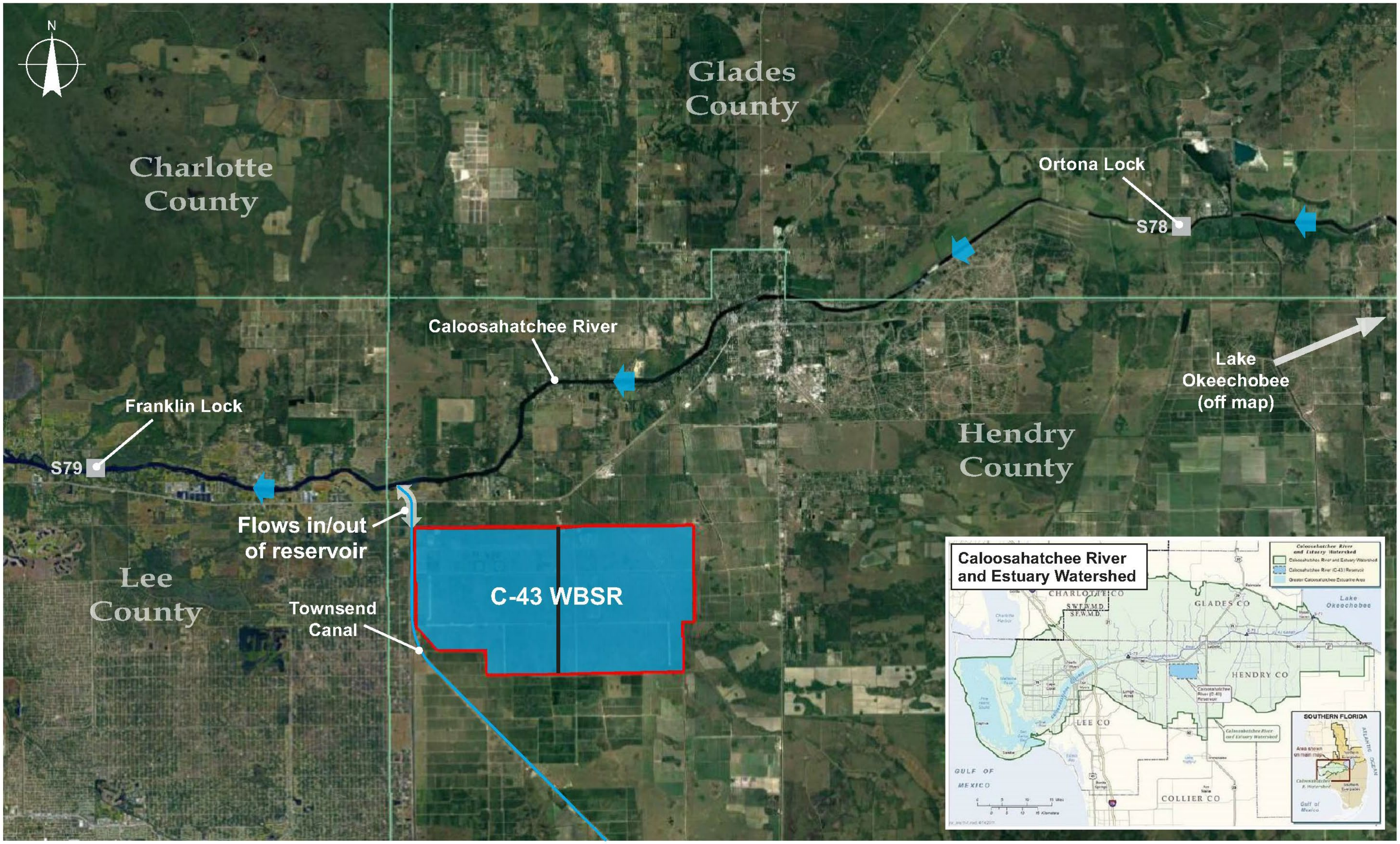


Figure 1-1. Location Map of C-43 West Basin Reservoir

2.0 Purpose and Need

2.1 Information Collection Summary Report

The Information Collection Summary Report is the preliminary document for the Study, which compiles pertinent information on the key topics of Caloosahatchee River Watershed water quality, blue-green algae ecology and management, and water quality improvement technologies. J-Tech gathered and reviewed documents related to the following general topic categories:

- Applicable watershed assessments;
- Watershed-specific feasibility studies/water quality improvement strategies;
- DEP Technology Library for Water Issues;
- Existing C-43 WBSR design information documents;
- Existing C-43 WBSR water quality testing documents;
- Previous treatment technology assessments by SFWMD and DEP; and
- Published literature on algae and nutrient management and control with a focus on waterbodies similar to the Caloosahatchee River Watershed.

Documents have been compiled on the Working Group's SharePoint site and the SFWMD/Working Group Study webpage (https://www.sfwmd.gov/content/c43waterqualitystudy) and organized into categories labeled by the key areas of interest. These documents were reviewed and are summarized in this Information Collection Summary Report.

2.1.1 Prevention and Management of Blue-Green Algae Blooms and Causal Factors in Similar Waterbodies

Increased delivery of nutrients to Florida's waterbodies is widely recognized as the primary driver of algal proliferation and subsequent degradation of aquatic ecosystems. Major sources of nutrients include, but are not limited to, agricultural operations, wastewater treatment plants, onsite sewage disposal systems (also known as septic systems), and urban stormwater runoff. Legacy nutrients (i.e., nitrogen and phosphorus sequestered in soils, groundwater, and sediments) contribute to excessive nutrient loading of surface waters throughout the state.

Nutrient effects, as they relate to the formation, magnitude, and persistence of blue-green algae blooms in Florida's waters, are expected to be exacerbated by regional changes in land use, associated alterations in hydrology as well as climate change, specifically increases in temperature and pronounced variability in precipitation patterns (Blue-Green Algae Task Force, 2019). In freshwater systems, HABs are dominated by cyanobacteria (blue-green algae), which are primary producers that conduct photosynthesis. Some cyanobacteria can regulate their buoyancy and take advantage of nutrients present in different areas of the water column. Some cyanobacteria can also fix nitrogen from the atmosphere, in addition to sources of nitrogen found in the water. They also thrive when temperatures are warm. Those various abilities and a high division rate enable cyanobacteria to out-compete eukaryotic algae when the environmental conditions are right (Rosen, Davis, Gobler, Kramer, and Loftin, 2017).

Today, most surface waters are no longer nutrient limited; instead, the major problem is excess nutrients. A complete understanding and comprehensive management of nutrient dynamics (nitrogen and phosphorus) are required to reduce the occurrence of HABs. Nitrogen and phosphorus supplies determine the total amount of algal production in the ecosystem, and the nitrogen to phosphorus ratio determines the food quality as well as the population and health of algal taxa that are present. These altered ratios lead to shifts in phytoplankton dominance and ultimately affect the entire food web of an ecosystem (Burkholder, 2019).

Various studies have been conducted on the effects of nitrogen and phosphorus on cyanobacteria in lakes. Dolman et al. (2012) found that cyanobacteria in 102 north German lakes were most abundant at both high TN and TP concentrations. The authors suggested that to decrease noxious cyanobacteria, such as *Microcystis*, both TN and TP must be controlled; however, different cyanobacteria species have variable nitrogen to phosphorus ratio preferences. Jankowiak et al. (2019) found similar results in the western Lake Erie where cyanobacterial abundance significantly increased when elevated TN and TP concentrations were present; however, both nitrogen and phosphorus reductions were needed to control cyanobacteria due to different taxa responses, especially as lake temperatures increased. As cyanobacteria increased, growth of green and brown algae were suppressed.

Similar findings have been observed in Lake Okeechobee where out-of-balance ratios have strongly influenced nutrient supplies coming out of sediments, and imbalance has been inadvertently exacerbated by common management actions (Burkholder, 2019). Many efforts to decrease phosphorus pollution largely leave nitrogen pollution alone and vice versa. Management activities to reduce phosphorus in the Lake Okeechobee Watershed have led to downward shifts in the nitrogen to phosphorus ratio, with high inorganic nitrogen and phosphorus supplies, which have promoted an increase in water-column phosphorus from internal loading and major food web changes, such as an increase in *Microcystis* outbreaks (Burkholder, 2019).

Microcystis is the key responder to altered nitrogen to phosphorus ratios from high nutrient supplies followed by reduction of one nutrient but not the other. It thrives with high phosphorus and inorganic nitrogen, and Lake Okeechobee sediments contain excessive amounts of accessible inorganic phosphorus (Burkholder, 2019). Successful control of *Microcystis* blooms will require major reductions in both phosphorus and inorganic nitrogen. After the 2016 *Microcystis* bloom in Lake Okeechobee, Kramer et al. (2018) recommended that reductions in nitrogen must occur if the goal is to minimize the intensity of future blooms.

Production of common cyanotoxins (e.g., microcystins) increases with increasing TN and TP concentrations (Burkholder, 2019). *Microcystis* blooms are a concern because they produce a toxin (microcystin) that can cause gastrointestinal problems and possibly kidney and liver damage if contaminated water is ingested and create low oxygen conditions that can cause fish kills. Microcystis toxins are detected in the air and can be detected and quantified at sites greater than three miles from known blooms (Parsons, 2019). The potential threat of β-methylamino-ʟ-alanine—a cyanobacterial neurotoxin found in contaminated seafood and shellfish, drinking water supplies, and recreational waters—also needs further study.

The key to preventing HABs, especially cyanobacteria in freshwaters and dinoflagellates in brackish or marine waters, is to minimize nutrient pollution, in particular human-related nitrogen and phosphorus supplies, and to re-establish healthy nitrogen to phosphorus ratios (Burkholder, 2019).

Although prevention of HABs is the overall goal, recently technologies have been developed to mitigate specific bloom events. The Florida Fish and Wildlife Conservation Commission has a monitoring network that provides weekly updates on HABs and red tide status. Monitoring and forecasting blooms allow for public awareness and targeted response if necessary. Lee County has implemented a DEP grant-funded test program to remove, process, treat and dispose of HABs from select test sites. The program removes the algae slurry from the waterbody, separating the algae solids from the liquids and disposing of the solids at a landfill. The liquids are treated to DEP specifications and pumped into a deep-injection well located 2,600 feet below ground and below the confined drinking water aquifer.

2.1.2 Caloosahatchee River Watershed Water Quality

The Caloosahatchee River Watershed encompasses approximately 1,339 square miles (DEP, 2017). The Caloosahatchee River, also known as the C-43 Canal, was once a shallow, meandering river with its headwaters near Lake Hicpochee (DEP, 2005). The river was connected to Lake Okeechobee in the 1880s and was subsequently straightened and deepened to improve navigation and provide flood control (Balci, Bertolotti, Carter, and Liebermann, 2012; SFWMD, DEP, and Florida Department of Agriculture and Consumer Services [FDACS], 2009b). The river runs approximately 43 miles from Lake Okeechobee through three combination lock and dam structures that were built by USACE to control river flow and releases from Lake Okeechobee (DEP, 2017; Balci et al., 2012; SFWMD, DEP, and FDACS, 2009b; Doering, Chamberlain, and Haunert, 2006; Doering and Chamberlain, 1999). The Caloosahatchee River is operated as part of the Okeechobee Waterway, linking the Gulf of Mexico to the Atlantic Ocean through Lake Okeechobee and the St. Lucie Canal and River (DEP, 2005).

Water flows from Lake Okeechobee through S-77 at Moore Haven, S-78 at Ortona, and S-79 at Olga. S-79, also known as the Franklin Lock and Dam, is the start of the CRE and is a salinity barrier. The estuary extends about 26 miles downstream to Shell Point, where it empties into San Carlos Bay (Armstrong et al., 2019; DEP, 2017; Balci et al., 2012; SFWMD, DEP, and FDACS, 2009b; Bailey et al. 2009a; Doering et al., 2006). The Caloosahatchee River receives flow from Lake Okeechobee and several streams and canals between S-77 and S-78, 14 tributaries between S-78 and S-79, and 23 waterbodies that discharge directly to the estuary below S-79. Drainage canals were constructed throughout the watershed to accommodate agricultural operations (DEP, 2005). At times, approximately half the volume of water that reaches S-79 has passed through S-77 from Lake Okeechobee (DEP, 2017; Bailey et al., 2009a). The contribution of Lake Okeechobee to the CRE is tied to Lake Okeechobee operations, runoff from the basin, and rainfall; therefore, it varies from year to year. The magnitude of inflow from each source—Lake Okeechobee, C-43, and Tidal Caloosahatchee—varies greatly (Armstrong et al., 2019).

These alterations have impacted the quality, quantity, timing, and distribution of flows to the estuary (Balci et al., 2012; DEP, 2005; Doering and Chamberlain, 1999). In the late 1970s and early 1980s, water quality was identified as a concern in the CRE when a Florida Department of Environmental Regulation (now DEP) wasteload allocation study determined that the estuary had reached its nutrient loading limits as indicated by elevated chlorophyll *a* (chl *a*) and decreased dissolved oxygen (DO) concentrations

(SFWMD, DEP, and FDACS, 2009b; Doering et al., 2006; Knight and Steele, 2005). In 2005, DEP completed its assessment and identified nutrients and DO as impairments in the tidal CRE (DEP, 2005).

In 2007, the Florida Legislature passed NEEPP, which was amended in 2016. NEEPP mandated development of a TN total maximum daily load (TMDL) for the tidal portion of the CRE by December 31, 2008 (Bailey et al., 2009a). The NEEPP also mandated that the Coordinating Agencies—SFWMD, DEP, and FDACS—create a Caloosahatchee River Watershed Protection Plan (CRWPP) by 2009 with three-year updates thereafter. The CRWPP focused on research and water quality monitoring, pollutant control, and construction of projects to address water quality and storage issues. The CRWPP included projects to reduce TP loads to the estuary by 39% and TN loads by 38% as well as 400,000 acre-feet (ac-ft) of water storage within the watershed (SFWMD, DEP, and FDACS, 2009b).

As directed by NEEPP, DEP adopted a TMDL in 2009 that required a 23% reduction in TN (Bailey et al., 2009a). TN has been linked to high chl *a* concentrations in the CRE downstream of the Franklin Lock and Dam (S-79). The TMDL was intended to increase light penetration in the estuary to allow for seagrass growth (DEP, 2017). Following TMDL adoption, DEP began working with local stakeholders on a BMAP to implement the TMDL, and the BMAP was adopted in 2012 and included measures to decrease TN loads to the estuary. During BMAP development, stakeholders identified issues with the 2009 TMDL and the associated models. To address these concerns, DEP contracted with Tetra Tech and Amec Foster Wheeler in 2016 to revise the models for use in TMDL and BMAP revisions and for development of TMDLs for impaired tributaries to the river (DEP, 2017). In December 2017, DEP released the 5-Year Review of the BMAP. In January 2020, an amended BMAP was adopted, which included an expanded BMAP boundary to add the tributaries and the East and West Caloosahatchee Sub-watersheds.

In July 2019, DEP adopted TN, TP, and biochemical oxygen demand (BOD) TMDLs for several Caloosahatchee River tributaries including the S-4 Basin, C-19 Canal, Lake Hicpochee, Long Hammock Creek, and Townsend Canal. These tributaries are located entirely in the freshwater portion of the Caloosahatchee River (Albright, 2019).

Additional initiatives are underway to improve the Caloosahatchee River Watershed, including the design of the CERP C-43 WBSR, revisions to the Lake Okeechobee Regulation Schedule, development and implementation of the Lake Okeechobee Watershed Protection Program and Lake Okeechobee BMAP, drafting of Caloosahatchee minimum flows and levels, and updates to the BMAP (Knight and Steele, 2005). Despite these ongoing efforts, the water quality in the watershed remains in poor condition.

2.1.2.1 *Causative Factors that Contribute to Blue-Green Algae Blooms*

The alterations to the Caloosahatchee River Watershed have increased the frequency of flood events and reduced dry season flows. Regulatory releases from Lake Okeechobee into the C-43 result in large freshwater volumes and nutrient loads into the CRE to maintain the lake level below the lake’s regulation schedule (Doering and Chamberlain, 1999). These releases, in particular elevated TP and TN loads, have led to an increased occurrence of excessive algal growth, blue-green algae blooms, red tides, and accumulation of drift algae both in the freshwater and marine portions of the Caloosahatchee River Watershed as well as offshore (Balci et al., 2012; SFWMD, DEP, and FDACS, 2009b; Knight and Steele, 2005). These blooms can lead to exceedances of the state water quality standard for chl *a* and to decreased water clarity and DO concentrations (Wetland Solutions, Inc. [WSI], 2012a, 2012b, 2010; SFWMD, DEP, and FDACS, 2009a; SFWMD, DEP, and FDACS, 2009b; Doering et al., 2006).

The science of understanding the factors that lead to blooms is complex. In 1982, SFWMD completed a three-year extensive monitoring effort. As part of this work, the researchers sought to determine how blooms could be predicted and prevented (Miller et al., 1982). Their findings noted that phytoplankton growth responds to increased water temperature, solar radiation, light intensity, and photoperiod. Temperature, nutrient availability, and residence times are important influences on phytoplankton growth; however, the data collected during the study did not provide a clear formula for predicting an algal bloom before it occurs (Miller et al., 1982).

2.1.2.2 Nutrient Concentrations and Loads in the Caloosahatchee River Watershed

Numerous extensive short-term and long-term monitoring efforts as well as associated analyses and reports exist for the Caloosahatchee River Watershed. However, limited data exist on the algal communities observed in the watershed. These monitoring efforts include those covered in Doering et al. (2006), Knight and Steele (2005), Doering and Chamberlain (1999), and Miller et al. (1982). The final TMDL report and associated appendices for the tidal Caloosahatchee TMDL provide water quality analyses for various stations in the CRE (Bailey et al., 2009a; Bailey et al., 2009b). The work of WSI in 2010 and 2012 provided an extensive analysis of the nitrogen species that comprise the TN loads in the Caloosahatchee River Watershed (WSI, 2010, 2012a, 2012b). These reports show similar trends in water quality parameters; therefore, this report focuses on a review of the most recent analyses conducted by SFWMD for the 2019 *South Florida Environmental Report* (Armstrong et al., 2019).

Table 2-1 shows that the total freshwater inflow to the CRE in water year (WY) 2018, May 1, 2017-April 30, 2018, was 3.063 million ac-ft. Of this inflow, the largest portion was from the C-43 Basin (45%), followed by Lake Okeechobee (39%), and the Tidal Caloosahatchee Basin (15%). The high total inflow in WY2018 resulted from high rainfall and was 63%, 29%, and 31% more than the long-term average (WY1977–WY2018), WY2016, and WY2017, respectively. Drought and El Niño conditions led to fluctuations in source contributions between WY1997 and WY2018 (Armstrong et al., 2019).

The annual nutrient loads to the CRE fluctuated with total freshwater inflow from WY1997 to WY2018. The TN and TP loads were notably higher in WY2018 than the long-term average (WY1997–WY2018), WY2016, and WY2017. These noted increases were attributed to the possible impact of Hurricane Irma.

As shown in Table 2-1, the TN load in WY2018 was 5,329 metric tons per year (mt/yr), which was 74%, 49%, and 56% greater than the long-term average (WY1997–WY2018), WY2016, and WY2017, respectively. For TN loading, the largest contributing source was the C-43 Basin (50%) followed by Lake Okeechobee (40%) and the Tidal Caloosahatchee Basin (11%) (Armstrong et al., 2019). The TP loading was 643 mt/yr in WY2018, of which 58% was from the C-43 Basin, 30% from Lake Okeechobee, and 12% from the Tidal Caloosahatchee Basin.

Table 2-1. Summary of Freshwater Inflow from Lake Okeechobee, the C-43 Basin, and the Tidal Caloosahatchee Basin

		WY1997-2018	WY2016	WY2017	WY2018
Inflow (10^6 ac-ft/yr	**Total**	**1.88**	**2.38**	**2.33**	**3.06**
	Lake Okeechobee	0.62	0.85	1.01	1.20
	C-43 Basin	0.88	0.96	0.93	1.39
	Tidal Caloosahatchee Basin	0.38	0.57	0.39	0.47
TN (t/yr)	**Total**	**3,070**	**3,567**	**3,417**	**5,329**
	Lake Okeechobee	1,091	1,590	1,559	2,115
	C043 Basin	1,545	1,350	1,465	2,641
	Tidal Caloosahatchee Basin	434	627	393	573
TP (t/yr)	**Total**	**297**	**302**	**317**	**643**
	Lake Okeechobee	74	106	104	195
	C-43 Basin	177	140	175	373
	Tidal Caloosahatchee Basin	47	56	38	76

Source: SFWMD, 2019a

Note: Table summarizes freshwater inflow in million acre-feet per year (10^6 ac-ft/yr) and TN loads and TP loads in mt/yr.

Table 2-2 lists the tributary basin annual flows, TP load, TP flow-weighted mean (FWM) concentration, TN load, and TN FWM concentration for the last five water years (WY2014–WY2018) in the Caloosahatchee River Watershed. The tributary basins of the Caloosahatchee River Watershed are the C-43, S-4, and Tidal Caloosahatchee basins. Inflows from Lake Okeechobee to the watershed are also accounted for in Table 2-2. Tributary basin runoff in the watershed accounted for 44% of total flow, 58% of TP load, and 46% of TN load to the CRE for the period of WY2014–WY2018. Lake Okeechobee contributed 38% of total flow, 30% of TP load, and 40% of TN load during the same five-year period.

Water quality is also measured in the CRE. Armstrong et al. (2019) chose three stations (CES04, CES06, and CES08) with the most complete records to characterize estuarine water quality. Concentrations of TN, TP, and chl *a* were assessed for WY2000–WY2018.

Chl *a* concentrations at the selected three stations varied from 0.25 to 106 micrograms per liter (µg/L). The long-term average concentrations were highest at CES04 and decreased moving downstream (Table 2-3). In WY2016 and WY2018, the highest measured annual average chl *a* concentration was at CES06 (Table 2-3). Dry and wet season average concentrations in WY2016 and WY2018 followed the same pattern. Chl *a* concentrations at both CES04 and CES06 in WY2018 were higher than the previous two WYs, but less than the long-term average. Station CES08 had a chl *a* higher concentration than either the long-term average or past two WYs. All three stations generally had higher chl *a* concentrations during the wet season than the dry season with some exceptions (Table 2-3).

TN concentrations were highly variable at all three stations and ranged from 0.03 to 4.97 milligrams per liter (mg/L). The long-term average concentrations decreased moving downstream, similar to the chl *a* concentrations (Table 2-3). TN concentration in WY2018 followed the same pattern as chl *a* with the highest concentration at CES04 and decreasing downstream. All three stations had higher concentrations than both the long-term average (WY2000–WY2018) and the previous two WYs, WY2016 and WY2017. During WY2018 and WY2017, wet season average TN concentrations exceeded dry season concentrations at all three stations. The WY2018 wet season average concentrations at all the three stations were higher than in WY2016 and WY2017, and the long-term averages (Armstrong et al., 2019).

Table 2-2. Caloosahatchee River Watershed Tributary Basin Annual Flow Volumes with TP and TN Loads and FWM Concentrations for WY2014-WY2018

Water Year	Inflow from Lake Okeechobee	C-43 plus S-4 Basins	Tidal Caloosahatchee Basin	Total
		Flow (10^3 x acre-feet)		
WY2014	1,145.7	1,377.1	499.8	3,022.6
WY2015	486.6	747.6	199.6	1,433.8
WY2016	849.6	956.7	570.5	2,376.7
WY2017	1,010.1	929.4	392.8	2,332.2
WY2018	1,201.1	1,391.9	474.4	3,067.3
		TP Load (metric tons)		
WY2014	108.0	268.8	41.8	418.5
WY2015	47.7	144.9	23.0	215.5
WY2016	105.9	140.0	55.8	301.7
WY2017	103.9	175.1	38.3	317.4
WY2018	194.7	372.8	75.6	643.1
		TP FWM Concentration (mg/L)		
WY2014	0.076	0.158	0.068	0.112
WY2015	0.080	0.157	0.093	0.122
WY2016	0.101	0.119	0.079	0.103
WY2017	0.083	0.153	0.079	0.089
WY2018	0.131	0.217	0.129	0.170
		TN Load (metric tons)		
WY2014	1,879.5	2,365.9	842.0	5,087.4
WY2015	725.2	1,171.2	182.5	2,078.9
WY2016	1,589.5	1,349.7	627.3	3,566.5
WY2017	1,559.2	1,464.7	392.9	3,416.9
WY2018	2,115.2	2,641.4	572.5	5,329.0
		TN FWM Concentration (mg/L)		
WY2014	1.33	1.39	1.37	1.37
WY2015	1.21	1.27	0.74	1.18
WY2016	1.52	1.14	0.89	1.22
WY2017	1.25	1.28	0.81	0.96
WY2018	1.43	1.54	0.98	1.41

Source: SFWMD, 2019a

Table 2-3. Summary of Water Column Concentrations of Chlorophyll *a*, Total Nitrogen, and Total Phosphorus at Three Stations in the Caloosahatchee River Estuary

	CES04						CES06						CES08					
	Dry[1]		Wet[2]		Total		Dry[1]		Wet[2]		Total		Dry[1]		Wet[2]		Total	
Chl *a* (µg/L)	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
WY2000-WY2018	8.43	7.60	11.18	17.26	9.81	13.38	7.00	7.33	11.39	14.04	9.21	11.41	2.40	2.07	4.51	3.72	3.36	3.11
WY2016	2.97	2.20	4.95	0.99	4.20	1.73	7.74	8.10	5.14	4.48	6.12	5.66	3.00	2.12	2.68	0.97	2.80	1.36
WY2017	4.13	1.82	8.33	6.00	5.70	4.11	5.47	2.31	3.61	0.76	4.77	2.04	1.67	0.84	3.65	2.23	2.41	1.69
WY2018	6.40	4.75	5.19	3.98	5.79	4.23	7.18	7.71	9.75	6.21	8.46	6.81	2.26	0.59	5.60	5.16	3.93	3.91
	CES04						**CES06**						**CES08**					
	Dry[1]		**Wet[2]**		**Total**		**Dry[1]**		**Wet[2]**		**Total**		**Dry[1]**		**Wet[2]**		**Total**	
TN (mg/L)	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
WY2000-WY2018	1.17	0.49	1.27	0.30	1.22	0.41	0.75	0.27	1.02	0.36	0.89	0.35	0.52	0.17	0.69	0.30	0.60	0.26
WY2016	1.16	0.08	1.07	0.08	1.10	0.09	0.98	0.18	0.94	0.19	0.96	0.17	0.73	0.14	0.75	0.31	0.74	0.25
WY2017	1.01	0.07	1.18	0.09	1.08	0.11	0.73	0.13	0.99	0.21	0.83	0.20	0.42	0.07	0.50	0.11	0.45	0.09
WY2018	1.25	0.30	1.34	0.21	1.30	0.25	0.84	0.31	1.16	0.29	1.01	0.33	0.60	0.24	0.86	0.41	0.74	0.35
	CES04						**CES06**						**CES08**					
	Dry[1]		**Wet[2]**		**Total**		**Dry[1]**		**Wet[2]**		**Total**		**Dry[1]**		**Wet[2]**		**Total**	
TP (mg/L)	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
WY2000-WY2018	0.12	0.04	0.17	0.09	0.14	0.07	0.08	0.03	0.12	0.05	0.10	0.05	0.05	0.02	0.08	0.04	0.06	0.03
WY2016	0.09	0.03	0.12	0.03	0.11	0.03	0.08	0.01	0.11	0.01	0.10	0.02	0.06	0.01	0.08	0.05	0.07	0.04
WY2017	0.10	0.02	0.11	0.02	0.10	0.02	0.07	0.00	0.11	0.03	0.08	0.02	0.04	0.00	0.06	0.02	0.05	0.01
WY2018	0.11	0.02	0.20	0.08	0.15	0.07	0.08	0.03	0.17	0.06	0.13	0.06	0.06	0.02	0.12	0.07	0.09	0.06

Source: SFWMD, 2019a

[1] Dry Season = November – April

[2] Wet Season = May – October

SD = standard deviation

Similar to chl *a* and TN concentrations, TP concentrations were highly variable at all three stations and ranged from 0.016 to 0.689 mg/L. The long-term average concentrations also decreased in the downstream direction (Table 2-3). The average concentrations and the range of variations at all the three stations were higher during the wet seasons compared to the dry seasons. Similar to the TN concentrations, the WY2018 wet season average concentrations at all the three stations were higher than in WY2016 and WY2017 as well as the long-term averages (Armstrong et al., 2019).

2.1.2.3 Algal Bloom History

The literature reviewed for this report was full of references to previous blooms; however, data on the blooms are limited. The majority of the information on these blooms comes from the Caloosahatchee and Estuary Condition Reports, which provide a scientific assessment on a weekly basis of Caloosahatchee River and Estuary conditions and how these conditions affect the health, productivity, and function of the system.

Red tide, caused by the dinoflagellate *Karenia brevis*, diatom blooms, and blue-green algae blooms are common in the Caloosahatchee. In 2011, HABs of cyanobacteria persisted in the Caloosahatchee River from Alva to Franklin Lock. A red tide bloom in September led to the death of several Kemp's Ridley sea turtles (Caloosahatchee and Estuary Condition Report, 2011). In 2012, a toxic blue-green algae bloom was identified from the City of LaBelle to S-79 and eventually reappeared at the Olga Water Treatment Plant, and a periodic red tide also occurred. In May 2012, microcystin toxin was detected at 0.16 µg/L. Similar toxic cyanobacteria blooms occurred in each of the past drought years when flow was cut off leading to stagnant water at the Franklin Lock and Dam (Caloosahatchee and Estuary Condition Report, 2012).

A low-level bloom of diatoms and cyanobacteria, 10 µg/L chl *a*, was detected in San Carlos Bay and on the beaches of Sanibel in May 2013. *Chaetoceros* sp. and *Rhizosolenia* sp. were the dominant diatoms. Cyanobacteria patches of *Lyngbya majuscule* were present on the sediment. In late May to June, cyanobacteria algae blooms occurred from LaBelle to the mid-CRE and eventually led to the temporary closure of the Olga Water Treatment Plant. Macroalgae washed up on the beaches of Fort Myers Beach and Sanibel Island (Caloosahatchee and Estuary Condition Report, 2013). In 2014, a phytoplankton bloom of *Akashiwo sanguinea* was detected, but no blue-green algae blooms occurred (Caloosahatchee and Estuary Condition Report, 2014).

In June 2015, a potentially toxic algal bloom at the Franklin Lock and Dam caused Lee County to shut down the Olga Water Treatment Plant and the Florida Department of Health to issue a health notice to avoid contact with Caloosahatchee River water due to the potentially toxic blooms. Algal blooms in the river and oxbows upstream of S-79 persisted for several months, and a red tide bloom occurred near the City of Sanibel in November 2015 that led to fish kills and several cases of brevetoxicosis in birds along Sanibel's beaches (Caloosahatchee and Estuary Condition Report, 2015).

In 2016, the Caloosahatchee River suffered low salinities and algal blooms from harmful flows for eight consecutive months. In May 2016, a red tide bloom was persistent along the coast, and a cyanobacteria bloom near Alva was observed. The blue-green algae blooms covered more than 27 miles of the river from the Alva Boat Ramp above the Franklin Lock downstream to the Colonial Bridge in the mid-CRE. In June 2016, a bloom of diatoms was present in Pine Island Sound, and a bloom of the bioluminescent, potentially toxic dinoflagellate, *Pyrodinium bahamense*, was detected in Pine Island Sound. A bloom of another dinoflagellate, *Certatium hircus*, was detected in July 2016. Shellfish harvesting was closed in Pine Island Sound due to the potential for paralytic shellfish poisoning from a bloom of the dinoflagellate, *Pyrodinium bahamense* (Caloosahatchee and Estuary Condition Report, 2016).

In February 2017, a red tide bloom began and lasted until March. In April 2017, cyanobacteria were observed at Alva Boat Ramp. In June 2017, cyanobacteria blooms again shut down the Olga Water Treatment Plant, and Lake Okeechobee began experiencing a cyanobacteria bloom in July (Caloosahatchee and Estuary Condition Report, 2017).

From December 2017-October 2018, red tide was persistent, caused fish kills along coastal beaches and was the suspected cause of one manatee death in Matlacha Pass (Caloosahatchee and Estuary Condition Report, 2018). Numerous wildlife, including many species of birds and sea turtles, were treated at Sanibel’s wildlife hospital for red tide related symptoms. High *Karenia brevis* concentrations and blooms still existed in November and December in the Gulf of Mexico.

In February 2018, a green algae, *Ulva*, was present across local beaches of the City of Sanibel, City of Fort Myers, and Town of Fort Myers Beach and colonized hard structures in the lower estuary (Caloosahatchee and Estuary Condition Report, 2018). That same month, the Lee County Environmental Lab detected cyanobacteria, including *Microcystis, Aphanizomenon*, and *Dolichospermum*. Other cyanobacteria, including *Planktothrix*, were observed on the upstream side of S-79. These species appear to be the most common cyanobacteria observed during blue-green algae blooms in the Caloosahatchee.

In late June 2018, an extensive cyanobacteria bloom was documented from Moore Haven to S-79, and blooms of *Microcystis* at the Alva Boat Ramp, Franklin Locks upstream, and downstream to Fort Myers Shores, five miles downstream of the Franklin Lock, and the beach was closed at Franklin Lock Park (Caloosahatchee and Estuary Condition Report, 2018). During the bloom, Lake Okeechobee releases contaminated with a cyanobacteria bloom increased the extent and intensity of the bloom on the Caloosahatchee River, causing beach closures and public health warnings (Caloosahatchee and Estuary Condition Report, 2018).

In July 2018, cyanobacteria blooms persisted within Lake Okeechobee and in the Caloosahatchee River, as well as red tide along the coast. The red tide caused a mass mortality of marine life and endangered sea turtles. An unprecedented volume of dead sea life was observed at the City of Sanibel and Town of Fort Myers Beach. In late August 2018, a third non-toxic bloom of *Oscillatoria* was detected fueled by nutrients from dead fish. Businesses were significantly impacted by water quality issues associated with blue-green algae and red tide. By late September 2018, the cyanobacteria blooms persisted within Lake Okeechobee as well as the CRE. Red tide persisted along the coast, and sea turtles were heavily impacted by the red tide. By October, a dead zone in the Gulf of Mexico that encompassed more than 600 square kilometers was observed. Cyanobacteria blooms dissipated in the Caloosahatchee River by October, but they still persisted in Lake Okeechobee.

2.1.2.4 Blue-Green Algae Task Force

Governor DeSantis, through Executive Order 19-12, directed the establishment of a Blue-Green Algae Task Force. This group was charged with expediting progress toward reducing the adverse impacts of blue-green algal blooms. In October 2019, the task force issued a final consensus document that recognizes the increased delivery of nutrients to Florida's waterbodies as the primary driver of algal proliferation and degradation of Florida's water resources. The task force also recommended that a diverse portfolio of technologies should be evaluated to aid in prevention of algal blooms and/or reduce nutrients in waterbodies. The technologies will need to be cost-effective, environmentally safe, and scalable. Several of the technologies being reviewed as part of this Study are also being evaluated for grant research by DEP. At this time, no documents exist from this task force that could be reviewed for this summary. However, the task force is a separate but parallel effort designed to identify ways to improve water quality in the Caloosahatchee River.

2.1.3 Technologies for Improving Water Quality in the Caloosahatchee River Watershed

This report provides a summary of available, technically feasible, conventional, and innovative biological, chemical, and physical treatment technologies for water quality improvement for eventual pre-treatment, in-reservoir treatment, and/or post-treatment application to the C-43 WBSR. Conventional technologies evaluated include, but are not limited to, physical and chemical methods used in water treatment, wastewater treatment, and environmental remediation. Physical methods include separating solids from water by use of filtration technologies. Chemical methods include removing solids or nutrients by introducing a chemical compound to coalesce particles for enhanced settling or to inactivate nutrients. Natural treatment systems include, but are not limited to, ponds; treatment wetlands dominated by emergent aquatic vegetation (EAV), floating aquatic vegetation (FAV), submerged aquatic vegetation (SAV), periphyton, or mixed marsh; and media filtration systems, such as vertical downflow subsurface flow systems (managed and passive).

In this report, J-Tech provides a summary of performance-related factors useful for evaluation and selection of treatment technologies. The literature review and data extraction effort focused on summarizing available information on nutrient concentration reduction, nutrient load reduction, literature-based unit costs (e.g., cost per unit area or per unit volume), scalability, applicability to C-43 WBSR, operation and maintenance requirements, regulatory constraints, schedule for implementation, general land area requirements, undesirable byproducts and implications of additional treatment requirements, energy requirements, and ancillary benefits (e.g., wildlife habitat creation). In the next task of the project, a conceptual nutrient concentration range will be developed based upon the results of the Caloosahatchee River Watershed data summary that will be used to establish a standardized basis of comparison for assessing reduction of nutrients and algal concentrations, where applicable, across all technologies. The evaluation of cost-benefit, alternatives, trade-offs, and presentation of results in a matrix format will be produced under Task 4.

As part of this review, operational strategies for the C-43 WBSR that could be incorporated into the C-43 WBSR without causing impact to the construction schedule and project objectives were investigated. J-Tech started the review with treatment technologies that are included in the DEP Technology Library for Water Issues (http://fldeploc.dep.state.fl.us/tech_portal/search.asp). Additional technologies were provided to J-Tech and Working Group members, which were also reviewed and are summarized in this report.

2.2 DEP Technology Library for Water Issues

The conventional water quality treatment alternatives described in this report are predominantly gathered from the DEP Accepted Water Technologies Library (DEP, 2020). As of January 16, 2020, there were 30 accepted technologies. These include 15 physical, 7 chemical, and 8 biological technologies.

Information on these technologies was gathered from DEP and the technology vendors listed on the DEP website. Section 3.0 summarizes the information provided by vendors. Where information was available, the treatment technology summary includes a brief description of the technology, key operational process, performance data, availability of Florida case studies, and information on capital and operational costs. Typically, case histories are available for technologies to provide specific information. In some cases, vendors have provided information intended to respond specifically to the potential application at the C-43 WBSR. In all cases, the original information used to derive the summary description below are included on the C-43 SharePoint site by citation.

3.0 Treatment Technologies Identification and Description

3.1 Treatment Overview

3.1.1 Water Quality Parameters

The C-43 WBSR will capture wet season flow from the C-43 Canal; therefore, nutrient concentrations in the stored water will be influenced by the nutrient composition in the source water and natural processes within the reservoir. Conversely, the water quality of the discharges from the C-43 WBSR during the dry season has the potential to affect nutrient concentrations in the C-43 Canal and CRE. In both cases, the presence of algae in the reservoir inflow or outflow would be undesirable, given the history of algae blooms in the C-43 Canal and CRE. The control of nitrogen, phosphorus, and algal suspended solids is a management priority and treatment objective for the Study. Consequently, the treatment of water during reservoir loading, storage, or reservoir releases should consider the following water quality parameters:

- Nitrogen
    - Dissolved organic nitrogen (DON)
    - Bio-available dissolved organic nitrogen (BDON)
    - Dissolved inorganic nitrogen (ammonia, nitrate, nitrite)
    - Total Kjeldahl nitrogen (TKN)
    - TN
- Phosphorus
    - Particulate phosphorus
    - Soluble reactive phosphorus (SRP)
    - TP
- Suspended Solids
    - Total suspended solids (TSS)
    - Algae (including chl *a* as a measure of algal biomass)
    - Particulates

3.1.2 Approach to Treatment: Natural and Conventional Methods

Treatment of water entering, residing in, or discharging from the C-43 WBSR can be accomplished by a wide range of treatment methods using processes that can be broadly characterized as physical, chemical, or biological. Generally, treatment methods can be described as natural or conventional (Kadlec and Knight, 1996), but combinations are increasingly common. Conventional treatment technologies apply these processes in concrete and steel tank enclosures and drive treatment using fossil-fuel based energy sources for mechanical mixing, aeration, and chemical application. Common applications of conventional treatment include stormwater detention and filtration and wastewater treatment by settling, aeration, biological assimilation, and chemical precipitation.

In contrast, natural treatment systems rely upon natural energy sources such as sunlight, wind, gravity, and stored biochemical energy to drive the same water quality improvement processes. Natural treatment systems typically are configured as constructed marshes comprised of shallow waterbodies vegetated by plant species tolerant of inundated conditions to create environments conducive to sedimentation, anaerobic transformation and retention of stored biomass, and passive precipitation with naturally occurring compounds. Common applications of constructed wetlands include stormwater treatment and polishing of secondary treatment wastewater. Natural treatment systems may also provide ancillary benefits by providing fish and wildlife habitat.

Conventional treatment systems typically require less land area than natural treatment systems due to the intensification of processes through energy input, whereas natural treatment systems require broad flat areas of a shallow depth for vegetative growth and capture of solar energy. For this reason, land availability is often a constraint to application of natural treatment systems. Capital and operational costs are typically greater for conventional treatment technologies than for natural treatment systems. Operational control and performance refinement is typically greater in conventional systems. For the Study, conventional and natural treatment systems are evaluated equally applicable to address the water quality treatment objectives. Final determination of technology acceptance will ultimately be based upon a comparison of technology performance relative to the objectives and constraints imposed by the site and application.

3.2 Natural Treatment Alternatives

Natural treatment alternatives consist of systems that are designed and operated to take advantage of the physical, chemical, and biological processes that occur in nature without the need for substantial chemical or energy inputs. In their simplest form, natural treatment systems include hydrologic restoration of wetlands to enhance contact between nutrient-enriched surface waters and wetland vegetation; applying reclaimed water to uplands to irrigate pasture grasses, lawns, tree plantations, or certain crops; applying reclaimed water to natural wetlands for the assimilation of excess nutrients; or directing excess surface water runoff to lakes and ponds where particulate nutrients settle and aquatic organisms process dissolved nutrients. This section focuses on the potential implementation of man-made treatment systems that are designed to replicate the water quality improvement functions that occur in nature. These systems are highly engineered and managed to achieve their intended purposes in comparison to the examples above, and in the relatively level terrain of south Florida, may require significant energy inputs to operate the pump stations needed to deliver water to or discharge water from the constructed treatment system. Because natural water quality processes generally occur at slower rates than in energy-intensive or chemically enhanced conventional treatment units, large land areas are typically required. As the need to treat additional and more complex water quality pollutants has increased and land costs have continued to escalate, natural treatment systems have been intensified through the addition of mechanical and chemical enhancements designed to reduce land requirements and accelerate the pollutant removal process. These intensified systems share many common features with the conventional treatment alternatives described in Section 3.3. For purposes of this review, natural treatment alternatives include ponds; treatment wetlands dominated by EAV, FAV, SAV, periphyton, or mixed marsh; and floating treatment wetlands (FTWs).

3.2.1 Applicability to the C-43 WBSR

Natural treatment systems, when appropriately sited, designed, and operated are capable of reducing nutrient concentrations and loads from C-43 Basin flows delivered to the C-43 WBSR, from water held within the C-43 WBSR (in the case of FWT), and from flows discharged from the C-43 WBSR back to the Caloosahatchee River. As described below, natural treatment system projects have been constructed in south Florida and within the C-43 Basin for similar purposes and operational data are available to guide the evaluation and design of natural systems specifically for implementation in conjunction with the C-43 WBSR. Further, SFWMD has decades of experience operating large-scale natural treatment systems, specifically constructed stormwater treatment areas (STAs), to enhance water quality. Figure 3-1 is a map of the Caloosahatchee River and Estuary watershed.

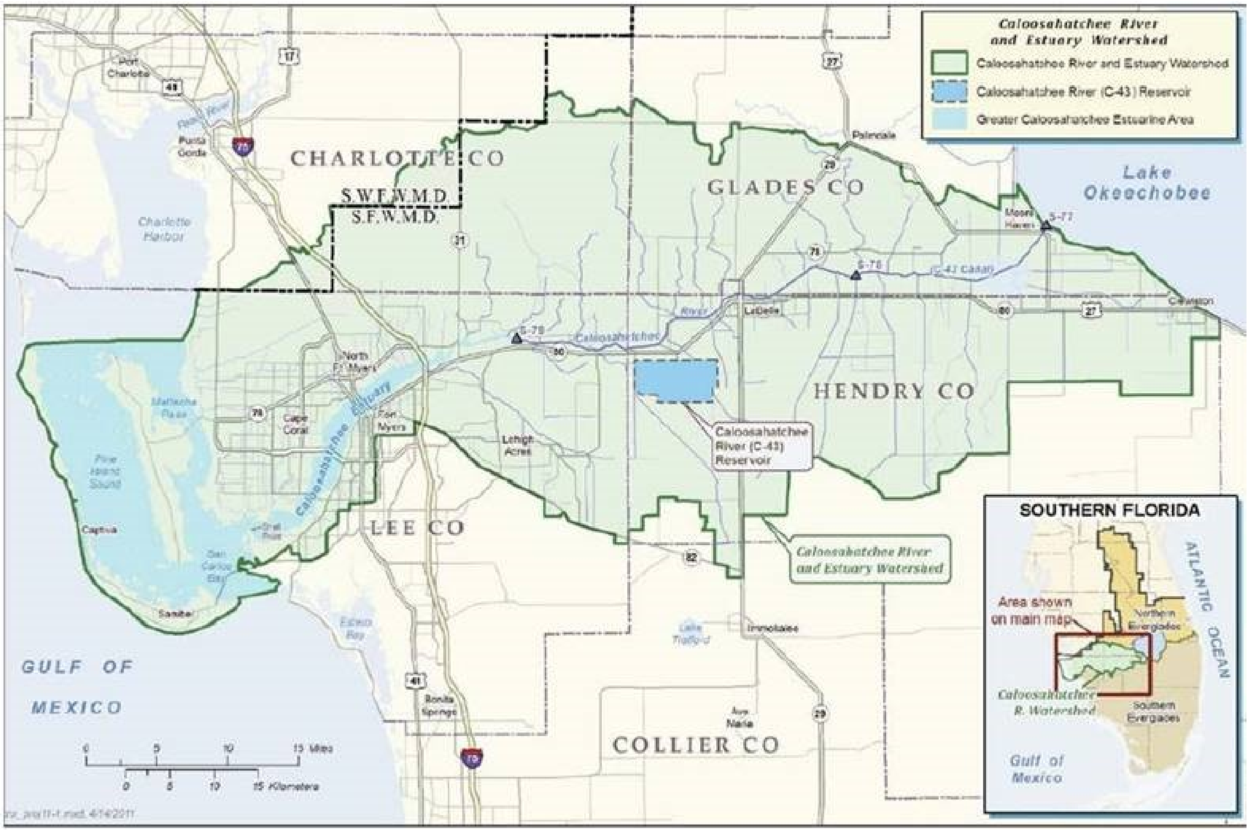


Figure 3-1. Caloosahatchee River and Estuary Watershed

3.2.2 Constructed Treatment Wetlands

Constructed treatment wetlands are shallow, man-made engineered impoundments that are vegetated with wetland plants. Water is applied to a constructed wetland so that it moves through the system slowly and evenly to maximize contact with the wetland bottom substrate and vegetation. The slow movement of water facilitates particle settling and adsorption of chemical constituents to sediments. Treatment wetlands also support microbial life that colonize as biofilms attached to sediment and plant surfaces that trap particulate matter, consume dissolved constituents as a source of chemical energy, and transform other dissolved constituents into harmless byproducts. Because treatment wetlands are generally large and shallow, exposure to ultraviolet sunlight at the surface and throughout the water column breaks down some chemicals so that they are more readily available for plant and microbial uptake. Figure 3-2 shows a general depiction of the types of the natural processes that improve water quality in aquatic ecosystems and are mimicked in constructed wetland treatment systems. Aquatic chemical cycles show that the ultimate fate for nutrients is the transfer of nitrogen from the water column to the atmosphere via the process of denitrification (Figure 3-3) and the burial of phosphorus as new organic sediments (Figure 3-4). Nitrogen may enter a natural treatment system in particulate and dissolved, and organic and inorganic forms. Particulate nitrogen is readily removed through sedimentation and trapping processes; however, nitrogen can change forms through microbial or chemical processes and be released in the dissolved fraction. Organic forms are more difficult to remove than inorganic forms, such as ammonium and nitrate. Depending on the form of nitrogen entering the system, net removal of nitrogen requires sequential processes that include mineralization (conversion of organic nitrogen to ammonium), nitrification (conversion of ammonium to nitrite and then nitrate), and denitrification (conversion of aqueous nitrate to gaseous nitrogen which diffuses from the water column to the atmosphere). The phosphorus cycle is similarly complex and removal in a natural system also depends on the incoming forms. Particulate phosphorus is easily settled but can release dissolved organic phosphorus to the water column under certain conditions. Some phosphorus removal mechanisms, such as the precipitation of calcium phosphate that occurs in SAV systems and periphyton stormwater treatment areas (PSTA) under high pH conditions, produces a stable substance that permanently removes phosphorus.

Treatment wetlands have been used throughout Florida to reduce nutrient concentrations in reclaimed water, industrial wastewater, stormwater runoff, and surface water. Treatment wetland projects are sometimes referred to as marsh flow-ways, filter marshes, or STAs. In south Florida, treatment wetland projects have most often been employed to reduce the concentration of phosphorus in agricultural runoff (such as the Everglades Agricultural Area [EAA] STAs) but have also been implemented more generally to reduce nitrogen, phosphorus, TSS, and algal biomass. In general, treatment wetland plant communities (Figure 3-5) have been installed in a hierarchical manner, based on inflow nutrient concentrations, beginning with FAV at the highest inflow concentrations and progressing through EAV, SAV, and an attached algal community called periphyton as inflow concentrations are reduced by upstream treatment compartments.

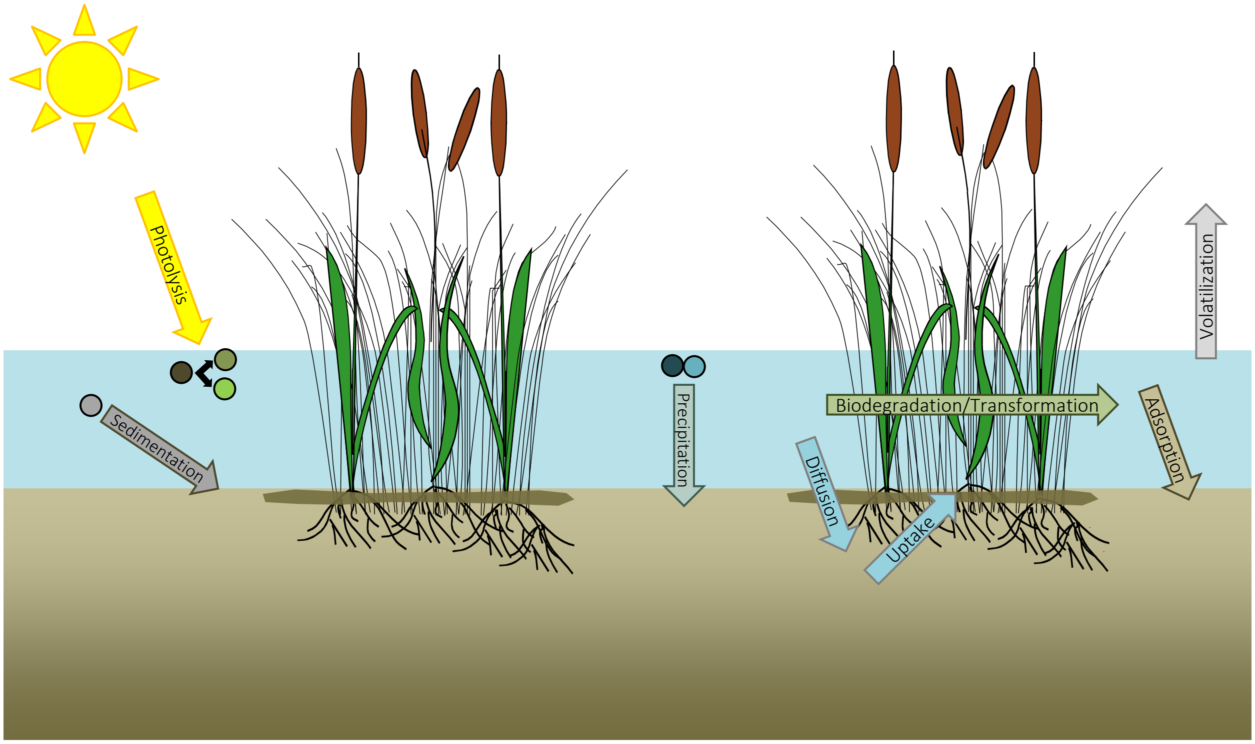


Figure 3-2. Generalized Wetland Water Quality Improvement Processes

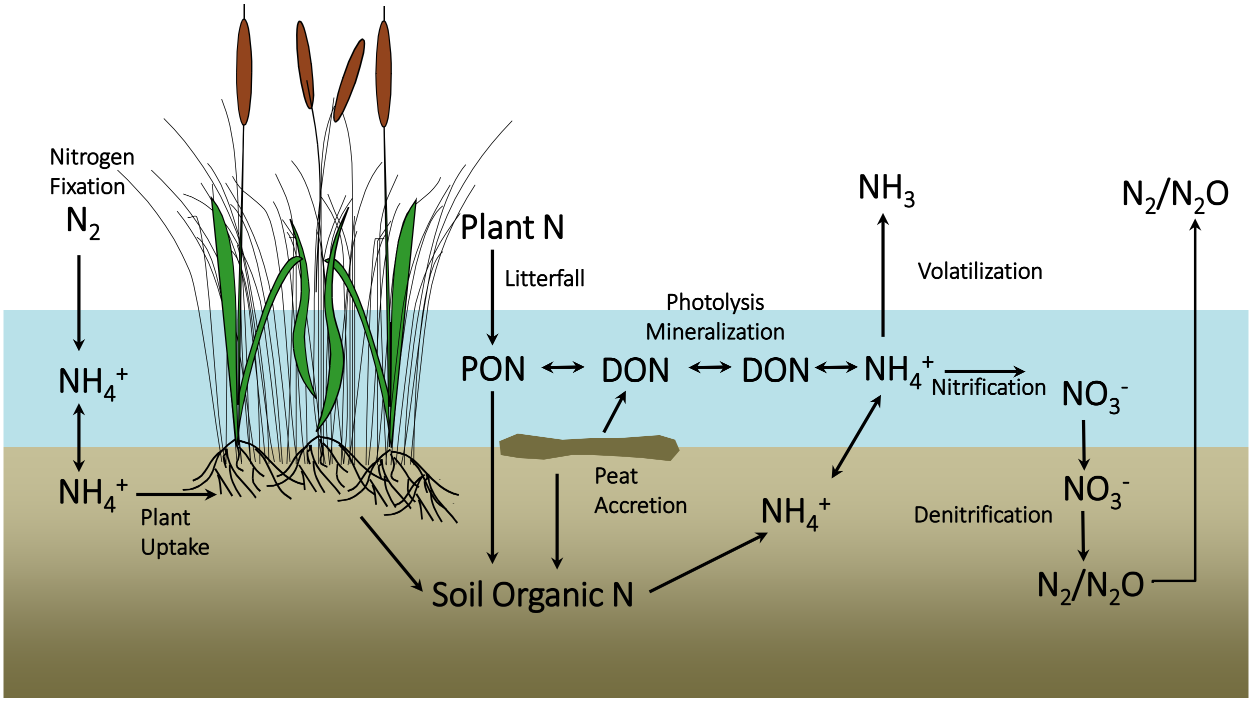


Figure 3-3. Aquatic Nitrogen Cycle

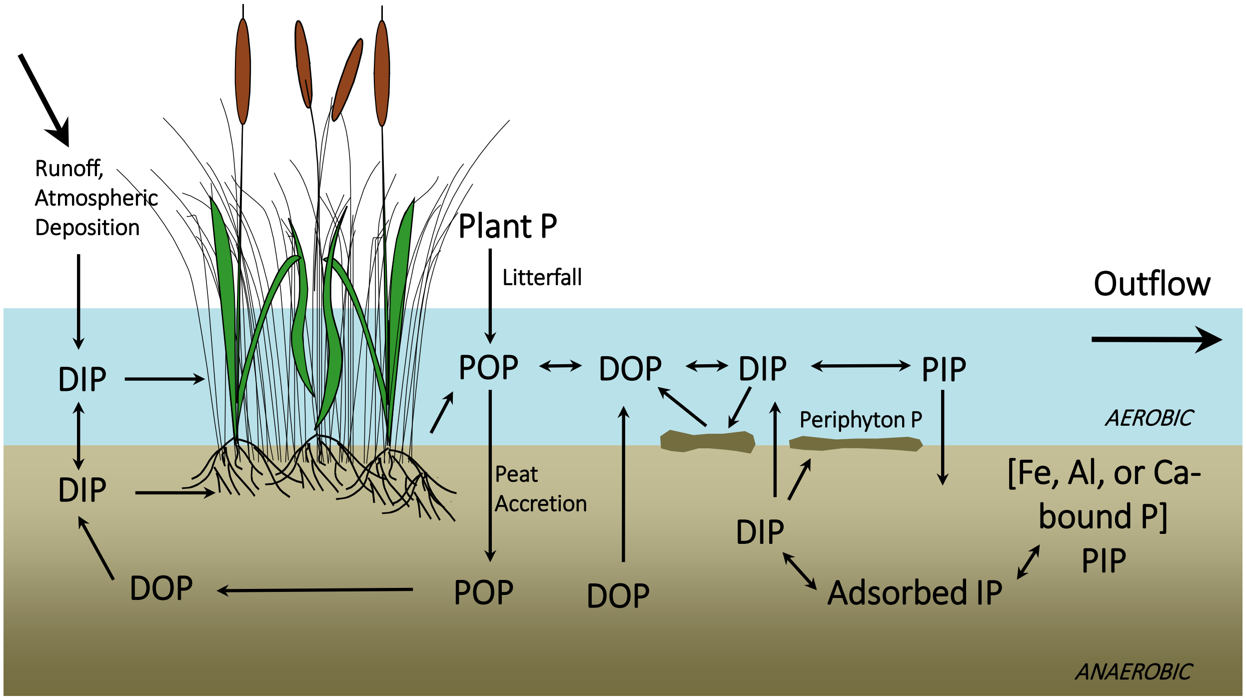
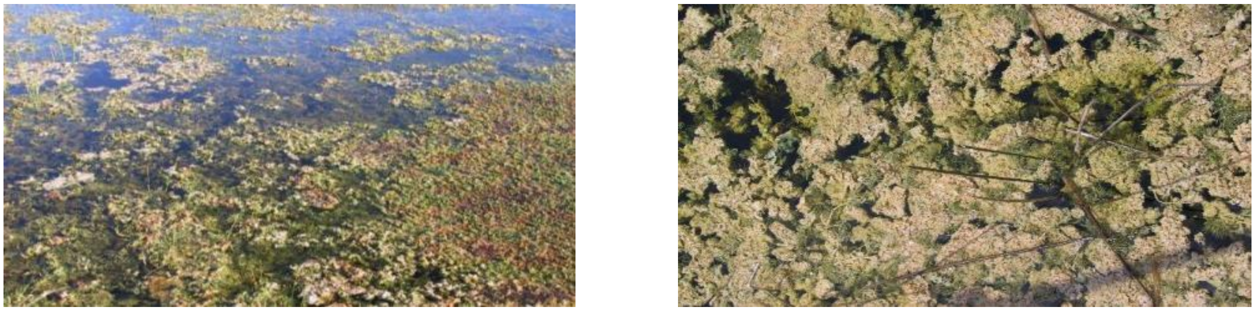


Figure 3-4. Aquatic Phosphorus Cycle

Floating Aquatic Vegetation (FAV)

Emergent Aquatic Vegetation (EAV)



Submerged Aquatic Vegetation (SAV)

Periphyton

Figure 3-5. Treatment Wetland Plant Community Types

As part of earlier efforts to select treatment technologies for the C-43 Basin, WSI (2012a) analyzed data from a variety of Florida treatment wetlands and summarized key findings and performance drivers. There is considerable evidence that TP is most effectively removed by SAV-dominated wetlands at intermediate TP concentrations in the range between 50 and 300 parts per billion (ppb; Walker, 2010). Emergent wetlands were found to likely be more effective for TP removal at higher inlet concentrations (greater than 300 ppb) and periphyton-dominated wetlands were more effective than SAV systems at lower inlet TP concentrations (less than 50 ppb). The lowest TP concentrations practically achievable in any type of treatment wetlands were in the range of 10 to 15 ppb. The most favorable substrate for achieving very low TP concentrations and for the highest removal rates appeared to be calcareous substrates, such as limerock. Organic substrates appeared to be next most favorable for effective phosphorus reduction, followed in last place by sandy soils. The relationship between lower TP outflow concentrations and the presence of organic soils were speculated to result from the SFWMD's preference for use of this plant community within the EAA where incoming concentrations tend to be lower than the other Florida treatment marshes that were evaluated and receive reclaimed water.

The lowest TN outflow concentrations observed were essentially all in the reduced forms (total organic nitrogen and ammonia-nitrogen) and equal to about 0.7 mg/L. As with TKN and total organic nitrogen, TN was most efficiently reduced in EAV and open water systems constructed upon sandy soils. Periphyton, FAV, and SAV were less effective plant communities and clay, limerock, and organic peat were less-effective substrates to efficiently achieve low TN outflow concentrations (WSI, 2012a).

The lowest TSS concentration typically attained by Florida treatment wetlands was about 1 mg/L. For TSS reduction, PSTAs and EAV were the most effective plant communities, followed by SAV, with open water and FAV least favorable. There was essentially no observed effect of substrate type on TSS reduction effectiveness (WSI, 2012a).

Representative treatment wetland projects completed by SFWMD, Working Group members, and other entities are identified in Table 3-1 and summarized below to demonstrate that treatment wetlands have been proven to reduce nutrient concentrations when inflows are in the range of values measured in the Caloosahatchee River and expected discharges from the C-43 WBSR. Projects summarized include those with adequate reported data to allow an assessment of performance. There are additional natural treatment system projects that have been implemented in southwest Florida for which data were not available.

Table 3-1. Representative Constructed Treatment Wetland Projects

Project	Description	Area (acres)	TN Reduction (%)	TP Reduction (%)	Cost (without land)
EAA STAs	Pumped, full-scale systems using EAV and SAV	57,000	14-45	66-85	>$1 billion
Wellington	Pumped pilot-scale system using EAV, SAV, PSTA, FAV, and upland grass	2	26	91	$1,300,000
C-43 Mesocosm	Pumped mesocosm-scale system using EAV and SAV	<1	22-24	75-83	$250,000
Ten Mile Canal Filter Marsh	Gravity flow mixed wetland community	13	15	61	$1,900,000
Briarcliff Filter Marsh	Gravity flow mixed wetland community	7.7	11	68	$1,170,000
Powell Creek Filter Marsh	Gravity flow mixed wetland community	18.8	14	72	$1,500,000
Lakes Park Water Quality Improvement Project	Gravity flow mixed wetland community	29.1	NA[2]	NA[2]	$2,300,000
Freedom Park	Pumped system using open water, EAV, SAV, PSTA	25.8	36-41	54-84	$11,300,000
Orlando Easterly Wetlands	Pumped system using EAV and SAV	1,200	54	73	$17,200,000
Apopka Marsh Flow-Way	Gravity inflow/pumped outflow system using EAV	760	24	26	$5,100,000

Nutrient reductions reported as changes between inflow and outflow concentrations.

[1] Costs for engineering and construction only. Land acquisition and operations are not included.

[2] No removal reported due to low inflow concentrations.

3.2.2.1 Everglades Agricultural Area Stormwater Treatment Areas

SFWMD has constructed massive treatment wetland projects, STAs, to improve water quality in discharges to the Water Conservation Areas (WCAs) and Everglades National Park (ENP). These projects were implemented to reduce phosphorus loads and minimize phosphorus concentrations delivered from Lake Okeechobee and watersheds within the EAA to the WCAs and ENP. To date, SFWMD has constructed five STAs (STA-1 East [STA-1E], STA-1 West [STA-1W], STA-2, STA-3/4, and STA-5/6) south of Lake Okeechobee (Figure 3-6). The total area of the STAs, including infrastructure components, is roughly 68,000 acres, with individual systems ranging in size from approximately 2,250 acres to more than 16,500 acres (SFWMD, 2019a; WSI, 2012a).

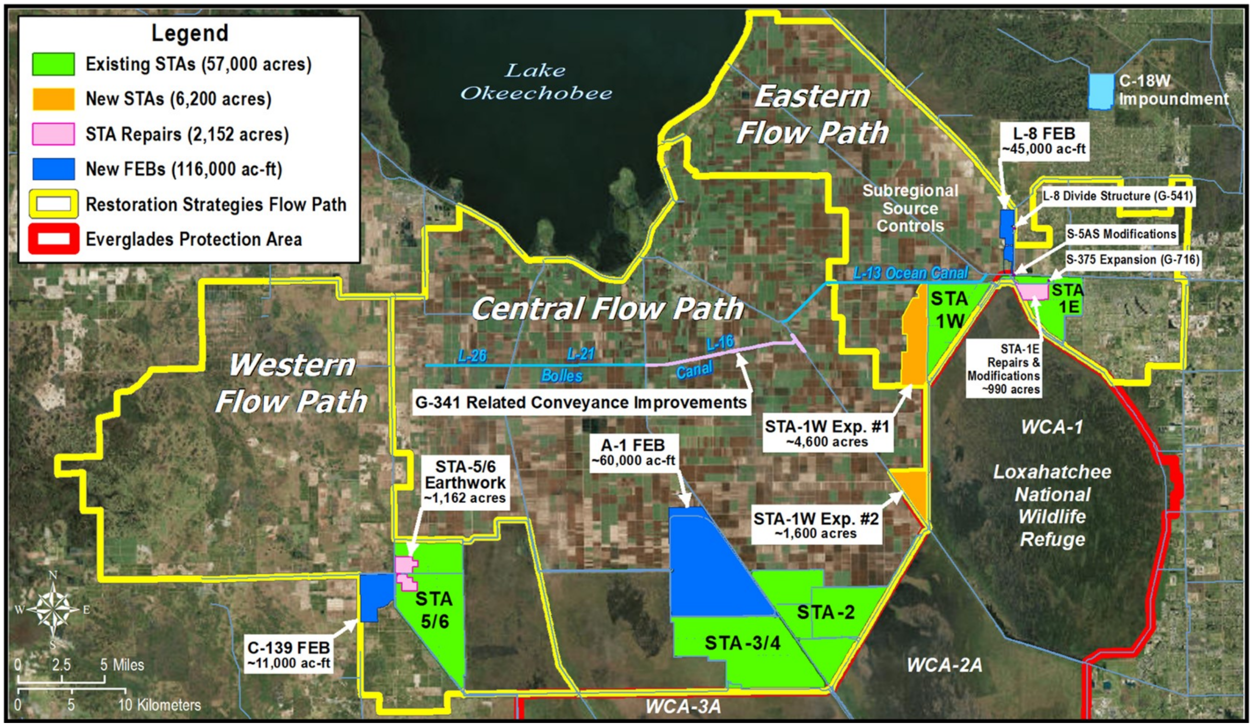


Figure 3-6. Location of SFWMD Stormwater Treatment Areas (SFWMD, 2019a)

The EAA STAs were largely constructed on land that was formerly used for agricultural operations, such as sugar cane production, sod production, and citrus groves. Existing substrates ranged from sandy mineral soils to very thick organic peat soils to exposed limestone caprock. The majority of the vegetation in the STAs was established through volunteer recruitment. Existing STA plant communities are diverse with a mixture of emergent wetland vegetation, including cattails and bulrush; SAV, such as southern naiad and coontail; and floating aquatic plant species, such as water hyacinth and duckweed (WSI, 2012a).

In WY2018 (May 1, 2017–April 30, 2018), the STAs treated over a combined 1.6 million ac-ft of water and retained 275 metric tons (mt) of TP, which equated to a 77% TP load reduction and produced an outflow FWM TP concentration of 0.036 mg/L (SFWMD, 2019a). The outflow FWM TP concentrations from individual STAs in WY2018 were 0.047, 0.039, 0.038, 0.012, and 0.074 mg/L in STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6, respectively. The percent TP load retained in WY2018 ranged from 62% (STA-5/6) to 90% (STA-3/4) (SFWMD, 2019a).

Since 1993, the STAs in combination have treated approximately 20.1 million ac-ft of water and retained 2,604 mt of TP with a 77% TP load reduction (Table 3-2). The overall outflow FWM TP concentration from the STAs during this period was 0.031 mg/L. STA-3/4, over its 15-year operational history, has treated the most water (approximately 6.5 million ac-ft), retained the most TP load (728 mt), achieved the highest percent TP load retained (85%), and discharged water at the lowest outflow FWM TP concentration (0.016 mg/L) of all the STAs (SFWMD, 2019a).

Table 3-2. Summary of Treatment Performance in Each of the STAs for WY2018 and the Period of Record

Parameter (unit[1])	STA-1E[2]	STA-1W	STA-2	STA-3/4	STA-5/6	All STAs
Effective Treatment Area (acre)	4,994	6,544	15,494	16,327	13,685	57,044
Adjusted Effective Treatment Area (acre) [3]	4,994	6,544	15,494	16,327	13,685	57,044
WY2018 Inflow						
Inflow Water Volume (ac-ft)	161,000	195,000	445,000	543,000	271,000	1,623,000
Inflow TP Load (mt)	53	55	87	87	78	359
FWM Inflow TP Concentration (mg/L)	0.265	0.228	0.158	0.128	0.234	0.180
Hydraulic Loading Rate (cm/d)	2.7	2.5	2.4	2.8	1.7	2.4
Phosphorus Loading Rate (g/m^2/yr)	2.6	2.1	1.4	1.3	1.4	1.6
WY2018 Outflow						
Outflow Water Volume (ac-ft)	173,000	225,000	506,000	631,000	324,000	1,860,000
Outflow TP Load (mt)	10.0	10.8	23.8	9.0	29.7	83
FWM Outflow TP Concentration (mg/L)	0.047	0.039	0.038	0.012	0.074	0.036
TP Retained (t)	43	44	63	74	49	272
TP Removal Rate (f/m^2/yr)	2.1	1.7	1.0	1.1	0.9	1.2
TP Load Retained (%)	81%	80%	73%	90%	62%	77%
Period of Record						
Start Date	September 2004	October 1993[4]	June 1999	October 2003	December 1997	WY1994-WY2018
Inflow Water Volume (ac-ft)	1,552,000	4,250,000	5,164,000	6,487,000	2,693,000	20,153,000
TP Inflow Load (mt)	338	925	652	856	627	3,400
FWM Inflow TP (mg/L)	0.177	0.177	0.102	0.107	0.189	0.137
Outflow Water Volume (ac-ft)	1,479,000	4,393,000	5,557,000	6,652,000	2,446,000	20,528,000
TP Outflow Load (mt)	75	249	149	128	194	795
FWM Outflow TP Concentration (mg/L)	0.041	0.046	0.022	0.016	0.064	0.031
TP Retained (mt)	263	677	503	728	433	2,604
% TP Retained	78%	73%	77%	85%	69%	77%

Source: SFWMD, 2019a

[1] Conversion factors: 1 acre = 0.40468 hectares or 4,046.8 square meters; 1 ac-ft = 1,233.5 cubic meters; 1 metric ton = 1,000 kilograms; and 1 centimeter/day (cm/d) = 0.39370 inches per day

[2] STA-1E was operated WY2005 for emergency flood control purposes and to establish wetland vegetation; it became fully operational in WY2006.

[3] Adjusted effective treatment area is time and area weighted to exclude any cells that were temporarily off-line.

[4] Flow-through operations in STA-1W did not begin until August 1994.

While the focus of the STA projects has been on phosphorus removal, SFWMD has also summarized performance of the STAs for TN (SFWMD, 2017). Table 3-3 shows the long-term changes in TN concentrations and loads for each of the STAs. Most of the STAs experienced higher inflow concentrations than observed in the C-43 Basin as a result of the greater storage of organic nitrogen in the peat soils that characterize much of the EAA. Lower inflow concentrations were measured at STA-5 (and later STA-5/6) and are in the range of concentrations typically observed in C-43 Basin water. STA load reduction performance for TN ranged from 9% at STA-5/6 to 53% at STA-1E (SFWMD, 2017).

Table 3-3. Summary of Nitrogen Treatment Performance in each of the STAs for the Periods of Record

STA	TN (mg/L)			TN (mt)			Period of Record	
	Inflow	Outflow	% Removal	Inflow	Outflow	% Removal		
STA-1E	2.19	1.52	31%	3,869	2,454	53%	WY2006	WY2016
STA-1W	3.56	2.31	35%	11,816	8,236	30%	WY2004	WY2016
STA-2	3.49	2.15	38%	20,317	13,325	34%	WY2003	WY2016
STA-3/4	3.43	1.88	45%	25,123	13,233	47%	WY2006	WY2016
STA-5	1.66	1.44	14%	2,595	2,053	31%	WY2001	WY2012
STA-6	2.09	1.43	32%	780	302	61%	WY2002	WY2007
STA-5/6	1.55	1.27	15%	271	247	9%	WY2014	WY2016

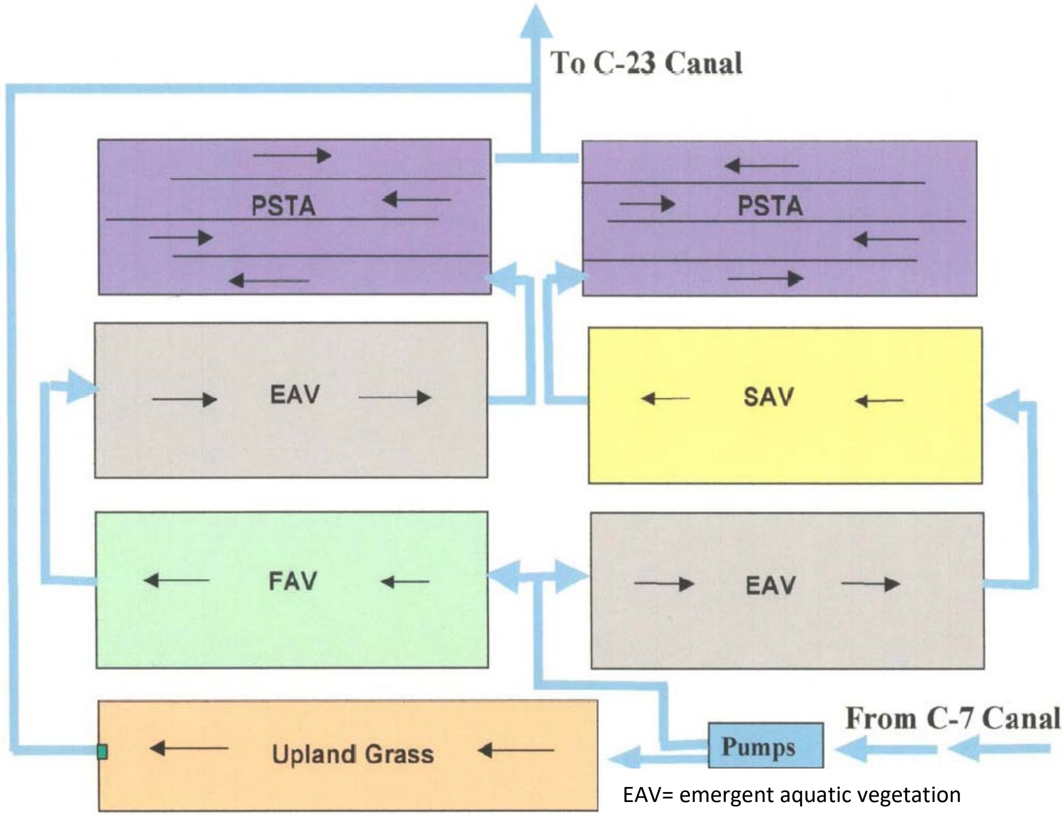
Source: SFWMD, 2017

With limited exceptions, individual flow paths in the EAA STAs include multiple cells in series that are generally managed for EAV in the upstream compartments and SAV in the downstream compartments. Initial nutrient removal is accomplished in the EAV cells. The SAV cells are used to maximize phosphorus removal. Per unit area, the biomass of SAV in the water column exceeds that of EAV. As SAV photosynthesizes, dissolved carbon dioxide is consumed from the water column and oxygen is transferred from the submerged leaves to the water column. This process results in wide diurnal swing in water column oxygen concentrations and pH. It is typical for daytime pH in SAV cells to exceed 9 standard units, which, when combined with dissolved calcium in the source water, facilitates the formation of calcium phosphate. Calcium phosphate is generally insoluble, precipitates from the water column, and accumulates at the sediment surface.

To further reduce phosphorus concentrations, SFWMD evaluated PSTAs at scales ranging from mesocosms to 100-acre demonstration cells. In unimpacted regions of the WCAs and ENP, periphyton survives by scavenging trace amounts of phosphorus from the water column and pore water. SFWMD summarized the results of the various PSTA projects and reported that the 100-acre field-scale system constructed within STA-3/4 was the most successful at consistently minimizing outflow phosphorus concentrations (SFWMD, 2019b). A key element of PSTA construction is either the removal of organic or mineral soils to the underlying limestone caprock or the capping of existing soils with imported crushed limestone (natural periphyton communities occur over calcium carbonate marl soils). Over 10 years of operation, the STA-3/4 PSTA system reduced TP from 0.016 mg/L to 0.010 mg/L at an average hydraulic loading rate of 6.5 (cm/d; SFWMD, 2019b). Costs for PSTA cells at the 100- to 200-acre size were reported to range from $27,500 to $29,000 per acre (SFWMD, 2019b). The SFWMD (2019b) did not summarize PSTA performance for nitrogen; however, data from one of the same experimental systems was reported by CH2M Hill (2003a). Over the monitoring period, the mesocosm-scale PSTA units reduced TN from 1.20 mg/L to 1.00 mg/L, but the 5-acre field-scale cells had higher outflow concentrations (1.80 mg/L) than inflow concentrations (1.65 mg/L).

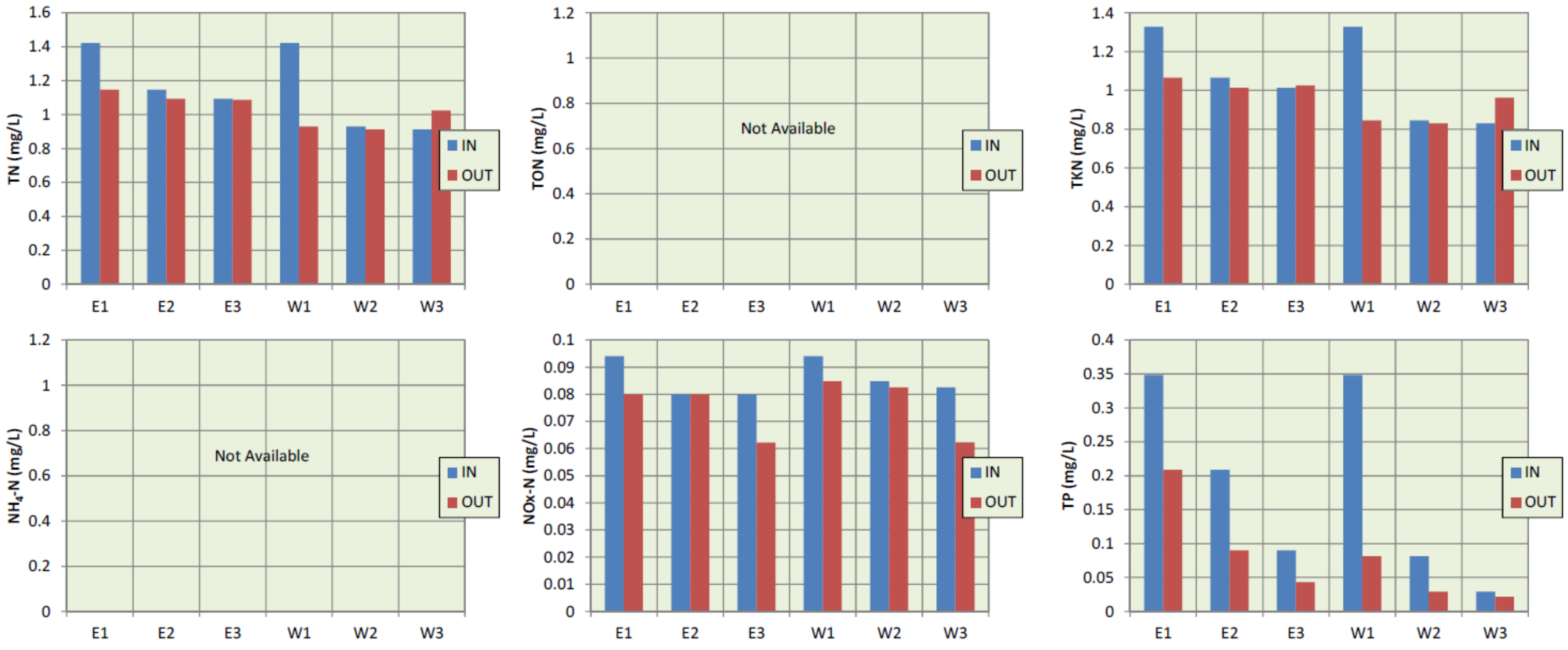
3.2.2.2 Wellington Aquatics Pilot Test Facility

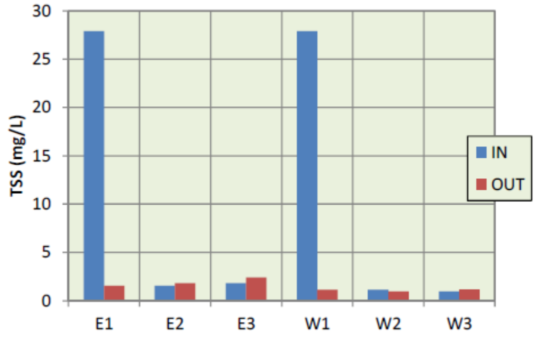
The Village of Wellington is responsible for the surface water management of a 13.6-square mile area within the village (CH2M Hill, 2003b). From November 2001 through February 2003, the Village of Wellington monitored the Aquatics Pilot Test Facility to evaluate phosphorus removal by natural treatment systems. The Wellington Aquatics Pilot Test Facility was a 2.0-acre site consisting of six cells operated in two parallel treatment series (east and west) of three cells each (Figure 3-7). The west series included a FAV cell followed by an EAV cell and a PSTA cell. The east series included an EAV cell followed by a SAV cell and a PSTA cell. An upland grass cell was also evaluated as a stand-alone system. Period-of-record average inflow TN and TP concentrations were 1.42 mg/L and 0.348 mg/L, respectively (Figure 3-8). The east series produced outflow concentrations of 1.09 mg/L for TN and 0.043 mg/L for TP. The West series produced outflow concentrations of 1.02 mg/L for TN and 0.022 mg/L for TP. Nitrogen performance at the Wellington site was better than the EAA STAs due to its construction on sandy soils and lower inflow concentrations (CH2M Hill, 2003b; WSI, 2012a).



EAV= emergent aquatic vegetation
SAV= submerged aquatic vegetation
FAV= floating aquatic vegetation
PSTA = periphyton-based stormwater treatment areas

Figure 3-7. Village of Wellington Aquatics Pilot Facility Layout (WSI, 2012a)





Wellington Aquatics Pilot Test Facility

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
E1	0.055	148.89	83.36	26.97	SAND	EMERGENT
E2	0.044	83.36	97.73	19.08	SAND	SAV
E3	0.049	97.73	52.80	19.82	LIME ROCK	PSTA
W1	0.047	155.74	73.39	33.49	SAND	FAV
W2	0.055	73.39	58.01	13.30	SAND	EMERGENT
W3	0.049	58.01	25.11	11.77	LIME ROCK	PSTA
Period of Record	Nov-01	Feb-03				

Figure 3-8. Village of Wellington Aquatics Pilot Facility Performance Summary (WSI, 2012a)

3.2.2.3 C-43 Water Quality Treatment and Testing Project – Phase 1 Mesocosm Study

Conceptual planning for the C-43 Water Quality Treatment and Testing Project (C-43 WQTTP) was completed in 2012 (WSI, 2012b) and proposed the construction and operation of a multi-scale testing facility to evaluate wetland-based treatment alternatives for the C-43 Basin. SFWMD constructed a mesocosm-scale facility in 2016 (Figure 3-9) and operated the system between July 2016 and December 2018 (J-Tech and WSI, 2019). The project was located at the Boma site, which was jointly purchased by SFWMD and Lee County for purposes of developing a water quality improvement project and used the Caloosahatchee River as the source water. The mesocosm project was designed to address the following hypotheses:

- What wetland vegetation community (EAV or SAV) provides the best treatment for TN and DON?
- What effect does the native soil have on nitrogen cycling? Soils were either native or acid-rinsed to remove organic matter.
- Which water hydraulic loading rate (1.5 cm/d or 6.0 cm/d) results in the most efficient nitrogen removal rate?

Figure 3-9. C-43 Water Quality Treatment and Testing Project Mesocosm Facility (J-Tech and WSI, 2019)

TN removal was similar in both the EAV and SAV mesocosms. The EAV cells reduced inflow TN from 1.49 mg/L to 1.12 mg/L, a 24% reduction. Mass removal averaged 34%. The SAV cells reduced the inflow TN from 1.49 mg/L to 1.18 mg/L (22% reduction). SAV mass removals were slightly lower (32%) due to the intermittent export of particulate nitrogen. Average DON concentrations were reduced by about 4%, but during the wet season, when more DON was available in the Caloosahatchee River source water, DON concentrations were reduced by 13.4% in the EAV cells and 13.8% in the SAV cells. Inorganic nitrogen (ammonium and nitrate) was effectively removed by both plant community types. Confirming the trends observed at the EAA STAs, the SAV cells performed better than the EAV cells for TP removal. EAV concentration reductions averaged 75% and SAV averaged 83%. Inflow TP concentrations were reduced from 0.158 mg/L to 0.039 mg/L in the EAV cells and 0.029 mg/L in the SAV cells.

Soils at the Boma site did not appear to have significant initial storages of labile nitrogen that influenced overall performance. The lack of a statistically significant reduction in TN for mesocosms with pre-treated soils was an important finding because it indicates that construction of a treatment wetland on a site in the C-43 Basin with sandy soils, like those on the Boma property, would not require pre-treatment of soils to successfully remove TN (J-Tech and WSI, 2019).

Hydraulic loading rate was not found to significantly affect outflow TN concentrations. The outcome of this finding could have substantial impacts on final design of any future treatment wetland in the C-43 Basin and should be carefully evaluated. Based on these results future wetland treatment projects should potentially evaluate hydraulic loading rates higher than 6.0 cm/d, although this requires attention to velocity effects on water depth that magnify with increasing system scale (WSI, 2009).

3.2.2.4 Ten Mile Filter Marsh

The Lee County Department of Natural Resources (LCDNR) implemented the first of several constructed wetland treatment projects, the Ten Mile Filter Marsh, in 2006 (Figure 3-10). The filter marsh initially consisted of four linear features adjacent to the Ten Mile Canal that alternated between deeper (6 to 7 feet) settling basins and shallower (1 to 3 feet) marsh cells (Johnson Engineering, 2008). The marsh cells were planted with wetland vegetation. In 2012, the project was widened and reconfigured to provide two separate filter marshes that share a single settling basin (Johnson Engineering, 2019). The total treatment area currently consists of approximately 13 acres. Water quality monitoring began in February 2007, and data are available through 2018. Sampling was interrupted by the 2012 Phase II construction effort between November 2012 and November 2013 (Johnson Engineering, 2019). Over the period of record, the flow-weighted inflow and outflow TN concentrations averaged 1.01 and 0.81 mg/L. Flow-weighted inflow and outflow TP concentrations averaged 0.074 and 0.029 mg/L. Gravity inflows to the filter marsh since the expansion in 2012 averaged 1.6 billion gallons per year (31.9 cm/d). The filter marsh underwent periodic maintenance including vegetation removal.

Figure 3-10. Lee County Ten Mile Canal Filter Marsh (Johnson Engineering, 2018)

3.2.2.5 Briarcliff Filter Marsh

The LCDNR constructed the 7.7-acre Briarcliff Filter Marsh in 2012 (Figure 3-11) for a cost of $1.17 million, excluding land acquisition. The Briarcliff Filter Marsh serves a drainage basin area of 12,627 acres. The system consists of a single settling pond and two marsh cells that can be operated in series or parallel. Monitoring was conducted between January 2014 and September 2015. Average TN concentrations were reduced from 0.93 to 0.83 mg/L and TP from 0.025 to 0.008 mg/L for the monitoring period. Annual gravity inflows averaged 1.3 billion gallons for the monitoring period which equates to an approximate hydraulic loading rate of 43 cm/d. Wet season performance for TN was notably better than dry season performance (Johnson Engineering, 2015a).

Figure 3-11. **Lee County Briarcliff Filter Marsh (LCDNR, 2016a)**

3.2.2.6 Powell Creek Filter Marsh

The Powell Creek Filter Marsh is an 18.8-acre treatment wetland system that was constructed by the LCDNR in 2012 (Figure 3-12). The system polishes runoff from a 7,500-acre watershed that comprises residential, agricultural, and natural (forested/wetland) land uses. Inflows are pumped from Powell Creek and Powell Creek Canal. The system consists of a series of shallow and deep wetland habitats. Water quality data were collected in 2013 and 2014 with results summarized by Johnson Engineering (2015b) and the LCDNR (2015). Inflow TN concentrations were reduced from 1.08 mg/L to 0.93 mg/L, and inflow TP concentrations were reduced from 0.87 mg/L to 0.24 mg/L. Nutrient loads were estimated to be reduced by 1,188 pounds per year (lbs/yr) for TN and 153 lbs/yr for TP. Flows were delivered by gravity and averaged 248 million gallons in 2014 (3.4 cm/d). The construction cost was approximately $1.5 million.

Figure 3-12. Lee County Powell Creek Filter Marsh (Johnson Engineering, 2015b)

3.2.2.7 Lakes Park Water Quality Restoration Project

The LCDNR's Lakes Park Water Quality Restoration Project (Figure 3-13) was completed in 2013 and consists of two filter marshes. The East Lake Filter Marsh is a 20.2-acre meandering wetland, and the West Lake Filter Marsh is an 8.95-acre series of constructed peninsulas with littoral plantings that were designed to lengthen the flow path through the system (LCDNR, 2016b). The site receives runoff from a 2,000-acre watershed. Inflow concentrations to the Lakes Park filter marshes were low with TN averaging 0.64 mg/L and TP averaging 0.03 mg/L during a 12-month monitoring period from January through December 2015 (LCDNR, 2016b). The project did not result in measurable water quality improvements during the monitoring period, and the lack of performance was attributed to the low inflow concentrations. The project was constructed for approximately $2.3 million. Flows were not measured.

Figure 3-13. Lee County Lakes Park Water Quality Restoration Project (LCDNR, 2016b)

3.2.2.8 Freedom Park

Collier County constructed the Freedom Park project to treat stormwater from the 961-acre Gordon River Watershed. Freedom Park consists of a 4.7-acre pond for stormwater storage and 6.7 acres of constructed treatment marshes, which flow through restored natural wetlands (14.4 acres) prior to discharge to the Gordon River (Bays and Bishop, 2014). During the wet season, inflows are pumped from regional drainage canals. In the dry season, an auxiliary pump station is used to pump base flows directly from the Gordon River (Figure 3-14).

Performance data for the Freedom Park project have been reported for the periods 2008 through 2013 (Bays and Bishop, 2014) and March 2016 through February 2017 (Griffiths and Mitsch, 2017). During the 2008–2013 period, median inflow and outflow TN concentrations were 1.47 mg/L and 0.87 mg/L, while median inflow and outflow TP concentrations were 0.21 mg/L and 0.033 mg/L (Bays and Bishop, 2014). TN data from 2016–2017 averaged 1.17 mg/L in the inflow and 0.86 mg/L in the outflow, while TP averaged 0.11 mg/L in the inflow and 0.051 mg/L in the outflow (Griffiths and Mitsch, 2017). The average hydraulic loading rate during the 2016–2017 monitoring period was 7.3 cm/d.

Total project costs were $30.5 million, which included $19.2 million for land acquisition, $1.3 million for design, and $10 million for construction (Bays and Bishop, 2014).

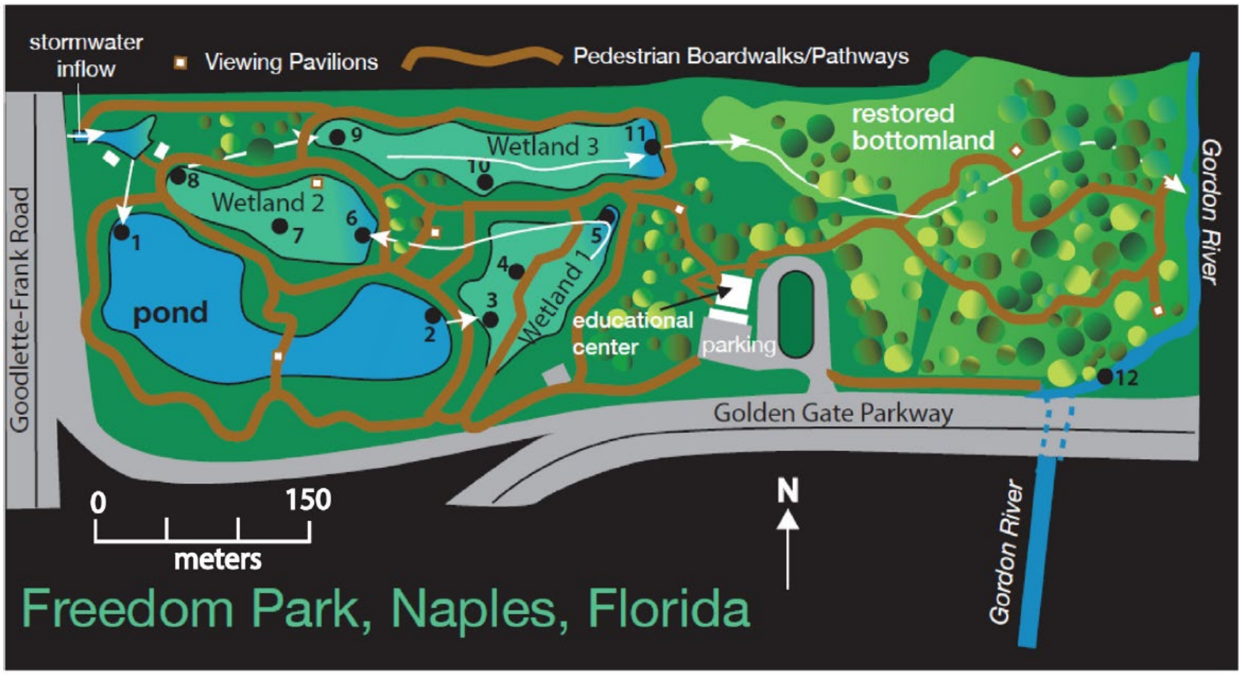


Figure 3-14. Freedom Park (Griffiths and Mitsch, 2017)

3.2.2.9 Orlando Easterly Wetlands

The 1,200-acre Orlando Easterly Wetlands began operation in 1987 and polishes advanced treated municipal effluent from the City of Orlando's Iron Bridge Water Reclamation Facility. While not a stormwater or surface water treatment system, this project is included in this section because it has demonstrated the long-term ability to discharge low nutrient concentrations. The Orlando Easterly Wetlands is divided into 17 cells ranging in size from 14 to 186 acres. The site was historically used as improved cattle pasture and consists of sandy soils underlain by clay. The wetland was created by constructing earthen berms and planting over 2 million aquatic plants (United States Environmental Protection Agency [USEPA], 1993). Water is pumped 17 miles (27 kilometers) from the Iron Bridge Water Pollution Control Facility to a splitter box that routes flow into three parallel treatment trains (Figure 3-15). Each train consists of deep marsh cells (approximately 3 feet in depth) initially planted with cattail and bulrush, followed by mixed emergent marsh cells, and finally a hardwood swamp. Bird rookeries in the hardwood swamp areas and antecedent soil TP concentrations contributed to a net release of TP from the system during the first several years following startup. Operators have used a variety of techniques to control vegetation and sediment accumulation, including prescribed burning, periodic draw downs, herbicide application, and muck removal. Figure 3-16 shows annual average inflow and outflow concentrations for nutrients for the period from 1991 through 2018 (City of Orlando, 2019). Long-term average inflow and outflow TN concentrations were 1.88 mg/L and 0.87 mg/L, respectively, a 54% reduction. The long-term average inflow and outflow TP concentrations were 0.23 mg/L and 0.06 mg/L, respectively, a 73% reduction. Long-term average flow and hydraulic loading rate were 17.3 million gallons per day (MGD) and 1.35 cm/d.

The total project cost was $21.5 million (1987 dollars), which included $4.4 million for land acquisition, $5.0 million for construction of the wetlands, $10.5 million for the inflow pump station and force main, and $1.7 million for engineering (USEPA, 1993).

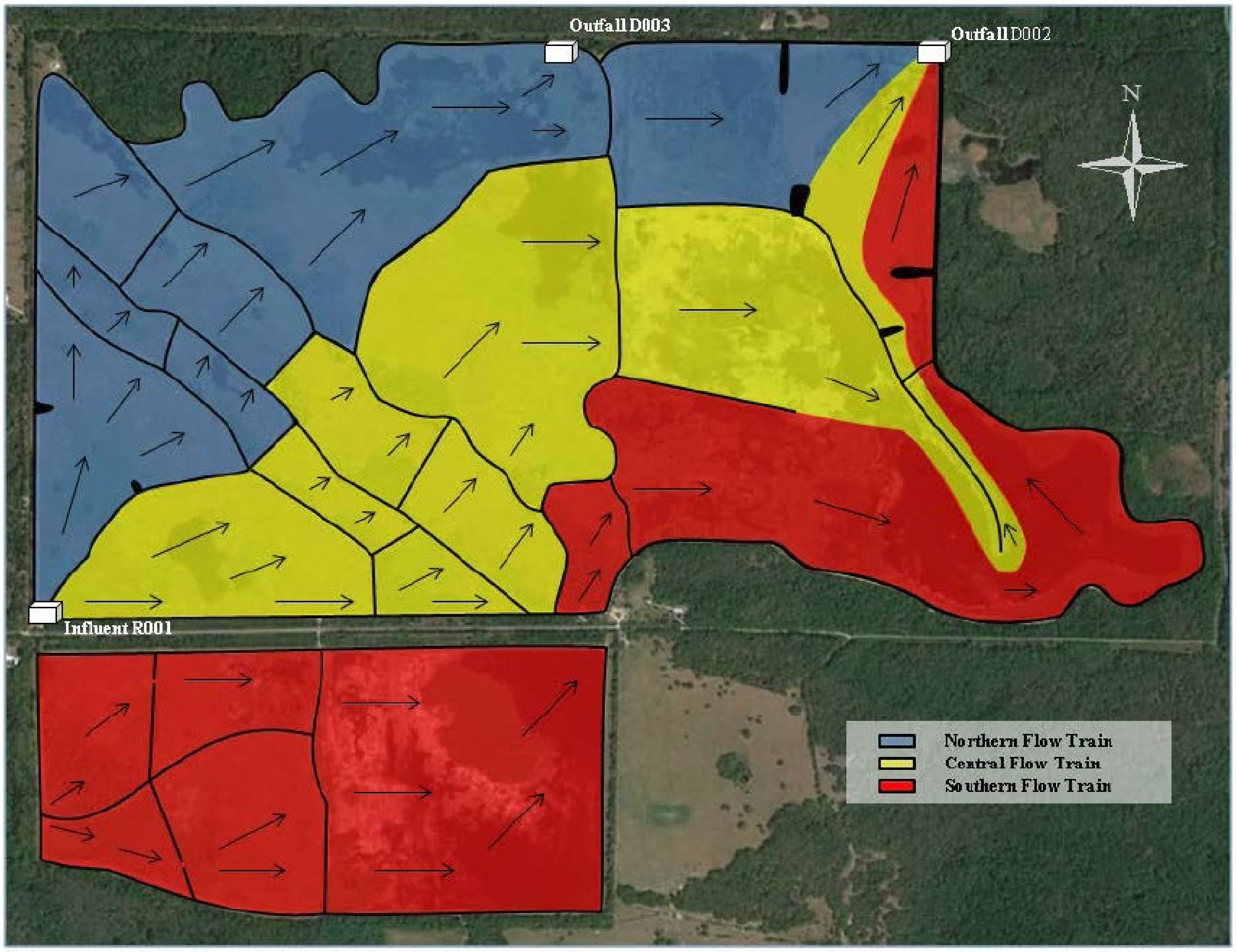


Figure 3-15. Orlando Easterly Wetlands Layout (City of Orlando, 2019)

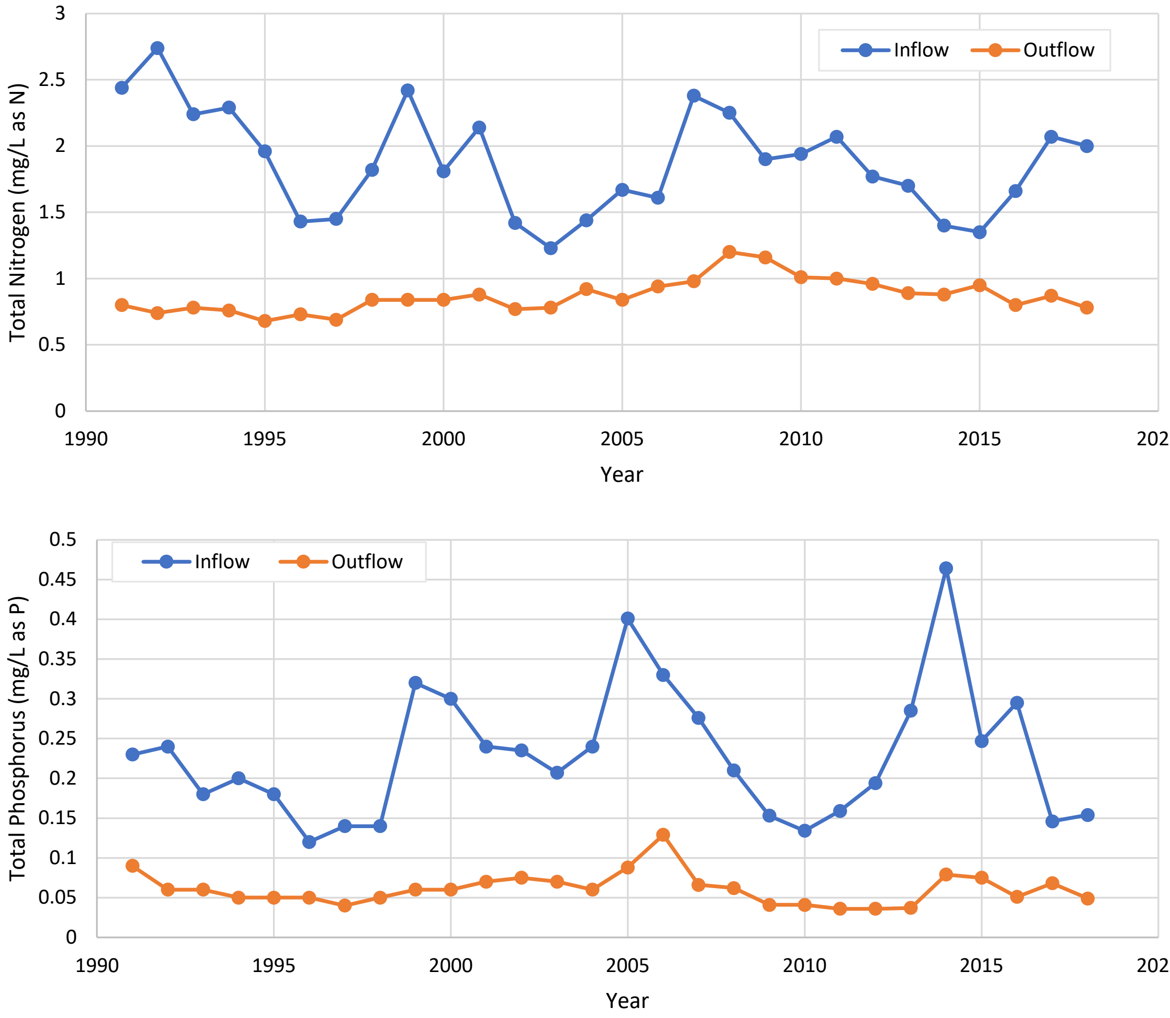


Figure 3-16. **Orlando Easterly Wetlands Performance 1991-2018 (City of Orlando, 2019)**

3.2.2.10 Lake Apopka Marsh Flow-Way

The Lake Apopka Marsh Flow-Way (Figure 3-17) was constructed by the St. Johns River Water Management District to reduce water column phosphorus concentrations from Lake Apopka. The lake is large, covering over 30,000 acres, and is characterized as hypereutrophic with nearly constant phytoplankton blooms. The flow-way is a four-cell constructed wetland system that totals about 760 acres and has been in operation since 2003 (Dunne et al., 2012). Lake water flows through the system by gravity and is pumped back to the lake after treatment. This project is included to show the effectiveness of natural systems when inflow water quality is poorer than other systems described above.

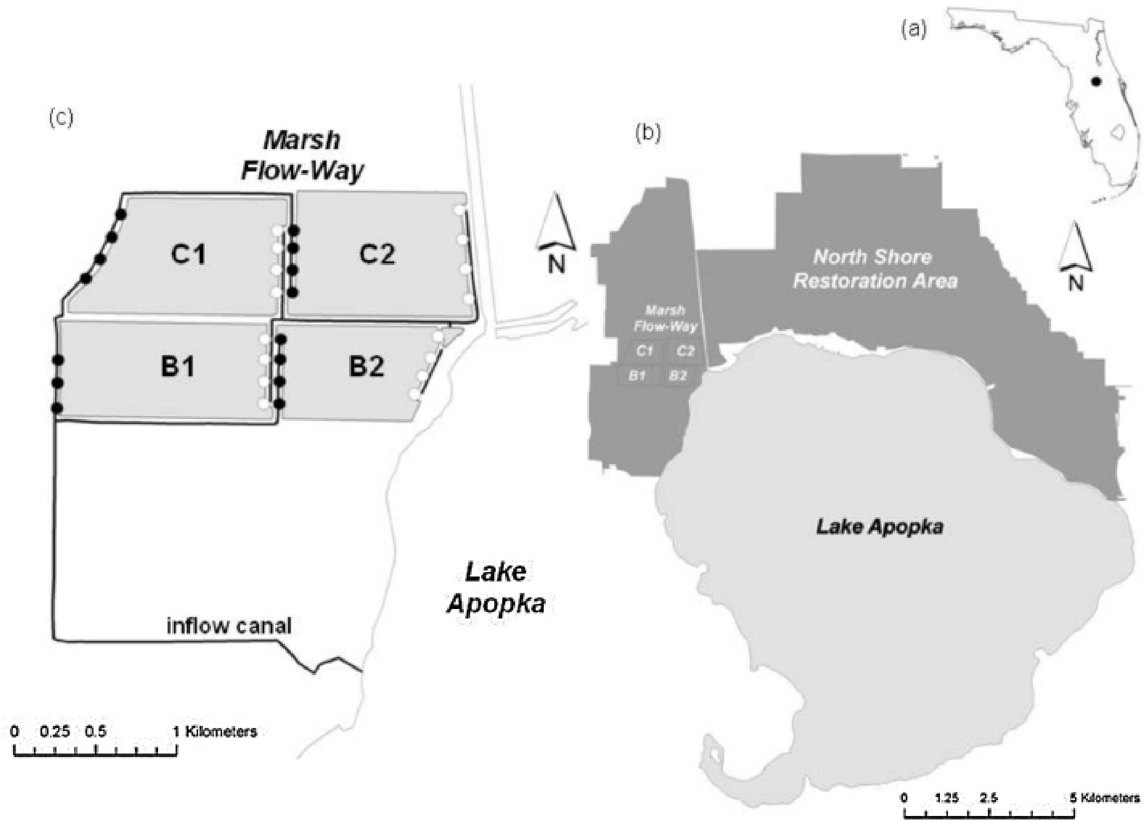


Figure 3-17. **Apopka Marsh Flow-Way (Dunne et al., 2015)**

Inflows to the Apopka system are dominated by particulate nutrients within algal solids. Between 2003 and 2012, the system was highly loaded, compared to many treatment wetlands, at an average hydraulic loading rate of 8.2 cm/d (Dunne et al., 2015). The TP mass removal rate averaged 26% and resulted in the retention of 2.6 mt of phosphorus. Settled particulate phosphorus from algal solids slowly decomposed and resulted in a net release of ortho-phosphorus and dissolved organic phosphorus, although at low concentrations compared to inflow TP (Dunne et al., 2015). Similar effects were observed for nitrogen where TN was removed, but the system produced DON and ammonia-nitrogen as algal solids decomposed (Dunne et al., 2013).

System costs were estimated and included $4 million for land acquisition and $5.1 million for construction. Annualized operations and maintenance costs were estimated to be about $455,000 (Dunne et al., 2015).

3.2.3 Open Water Systems (Ponds, Lakes, and Reservoirs)

3.2.3.1 C-43 WBSR Test Cells

The C-43 WBSR is an important component of CERP and is designed to capture and store approximately 170,000 acre-feet of water during the wet season. The C-43 WBSR Test Cell Program was initially implemented to evaluate alternative construction methods to control seepage in the full-scale reservoir; however, SFWMD conducted a water quality testing program in conjunction with the seepage investigations (WSI, 2007a). The Test Cell Program consisted of two test cells constructed within the footprint of the full-scale reservoir (Figure 3-18).

The test cells were constructed between March and June 2006, with initial pumping to fill the cells beginning in June 2006. The test cells were constructed with a wetted area of approximately 2.5 acres at the inside toe of slope and 4.5 acres at the target maximum water depth of 19 feet (WSI, 2012a). The test cells were operated with no surface outflows (pumping was controlled within a target range of stages, and all outflows were by evapotranspiration and leakage).

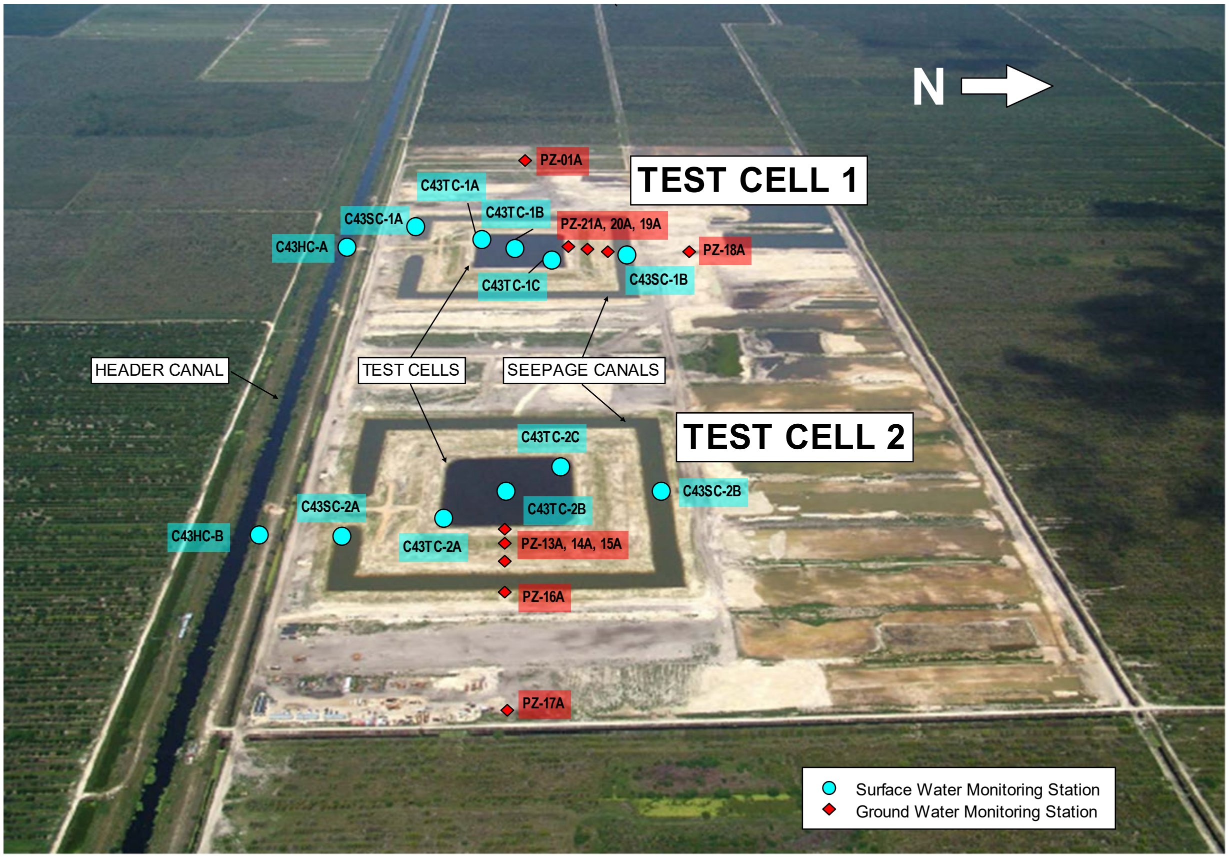
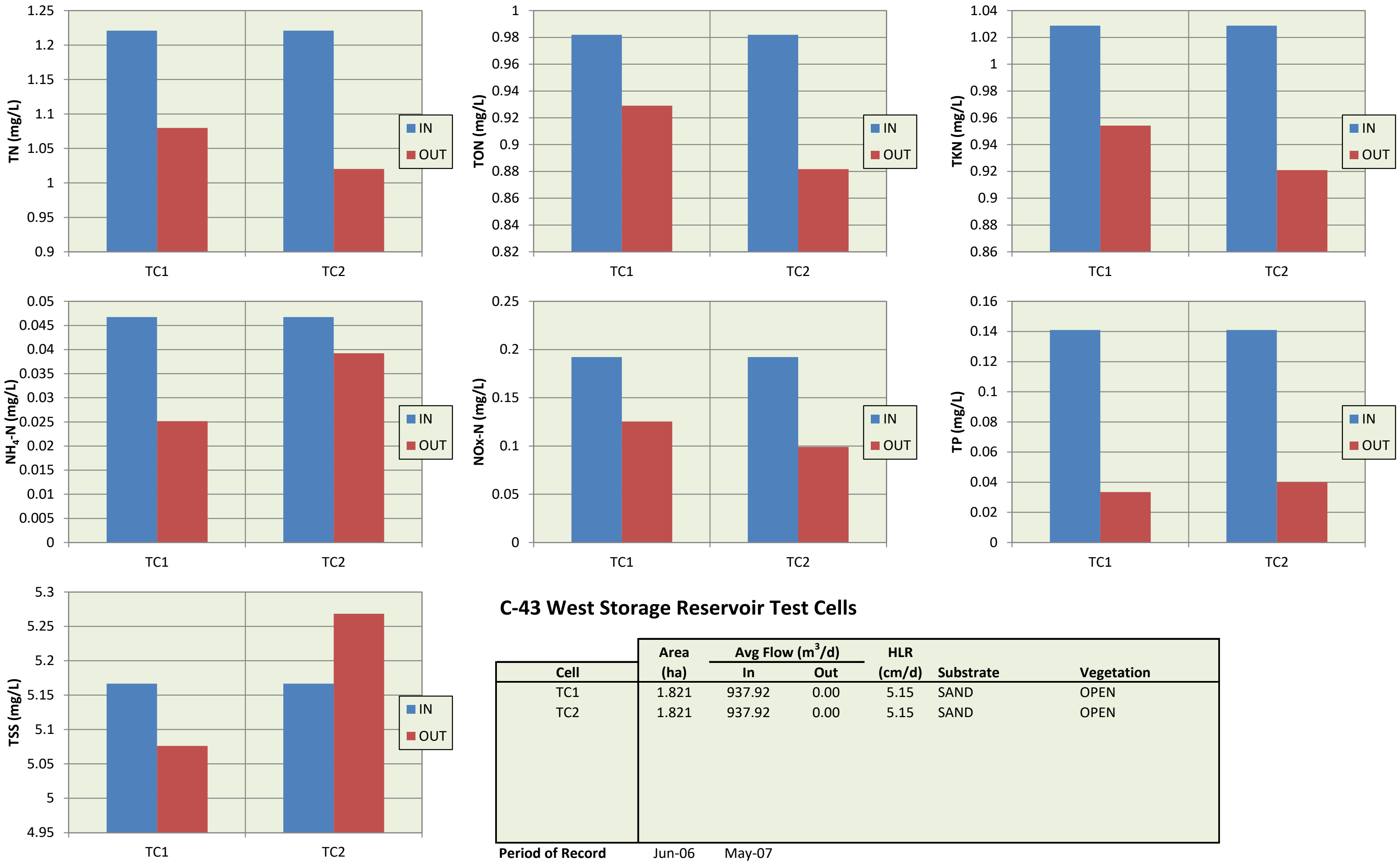


Figure 3-18. C-43 West Basin Storage Reservoir Test Cells (WSI, 2007a)

Figure 3-19 shows monthly average inflow and outflow concentrations for nutrients and solids (June 2006 to May 2007). Nutrient concentrations were generally reduced through the test cells with a 14% long-term average reduction of TN (1.22 mg/L to 1.05 mg/L) and an average 74% reduction for TP (0.141 mg/L to 0.037 mg/L). The long-term average TSS was relatively unchanged with a concentration of 5.17 mg/L at the inflow and within the test cells. TSS was being produced in these open water cells due to growth of phytoplankton.



C-43 West Storage Reservoir Test Cells

Cell	Area (ha)	Avg Flow (m³/d) In	Avg Flow (m³/d) Out	HLR (cm/d)	Substrate	Vegetation
TC1	1.821	937.92	0.00	5.15	SAND	OPEN
TC2	1.821	937.92	0.00	5.15	SAND	OPEN
Period of Record	Jun-06	May-07				

Figure 3-19. C-43 West Basin Storage Reservoir Test Cell Water Quality Summary (WSI, 2012a)

3.2.3.2 C-44 Storage Reservoir/Stormwater Treatment Area Test Cells

The C-44 Storage Reservoir/STA Project is one component of the proposed CERP Indian River Lagoon-South Integrated Project Implementation Report and Environmental Impact Statement (USACE and SFWMD, 2004). The C-44 Storage Reservoir/STA Project, which is currently under construction, is expected to retain and treat watershed runoff flows from the C-44 Canal (St. Lucie Canal) prior to discharge either to the St. Lucie River through S-80 or to Lake Okeechobee through S-308. The site for the C-44 Storage Reservoir/STA Project is located north of the C-44 Canal about mid-way between Lake Okeechobee and the St. Lucie River in Martin County.

A test cell program was initiated in early 2006 to assess storage reservoir seepage rates, water quality conditions during storage reservoir startup (initial flooding response), storage reservoir nutrient removal rates in response to reservoir water depth and hydraulic residence time, STA seepage rates, STA vegetation establishment from planting versus natural recruitment, water quality conditions during STA startup (initial flooding response), and STA nutrient removal performance (WSI, 2012a).

Two reservoir test cells and two STA test cells were constructed between March 2006 and June 2006 (Figure 3-20). Initial pumping began between mid-May and mid-June 2006, with the actual dates varying by cell. The reservoir test cells were constructed with a wetted area of approximately 2.2 acres at the inside toe of slope and 3.7 acres at the target maximum water depth of 15 feet. The STA cells were constructed with a wetted area of about 4.3 acres each at a target depth of about 1 foot in the marsh zones (WSI, 2007b). These test cells were operated with no surface outflows (pumping was controlled within a target range of stages and all outflows were by evapotranspiration and leakage).

Figure 3-21 shows monthly average (July 2006 to June 2007) inflow and outflow concentrations for nutrients and solids. Nutrient concentrations were generally low in the test cells with an average TN concentration of 0.87 mg/L (3% reduction) and a TP average of 0.022 mg/L (58% reduction). TSS concentrations were reduced but still fairly high with an average inflow concentration of 29.3 mg/L and an outflow average of 14.3 mg/L (51% reduction). The C-44 STA-2 was the only STA cell that displayed a long-term average TP and TSS reduction (TP – 0.060 to 0.031 mg/L [48%], TSS – 11.6 to 8.1 mg/L [30%]). The TN concentration was unchanged or increased in both STA cells, apparently as a result of TN release from the pre-existing site soils (WSI, 2012a).

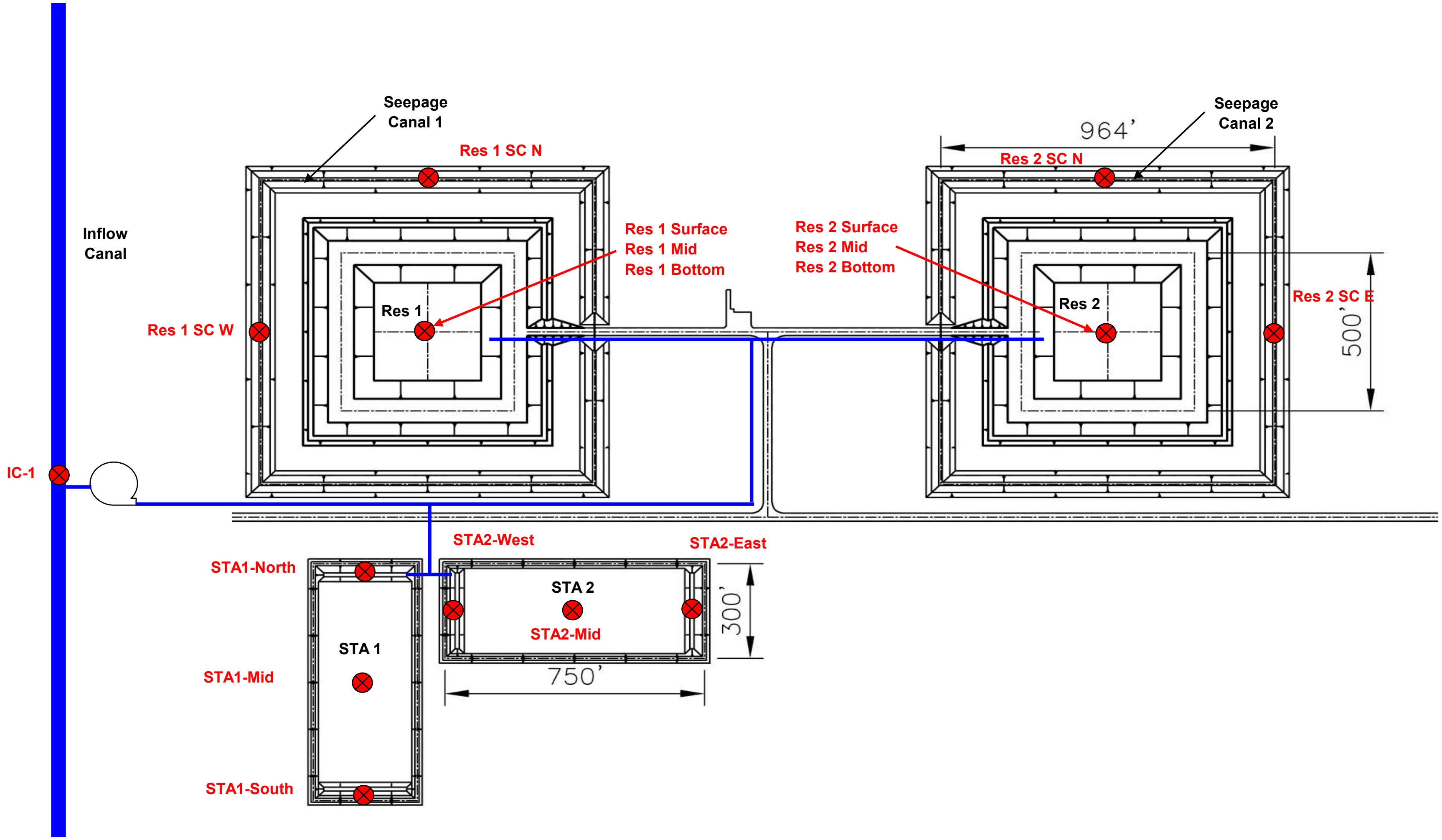
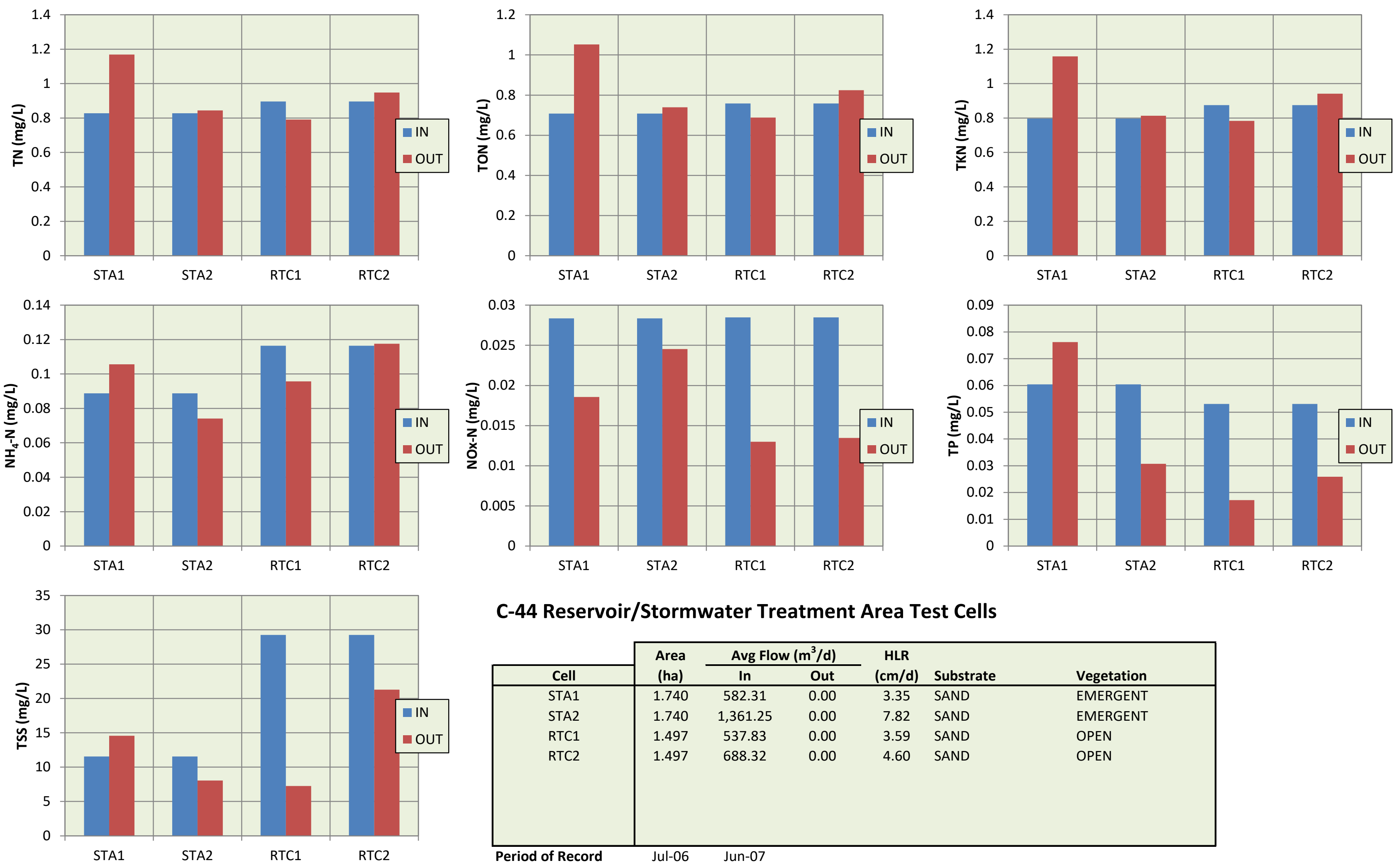


Figure 3-20. C-44 West Basin Storage Reservoir Test Cells (WSI, 2007b)



C-44 Reservoir/Stormwater Treatment Area Test Cells

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
STA1	1.740	582.31	0.00	3.35	SAND	EMERGENT
STA2	1.740	1,361.25	0.00	7.82	SAND	EMERGENT
RTC1	1.497	537.83	0.00	3.59	SAND	OPEN
RTC2	1.497	688.32	0.00	4.60	SAND	OPEN
Period of Record	Jul-06	Jun-07				

Figure 3-21. C-44 Reservoir and STA Test Cell Water Quality Summary (WSI, 2012a)

3.2.3.3 Lee County Best Management Practice (BMP) Study

Lee County conducted a water quality study on three wet detention ponds (Johnson Engineering, 2009) to measure nutrient removal performance. The primary purpose of the project was to compare design criteria and performance to guidance proposed in the state of Florida's draft stormwater manual. Each site represented a different land use. The sites included Laguna Lake (residential), Walmart (commercial), and The Brooks (golf course/residential). Water quality and hydrologic data were collected during 15 events over an 18-month period. On average, the Laguna Lake pond reduced TN from 1.92 mg/L to 1.42 mg/L (26% removal). The Walmart site reduced TN from 1.27 mg/L to 0.64 mg/L (50% removal), and The Brooks site reduced TN from 2.29 mg/L to 1.17 mg/L (49% removal). Data were reported for inorganic nitrogen and showed that ammonia was typically reduced by at least 50% and nitrate by at least 80%. Results were also reported for ortho-phosphorus and TP, but ortho-phosphorus exceeded TP in all cases, and these data are considered suspect. Project costs were not reported.

3.2.4 Floating Treatment Wetlands

3.2.4.1 Pasco County Reclaimed Water Reservoir

FTWs were evaluated as a technique to reduce nutrient concentrations in a reclaimed water storage reservoir in Pasco County, Florida (Vazquez-Burney et al., 2014). A total of 20 FTWs, comprising 1,600-square feet in surface area, were installed within a 4-acre reclaimed water storage pond at the Wesley Center Wastewater Treatment Facility. Water quality data were collected during the grow-in period (July 2012 through December 2012), the performance period (January 2013 through August 2013), and the control period after island removal (September 2013 through November 2013). The test-cell system operated at an average hydraulic residence time of 15.7 days. TN was dominated by nitrate-nitrogen and was reduced by 54% during the grow-in period, 70% during the performance period, and 30% during the control period (Figure 3-22). TP was reduced from 1.96 mg/L to 0.63 mg/L during the performance period and from 1.37 mg/L to 1.00 mg/L during the control period. Reductions in BOD and TSS concentrations were not observed and algae was reported to "flourish" in the reclaimed water storage pond. Average capital costs were reported by the manufacturer to be $30 per square foot of mat.

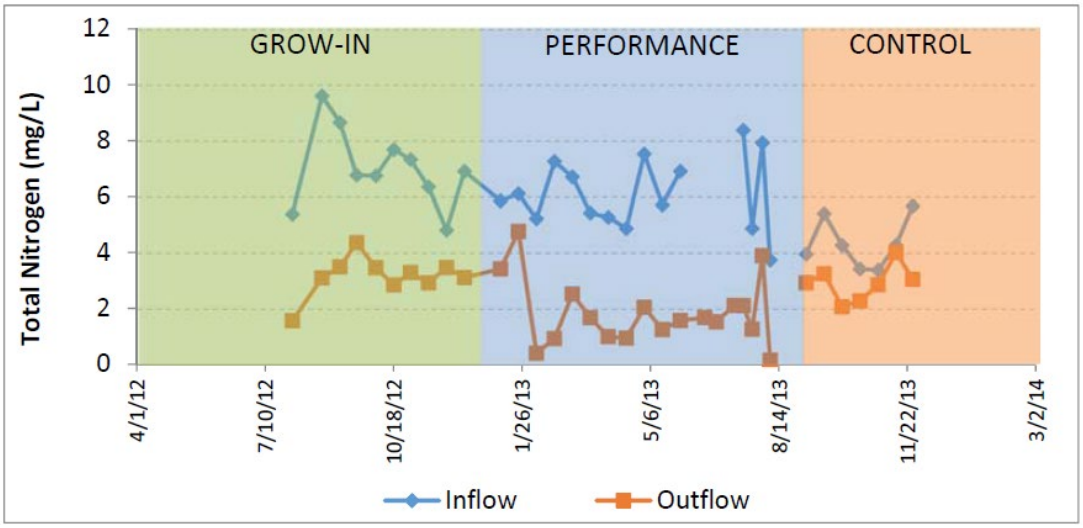


Figure 3-22. Pasco County FTW Nitrogen Performance (Vazquez-Burney et al., 2014)

3.2.4.2 Lake June

A 0.06-acre FTW was installed near the center of the 4-acre hypereutrophic Lake June (Figure 3-23) in August 2003 (DeBusk et al., 2005). The circular FTW included a flexible fabric skirt that extended from the water surface to the sediments, isolating a column of water about 9-feet deep. A solar-powered pump was used to pump lake water into the FTW zone at a rate which exchanged the lake volume in 10.5 months. Water quality data were collected for a 1-year period beginning in November 2003. FTW inflow samples were collected from the lake on the outside of the FTW barrier. Outflow samples were collected from an outlet pipe from the FTW compartment. Aluminum sulfate (alum) was dosed monthly to enhance phosphorus removal. Inflow and outflow TSS concentrations averaged 17 mg/L and 6 mg/L, respectively. TP was reduced from 0.168 mg/L to 0.084 mg/L. TN was reduced from 1.80 mg/L to 1.08 mg/L on average. Chl *a* was reduced from 78 milligrams per cubic meter to 26 milligrams per cubic meter. DO was significantly reduced under the FTW, decreasing from 9.6 mg/L in the lake water to 1.2 mg/L after wetland treatment. Cost data were not reported.

Figure 3-23. Lake June Floating Treatment Wetland (DeBusk et al., 2005)

3.2.4.3 Naples Floating Treatment Wetlands

Dettmar (2015) studied the effects of FTWs installed in three approximately 1-acre ponds in the City of Naples, Florida. Two FTWs (1.5 m x 2.5 m) were installed at Pond A, two at Livingston Pond of the same dimensions, and a single FTW (1.5 m x 3.0 m) at Collier Pond. The researcher reported that plant roots exuded allelopathic chemicals that inhibited algal growth, but more research was needed to determine dosing rates.

3.2.4.4 Lee County Floating Treatment Wetlands

Lee County installed three FTWs in a structurally controlled portion of Mullock Creek in 2008 (PSI, 2007). The study focused on quantifying nutrient uptake by the vegetation planted on the FTWs; however, water quality data were also collected at the inflow and outflow of the system. The data did not exhibit decreasing trends between the inflow and outflow that would demonstrate a positive effect of FTW installation on water quality.

Figure 3-24. Mullock Creek Floating Treatment Wetland (PSI, 2007)

3.3 Conventional Water Quality Treatment Alternatives

The conventional water quality treatment alternatives described below are predominantly gathered from the DEP Accepted Water Technologies Library (DEP, 2020) but also include information submitted directly to J-Tech and Working Group members from 8 vendors, which include 5 physical, 2 chemical, and 1 biological treatment technologies. Information on these additional technologies was gathered directly from the vendor as well as from a focused search on the Internet.

3.3.1 Physical Treatment Technologies

Physical treatment technologies are categorized for this report as filtration, sorption, dissolved air flotation (DAF), oxidation, sonication, and aeration. This section provides summaries of each physical treatment technology.

3.3.1.1 Filtration

Filtration is a well-established water treatment technology and is the most common physical water treatment type. Filtration is a process that removes impurities from water by means of a physical barrier (CDC, 2020). The physical barrier may be comprised of inorganic or organic media or engineered membranes, such as microfiltration or reverse osmosis. Discussion of engineered membranes is included in the section on biological treatment using advanced wastewater treatment below.

Inorganic materials used to create a physical barrier can consist of sand, gravel, woodchips, and charcoal or any mixture of the composites. The filter media is typically contained within a basin to guide water through the media. Depending on the water composition and constituents for removal, the grain size of the media is engineered to remove the pollutants while promoting the desired flowrate through the filtration technology.

Although filtration is a widely accepted treatment technology for pathogens and nutrients, filtration has its limitations. The longevity of a filtration system is the defining factor for the use in large systems, such as the C-43 WBSR. Long-term projects sometimes require significant maintenance depending on the purity of the water being treated. Filtration systems are susceptible to clogging from natural biofilm growth and the filling of the pore space from the pollutants filtered out of the water column. To combat this effect, conventional filtration systems typically include a mechanism to backwash filters and periodically replace the filter media. The lifetime of the filter depends on the concentration of pollutants in the water as well as the treatment efficiency due to grain size of the filter.

Filtration treatment occurs by prohibiting pollutants (including nutrients) from passing through the media while allowing the water through. Filtration is less effective for removing dissolved nutrients. However, for larger particles, including algae and sand particles, which may include phosphorus bonded to the surface, filtration effectively blocks the flow of the particles through the media while allowing the transport water to pass.

The following technologies from the DEP Accepted Water Technologies Library (DEP title and project identification number) use filtration as their pollutant removal technology:

StormSack™ (DEP Number 1479)

StormSack™, designed by Fabco Industries, Inc., is a catch basin insert to capture sediments, trash, and debris before entering a stormwater conveyance system. The technology is made with a woven geotextile filter bag intended to promote high treatment flow rates while capturing sediments and other solids (Fabco Industries, Inc., 2020a). StormSack™ is not designed for applications of constant high flow rates, like those at the C-43 WBSR.

StormBasin (DEP Number 1480)

StormBasin, technology by Fabco Industries, Inc., is a stormwater catch basin insert designed to prevent pollutants, such as sediment, trash, vegetation, nutrients, coliform bacteria, oil/grease, and dissolved metals from entering the stormwater conveyance system. The catch basin insert features a lightweight filter cartridge to target specific pollutant removal (Fabco Industries, Inc., 2020b). StormBasin is not designed for applications of constant high flow rates, like those at the C-43 WBSR.

Hydro DryScreen and Up-Flo Filter – Physical Process (DEP Number 1696)

The Hydro DryScreen® and Up-Flo® Filter are technologies designed to capture sediment, trash, and organic materials. The Hydro DryScreen® is a modified baffle box designed to store organic materials to prevent nutrient from leaching into the conveyance system. The Up-Flo® Filter combines sedimentation and screening to remove 80–98% TSS (Hydro International, 2020a; Fink, 2019). The Hydro DryScreen® and Up-Flo® Filter are technologies designed for improving stormwater quality in urban watersheds. These technologies are infeasible to implement at the scale of the C-43 WBSR and were not evaluated further.

Downstream Defender® (DEP Number 1756)

Downstream Defender® is a stormwater treatment technology that uses a hydrodynamic vortex separator to remove fine and coarse particles, oils, and floatable debris. Downstream Defender® introduces a flow-modifying center shaft and cone that minimize turbulence and headloss preventing washout of stored pollutants. Downstream Defender® is designed to be used in green infrastructure, high solid stormwater applications, and upstream of sediment sensitive environments (Hydro International, 2020b). There are no documented Florida case studies. Studies include New York and New Hampshire with international applications in Qatar, Russia, and London (Hydro International, 2020b).

Performance indicated by the vendor indicate 70% TP removal with up to 79% TKN removal. Downstream Defender® was implemented as a BMP for agricultural effluent (Moffa & Associates, 2002). Peak treatment flow rate is 38 cubic feet per second (cfs) for a 12-foot-diameter unit (Hydro International, 2020b). Downstream Defender® captures and stores sediment and oil within the chamber. A sump-vac is used to remove captured sediment and floatables through the access ports located at the top (Hydro International, 2020b). Sediment disposal is needed after removal. Downstream Defender® is designed to be used in a surface water runoff treatment system using the flow from the storms, meaning there is no need for power input. The cost of Downstream Defender® for treating the active farm effluent was approximately $45 to $112 per pound of TP removed per year and $10 to $100 per pound of ammonia-N removed per year (Moffa & Associates, 2002). Because the Downstream Defender systems are designed for high flows, multiple units could be combined to scale up to accommodate C-43 WBSR flows. For this reason, the Downstream Defender was retained for further evaluation.

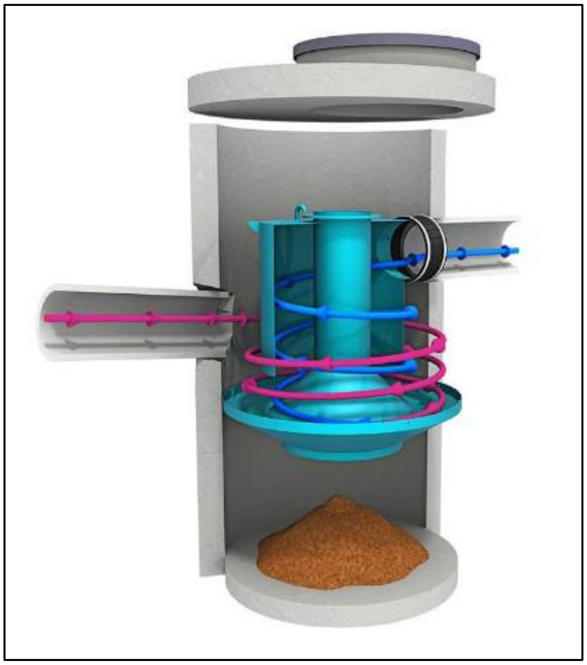


Figure 3-25. Hydro International Downstream Defender Flow Diagram (Hydro International, 2020b)

Aqua-Filter™ (DEP Number 1847)

The Aqua-Filter™, a technology created by AquaShield™, Inc., is a treatment train that uses a hydrodynamic separator followed by a filter system designed to remove sediment, debris, and free-floating oil (Figure 3-26). The Aqua-Filter™ is designed as an advanced treatment system for stormwater to remove both coarse and fine pollutants. By treating the stormwater with a hydrodynamic separator first, the filtration system lifespan is extended decreasing maintenance costs. The hydrodynamic separator uses a tangential inlet pipe to impose a vortex flow pattern encouraging gravitational and hydrodynamic settling of coarse particles. The pretreated water then continues into the filter system that distributes water over the filters allowing the water to downflow through the filter and leave through the outlet. The filter media can be changed based on the desired constituents to remove. No case studies have been documented in Florida. Aqua-Filter™ has been deployed in Maryland and Pennsylvania (AquaShield, Inc., 2020b).

Vendor information indicates that the Aqua-Filter™ removes over 91% TSS (AquaShield, Inc., 2013). Aqua-Filter™ is designed to capture and treat urban stormwater from landscaped areas, roads, and roof runoff (AquaShield, Inc., 2013). Loading of the system is designed for stormwater with a loading rate of 6.1 gallons per minute per square foot (gpm/ft^2) (0.014 cfs) (AquaShield, Inc., 2012). Aqua-Filter™ is designed to remove sediments, heavy metals, and residual oil. Maintenance of the system depends on site-specific pollutant loading conditions of TSS and suspended sediment concentration. The hydrodynamic separator is capable of being maintained using a vacuum truck, but the filters need to be replaced by entering the system. The removed sediment and filters are placed in a landfill or removed from the site. Aqua-Filter™ is designed to be used in a stormwater system using the flow from the storms, meaning there is no need for power input. No cost information has been provided for the Aqua-Filter™. The Aqua-Filter is most appropriate for application at the urban watershed scale and is not evaluated further for the C-43 WBSR.

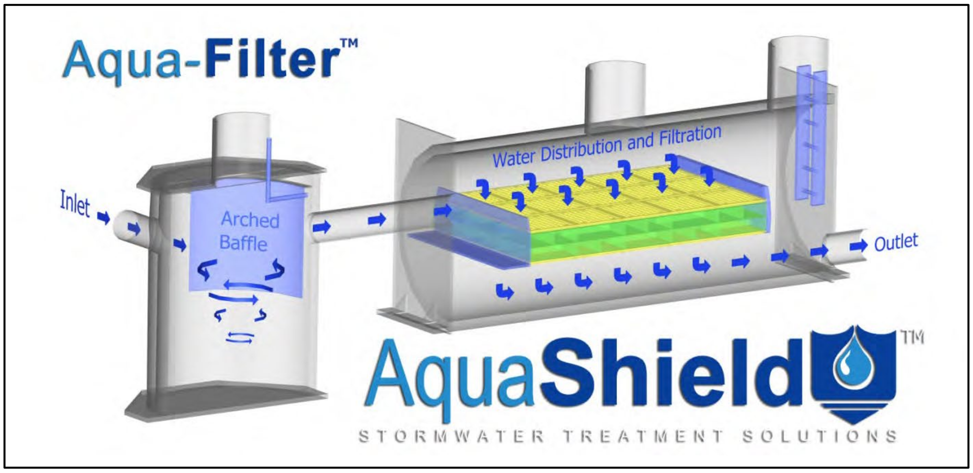


Figure 3-26. **Aqua-Filter Water Treatment Process Diagram (AquaShield, Inc., 2013)**

Aqua-Swirl® (DEP Number 1843)

Aqua-Swirl® is a technology developed by AquaShield™ and is the first step of the Aqua-Filter™ process described above. The Aqua-Swirl® is a single chamber hydrodynamic separator specializing in the removal of sediment, debris, and free-floating oil. The inflow enters the chamber through a tangential pipe which produces a vortex, or circular, flow pattern that decreases the velocity in the chamber and allows the solids to fall out. The technology uses hydrodynamic forces during high flow conditions and uses gravitational settling forces in between storms to settle out the smaller solids. Figure 3-27 shows the flow pattern for the Aqua-Swirl® (AquaShield, Inc, 2012). No documented case studies were available from Florida. Aqua-Swirl® has been deployed in Maryland, California, Colorado, and Tennessee (AquaShield, Inc., 2020a).

Vendor information indicates that Aqua-Swirl® removes up to 86% TSS and 87% suspended sediment concentration. The Aqua-Swirl® is designed to capture and treat urban stormwater from landscaped areas, roads, and roof runoff. Modular sizes are available ranging from 2.5- to 13-foot diameters. Loading of the system is designed at approximately 10.4 gpm/ft^2 (AquaShield, Inc., 2020a). Aqua-Swirl® is designed for removal of the settled solids through the access pipe at the top of the chamber. The system can be maintained using a vacuum truck to remove the captured sediment and free-floating oils (AquaShield, Inc, 2012). The sediment requires disposal after drying. Aqua-Swirl® is designed to be used in a stormwater system using the momentum of flow from the storms with no need for power input. No cost information has been provided for the technology. Aqua-Swirl was retained for further evaluation given vendor information on solids removal and discussions indicating the system could be configured for C-43 flow ranges.

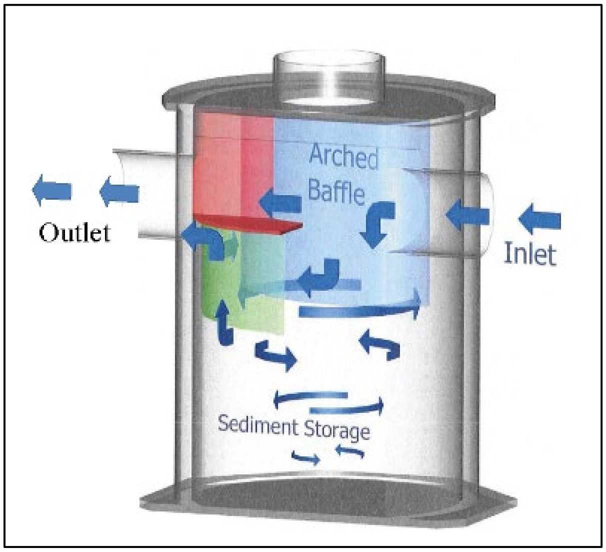


Figure 3-27. Aqua-Swirl Flow Pattern (AquaShield, Inc., 2020a)

Kraken Filter (DEP Number 1865)

The Kraken Filter, a technology by BioClean, is a membrane filtration technology designed to remove TSS, metals, trash, nutrients, and hydrocarbons from stormwater. The Kraken filter is designed to treat up to 5 cfs and is, therefore, not being evaluated further for this project. The vendor expressed that the Kraken unit is not intended for this application but is better suited for efficient removal of constituents from stormwater systems. This technology was not retained for further evaluation.

Bio Clean Catch Basin Filter (DEP Number 1885)

Bio Clean's Multi-Level Screen Catch Basin Filter is a stormwater catch basin insert using various screen sizes to prevent TSS from entering the stormwater conveyance system. The catch basin insert features a 100% stainless steel filter removing up to 86.6% TSS (Kent, 2019a). The Multi-Level Screen Catch Basin Filter is not designed for applications of constant high flow rates expected at the C-43 WBSR and was not retained for further evaluation for the C-43 WBSR.

Debris Separating Baffle Box (DEP Number 1886)

The Debris Separating Baffle Box (DSBB), developed by Bio Clean, is a stormwater baffle box specializing in separation of organics and trash from standing water (Figure 3-28). Additionally, the DSBB uses self-cleaning screens to prevent clogging and hydrodynamic separation to capture pollutants. The DSBB is designed as a triple-chamber baffle box removing a wide range of particle sizes. A deflector shield ensures little to no scouring during high-flow conditions allowing the system to be connected in-line to stormwater conveyance system (Kent, 2019b). No case studies have been provided at the time of this report. The vendor indicates removal rates of 83% TSS and 100% trash and debris removal down to 5 millimeters. No information is available on the design flow rates, but the DSBB is designed for stormwater flow treatment (Kent, 2019b).

Organics, trash, debris, and sediments are collected and stored. A vacuum truck is capable of removing the residuals from the DSBB without confined space entry (Kent, 2019b). Disposal of residuals is required after cleaning. The DSBB is a hydrodynamic separator requiring no energy input. The separation of debris, trash, and organics is accomplished using screens and hydrodynamic settling.

No cost information has been provided by this submittal. This technology is most feasible for urban watershed stormwater control and is not evaluated further.

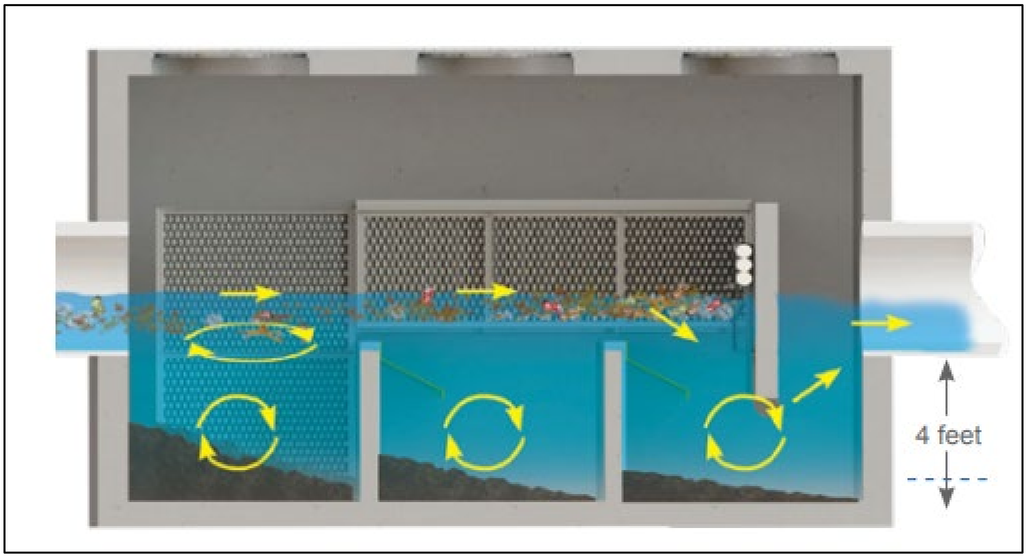


Figure 3-28. Debris Separation Baffle Box Flow Pattern (Kent, 2019b)

SciCLONE™ Separator (DEP Number 1891)

SciCLONE™, developed by Bio Clean, is a hydrodynamic separator for the removal of TSS, free-floating oils, and trash. The SciCLONE™ uses an inlet flow splitter to redirect flows along the system’s perimeter toward the oil skimmer. The skimmer wall redirects the flows to the center creating two swirling vortexes to maximize flow path and direct fine sediment to settle. The outlet weir provides an even surface for flows to pass over reducing the exit velocities and maximizing the available area within the system for separation (Kent, 2019c). Figure 3-29 provides an example of the flow path through the SciCLONE. No case studies have been provided at the time of this report.

Materials provided by the vendor indicate 80% removal of TSS and 99% removal of oils and grease (Kent, 2019c). The design flow rate for the 12-foot-diameter SciCLONE is 6.3 cfs (Bio Clean, 2020). Residuals include TSS, oils, and grease (Kent, 2019c), which are removed through the top of the SciCLONE using a vacuum truck. The residuals require post-processing and disposal. No information provided by the vendor on the possible disposal mechanisms or reuse of the residuals. SciCLONE™ is a hydrodynamic separator requiring no energy input after installation. The separation of TSS, oil, and grease uses hydrodynamic settling. No cost information has been provided by this draft submittal. The SciClone was retained for further evaluation, given the potential for scaling up to large flows.

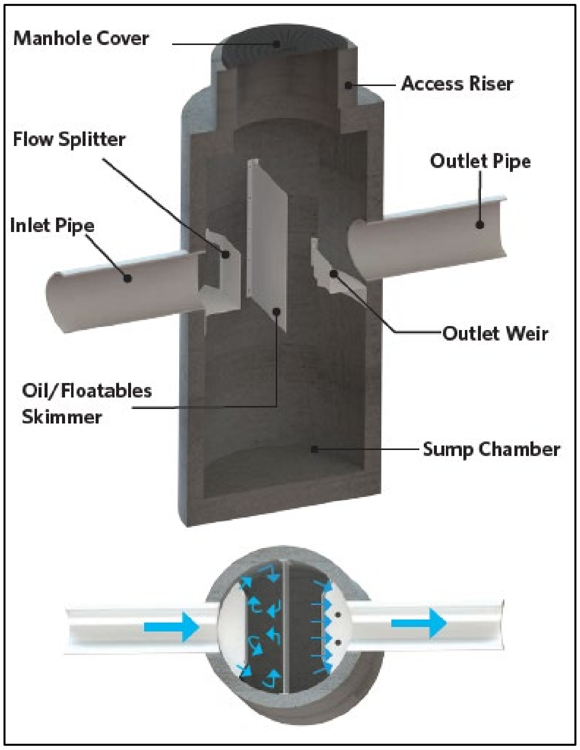


Figure 3-29. SciCLONE Components and Flow Path (Bio Clean, 2020)

StormPro® (DEP Number 1900)

The StormPro® technology, designed by Environment21, is a hydrodynamic separator using Stoke's Law that specializes in the separation of sediment and floatables from stormwater. StormPro® is fabricated to collect and store the first flush pollutants while bypassing the larger high flows caused by large storms. The technology prides itself in a small sump depth with minimal horizontal surfaces allowing for maintenance access and a reduction in installation excavation. The system is custom-configurable to be fabricated as an inline or offline system with the capability of multiple inlet pipes. Figure 3-30 provides an example of the flow path through the StormPro®. No case studies have been documented in Florida. StormPro® has been deployed in Ohio and New York (Environment21, 2019).

The vendor indicates a removal of 80% TSS and 40% phosphorus reduction at the manufacturer's treatment flowrate. The maximum flowrate is approximately 13 cfs with a tank size of 26 feet by 13 feet. The design detention time within the system is approximately 104 seconds (Environment21, 2019). The StormPro® is used for the treatment of urban landscaped stormwater treatment. StormPro® is designed to be used in a stormwater system using the flow from the storms, meaning there is no need for power input. StormPro® is designed to remove sediments, oils and floatable debris. StormPro® is maintained using a vacuum truck. The removed sediment is then disposed in a landfill or removed from the site. The vendor has not provided cost information by this submittal. This technology was retained based on the potential for scaling and available information on nutrient removal.

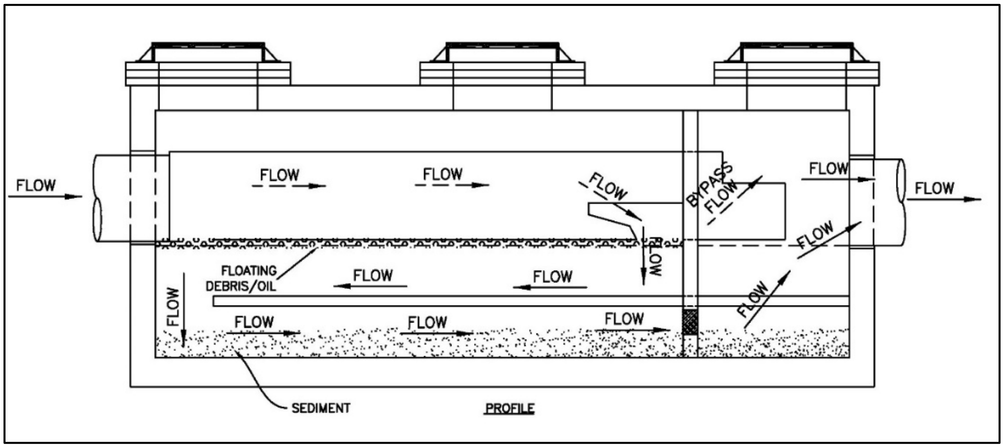


Figure 3-30. StormPro Flow Path (Environment21, 2019)

Large-Scale Sand Filtration

Sand filters have long been used for treatment of wastewater beginning in the 1800s. Sand filters are multi-chamber structures, composed of a sediment forebay, a sand bed, and typically an underdrain collection system. The mechanisms for pollution removal are dominated by filtration with gravitational settling and adsorption providing additional treatment. Microbial communities in the upper depths of a sand filter provides additional assimilation of nitrogen and phosphorus beyond simply physical filtration. Treatment capacity can be affected with continuous operation requiring a drying period. One aspect of a sand filter that may be favorable to the C-43 application is the potential for water treatment during the discharge from the reservoir and then allowing to remain dry for storage and filling periods (Bays et al., 2019).

Case studies for large-scale sand filters include water treatment of phosphate mines in Florida. One case study located in Hardee County treated phosphorus mine water for 2–3 years. The sand filter was operated following constructed wetland treatment and received up to 2 MGD. The demonstration system was approximately 4 acres in size (Bays et al., 2019). Figure 3-31 shows the phosphorus mine wastewater sand filter treatment system. Inflow TP concentrations ranged from 0.14 mg/L to 1.1 mg/L, averaging 0.45 mg/L. The outflow concentrations averaged 0.23 mg/L with an average TP reduction of 48%. Inflow turbidity averaged 30 nephelometric turbidity units (NTU) and outflow turbidity averaged 4.5 NTU. The average reduction was 85% for turbidity. The hydraulic loading rate over this period was approximately 1.9 meters per day. It was determined that a 2-acre sand filter is needed to treat 1 MGD (Bays et al., 2019).

Monitoring of sand filter capacity recommends replacement of the top layer every 3 to 5 years. Maintenance of the top layer requires periodic scarification to overcome biological clogging of the pore spaces. Sand removed from the system collection and handling, which may include hauling and disposal (Bays et al., 2019). Sand filtration is a passive treatment of TSS and TP that does not require any external energy for the treatment process, other than power and pumping cost to convey water to and from a site (Bays et al., 2019).

Cost information provided estimates the cost of a 100,000-cubic-foot sand filter to be $691,000 (2005 present cost). According to this price, the cost of a 1-acre sand filter at 10-foot depth would be approximately $3,000,000 (Weiss et al., 2005). Updated cost information is needed to estimate the total cost to treat the flow for the C-43 WBSR. This technology was retained for further evaluation given the high flow capacity, relatively small footprint for a passive technology, and proven Florida applications.

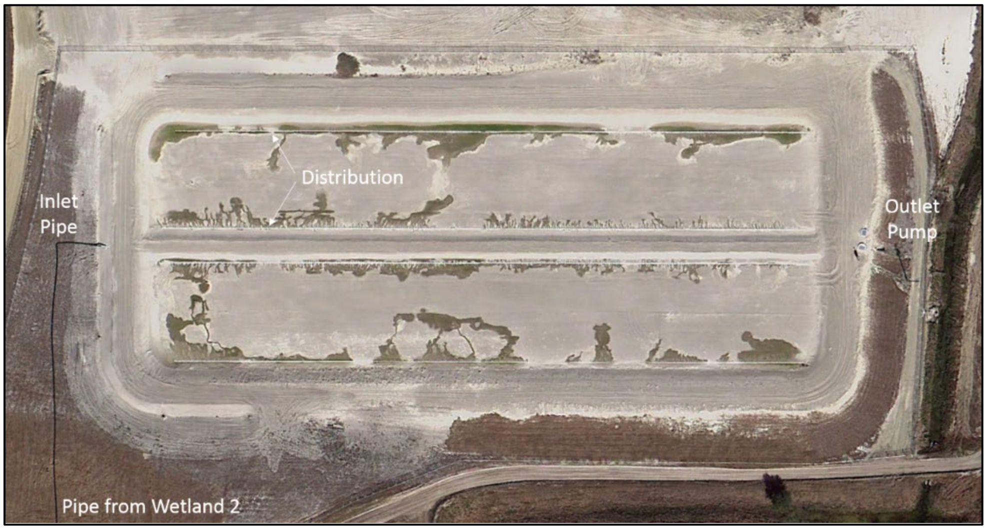


Figure 3-31. Sand Filters for Treatment of Phosphorus Mine Wastewater (Bays et al., 2019)

3.3.1.2 Sorption

Sorption is the common term used to describe absorption and adsorption. Absorption is the process where one substance takes in another substance through the spaces between its molecules. Adsorption involves the adhesion of one substance to another's surface through chemical binding. Absorption takes in the entire volume of substance whereas adsorption is the bonding between two surfaces.

Sorption, similar to filtration, uses a media to remove pollutants from the water column, but sorption differs as the pollutant becomes chemically bonded with the media rather than impeded from flowing through the media. Media designed for physical removal through sorption often have a chemical bond to the media that forms with the pollutant that is being treated. Iron-enhanced sands and activated carbon are two of the many media used for this treatment technology. Polluted water is passed through the media where the pollutant is bound to the media and therefore removed from the water column. The sorption media needs replacing on regular intervals just as filtration. The primary advantage of using a sorption material over simple filter material is the capacity to remove soluble pollutants. As the water is passed over and through the media, soluble pollutants are bound to the sorption media removing the pollutant from the treated water.

The following technologies use sorption as the pollutant removal technology:

PhosRedeem (DEP Number 1641)

PhosRedeem, produced by US Iron, is an adsorbent media which is specialized in the capture of dissolved phosphorus (Miller, 2019). The media is an iron oxide-based media capable of being recycled to keep costs for producing media down (PhosRedeem, 2020). No further information has been provided by the vendor. This technology was not evaluated further.

NutriGone™ Biosorption Activated Media (DEP Number 1678)

NutriGone™, developed by EcoSense International, is a media mixture of inorganic carbon, organic carbon, and ion adsorption mineral. NutriGone™ is primarily used in the removal of bionutrients from stormwater prior to discharge, intercepting groundwater near surface water interfaces and filtering surface water from ponds and swales. NutriGone™ is capable of being used in multiple different applications but EcoSense International has developed two technologies to house the media for stormwater filtration (EcoSense International, 2019).

NutriGone™ has a stormwater project located in Brevard County, Florida. The Micco I Stormwater Improvement project researched the treatment efficiency of NutriGone™ as a BMP (Schmidt and Housley, 2016). Data from the Micco I project indicated inflow concentrations of 0.14 mg/L nitrate and 0.09 mg/L TP. The average removal rates were approximately 10% and 22%, respectively (Schmidt and Housley, 2016). The vendor expects 75% to 85% TN and 50% TP removal for C-43 WBSR concentrations. The vendor estimated that roughly 56 acres are required to treat 695 cfs (Burden, 2020). Figure 3-32 provides a visual representation of the suggested technology configuration to use NutriGone™ media.

NutriGone™ media sorbs the nutrients to the media. The vendor expects the media will last 353 days before being at maximum capacity for phosphorus. The media will need to be removed and new media added. The vendor suggests construction of a media production facility near the filter site. Vendor materials indicate that the media is capable of being sold as a soil amendment after being used in the filter at roughly 50% of the original price (Burden, 2020). No power information is provided given the technology is a media. The media production facility is expected to require electricity, but no further information has been provided.

The cost estimate for a facility at the C-43 WBSR given a flow of 695 cfs is approximately $14,290,000 per 353 days. This includes the cost of the media and a media production center amortized over 20 years. Given a 50% TP removal rate, the cost is estimated at $108 per pound of TP removed (Burden, 2020). This technology was retained for further evaluation given the reported treatment performance, relatively passive performance and potential to add units to scale up to C-43 flow ranges.

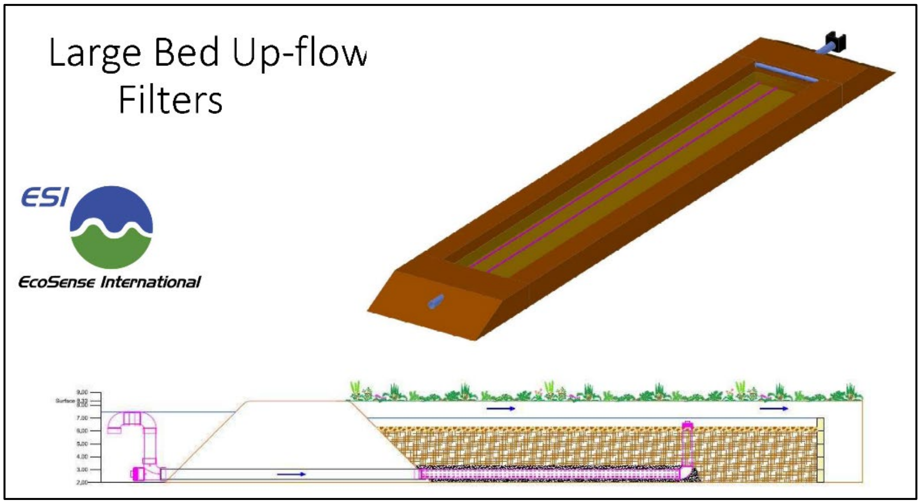


Figure 3-32. Example of NutriGone Large Bed Up-Flow Filters (EcoSense International, 2019)

Bold & Gold

Bold & Gold is a biosorption activated media formulated to remove nitrogen species, phosphorus species, algal toxins, algal mass, Escherichia coli, and per- and poly-fluoroalkyl substances (University of Central Florida, 2019). The media can be used in many different applications including upflow filters, side-bank filters within wet detention ponds, dry detention systems, infiltration basins, rain gardens, pervious pavers, vegetated filter strips, drainfields, and rapid infiltration basins. Bold & Gold is a mixture consisting of primarily mineral (Florida-based sand and Florida mined clay) and relatively slow degradable recycled materials (tire crumb) (Bogdan, 2020).

Bold & Gold has been used in more than 200 locations across Florida with various applications for the reduction of both phosphorus and nitrogen. Recently, the University of Central Florida requested a grant to treat the water upstream of the St. Lucie River and Estuary. The project proposed building a filter with a size of approximately 2 acres to treat 0.05 gpm/ft^2 flow with an average annual nitrogen concentration of about 1.5 mg/L. Target volume of flow was about 750 million gallons treated over 250 days (University of Central Florida, 2019).

Performance data in applications treating stormwater state a nitrogen removal rate of approximately 75% to 95%. In wastewater treatment with nitrate input of 3.61 mg/L, the removal of nitrate was approximately 83%. This application included a period where the filter was not saturated (University of Central Florida, 2019). The filters are estimated to be in service for 15 years with a treatment rate of0.05 gpm/ft^2 (University of Central Florida, 2019). Materials supplied by the vendor do not discuss the handling of residuals. No power information is provided. Information materials provided discuss the need to run pumps and aeration of the top sand layer every two years (University of Central Florida, 2019). No information on the amount of aeration is provided.

Cost estimates provided are for the St. Lucie River and Estuary site discussed above. The filters were roughly 2 acres in size. The construction cost for the filters were estimated at $1,588,000. The annual operating cost is approximately $22,000 per year including the cost of electricity to run the pumps and aeration of the top sand layer every two years. The cost per pound of nitrogen removed is estimated at $10.23 for the 15-year lifespan (University of Central Florida, 2019).

ACF Environmental has provided an example application of Bold & Gold media for the treatment of large flows. Side bank filters are added into all or part of the inner banks of wet ponds or retention ponds. They are designed with a free draining cover layer, followed by 2 feet of Bold & Gold filter media, then a layer of bridging stone to surround the collection pipe. Water is introduced into the pond and, once the water reaches the filter depth, it is filtered before being distributed to an outlet pipe for discharge. Information provided by ACF Environmental indicates that the filters remove approximately 75% TN and 95% TP (Gorneau, 2019). Figure 3-33 provides an example side bank filter by ACF Environmental. The use of Bold & Gold and its configurations was retained for further evaluation for the C-43 WBSR.

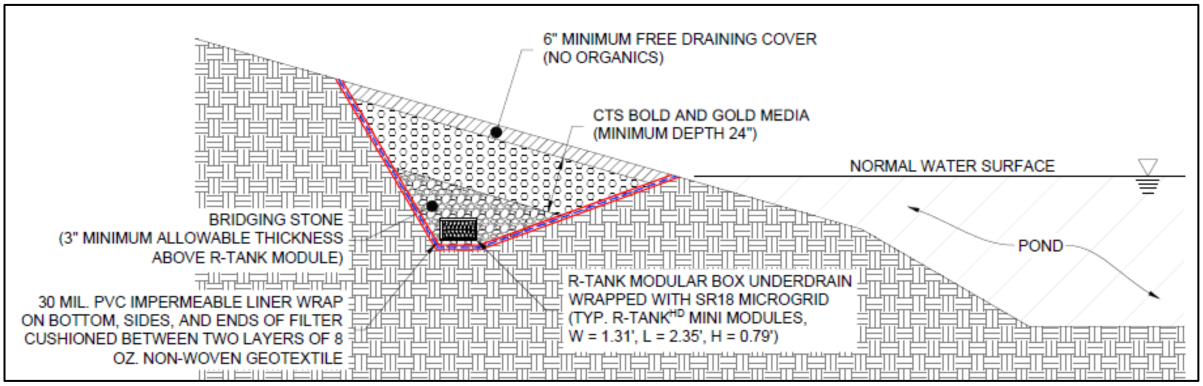


Figure 3-33. Example of Side Bank Filter Constructed by ACF Environmental (Gorneau, 2019)

3.3.1.3 Dissolved Air Flotation

DAF is a technology that removes suspended particles from the water column using dissolved air bubbles to float particles within a water column to the surface to collect and remove. The mixture to be separated is saturated with air and then air pressure is reduced within the treatment tank. As air escapes the solution, microbubbles form and readily adsorb onto suspended solids (including algae). The suspended solids that are floated to the surface are skimmed off the top while the treated water flows off the bottom (ScienceDirect, 2020).

DAF is capable of efficiently removing algae and other suspended solids with precise calculation of the air bubble size to ensure the buoyancy is great enough to float the particles to the surface. When needed, DAF is preceded by an introduction of a flocculant to increase the size of the particles to increase the ability of the particle to be removed. The largest particles, including sand, are collected at the bottom of the DAF system through gravitational settling. DAF is efficient in the removal of sediment bound phosphorus and algae. Soluble nutrients, including nitrates, are not removed through DAF because the nitrogen does not bind with the air bubbles and, therefore, passes through the chamber with the treated water. If nitrogen is the limiting pollutant, DAF must be partnered with a system designed for the treatment of soluble pollutants like sorption.

The following technology from the DEP Accepted Water Technologies Library uses DAF as their pollutant removal technology:

AquaLutions®™ (DEP Number 1579)

AquaLutions®™ is a water quality restoration technology designed to harvest algae and cyanobacteria from the water column at a commercial scale using a modified DAF system. By removing the algae and cyanobacteria, the nutrients and pollutants bound within the algae are also effectively and efficiently removed from the water column. DAF uses dissolved air bubbles to float the species to the surface of the water column where they are collected and removed. The clean water is then returned to the source void of algae, with reduce nutrients and with a heightened oxygen saturation (Eggers, 2019).

AquaLutions®™ has been deployed in Florida to improve water quality in several locations (Caloosahatchee River, St. Lucie Canal, and Banana River Lagoon). The prominent case study for AquaLutions®™ in Florida was at Lake Jesup where the DAF process was used to remove TP from the lake through a 5-year contract with the St. Johns River Water Management District. The project removed more than 6,500 lbs of TP, 90,000 lbs of TN, and 1.1 million lbs of dry weight algae from the lake (Eggers, et al., 2014). Figure 3-34 shows an overhead visual of an AquaFiber's®™ AquaLutions®™ project site.

AquaLutions®™ removes up to 90% TP, 65% TN, and 80% TSS (Eggers, 2019). AquaLutions®™ treatment produces residuals including algae and TSS. Algae that is collected is then made into fertilizer pellets or destroyed. Post-processing of the algae depends on the need for fertilizer in the surrounding communities. Providing fertilizer pellets to the farmers may reduce the transport of nutrients into the watershed by recycling nutrients that ran off the watershed. TSS removed would require dewatering and disposal (Eggers, 2019).

The AquaLutions®™ technology requires electricity to power the air blowers that produce the micro-air bubbles. The Lake Jesup project site required 0.9 to 1.0 kilowatt-hours (kWH) per 1,000 gallons (greater than 6 MGD facility), but the vendor comments that a facility at the C-43 WBSR would require less depending on many factors including available head, pumps used to achieve the desired flow, and ability to create electricity onsite (e.g., renewable energy techniques, fluidized gas bed, vapor recovery) (Eggers, 2020).

Capital costs for a 20 MGD facility were projected to be approximately $20,500,000 including design, permitting, and construction of the treatment plant. Unit operation and maintenance costs are lowered with increased flow treated with an approximate cost of $1/1,000 gallons for the 20 MGD site. AquaLutions was retained for further evaluation based upon the strong Florida case study experience and significant potential for scaling up.

Figure 3-34. Overhead view of an AquaFiber AquaLutions Project Site (Eggers, 2020)

3.3.1.4 Oxidation

Oxidation is a chemical process in which a substance gains oxygen. The application to the C-43 WBSR would be to oxidize organic matter through decomposition, and to nitrify ammonia for nitrogen removal. The following technologies use oxidation as the pollutant removal technology:

MagneGas (DEP Number 1769)

MagneGas, a technology by Taronis Technologies, is described as a venturi flow system based on flowing the river water through a submerged electric arc between two electrodes. The arc breaks the molecules into atoms and forms a plasma around the tips of the electrodes. The venturi then moves the plasma away from the electrodes and controls the formation of gas that rises to the surface for collection (Taronis Technologies, 2020). MagneGas has been used in a pilot project to treat HABs in Clearwater and St. Petersburg, Florida as well as a United States Department of Agriculture grant to treat a dairy lagoon in central Florida (Conz, 2019).

The vendor indicates the system kills pathogens and algae, breaks down cyano-toxins and pharmaceuticals, reduces nutrients and metals, and increases DO (Conz, 2019). Email conversations with the vendor informed that a single 300 kW system, capable of treating 60 gpm, is the size of a 40-foot shipping container (Conz, 2019). This technology was not further evaluated, given the relative difficulty in scaling up at this stage in its development.

3.3.1.5 Sonication

Sonication is the process of using ultrasonic frequencies to control different types of algae in a waterbody. The ultrasonic frequencies target the gas vesicles in the algae and create an ultrasonic pressure in the top layer of the water. The ultrasonic sound barrier prevents the algae from rising to the surface to absorb light for photosynthesis stunting their growth. Without the ability to photosynthesize, the algae die sinking to the bottom of the water reservoir and are degraded (LG Sonic, 2020a).

The following technologies use sonication as the pollutant removal technology:

MPC-Buoy

The MPC-Buoy is a solar-powered floating system that emits various ultrasonic frequencies to treat algae. The MPC-Buoy uses a three-step process to control algae. The first step involves monitoring of water quality by collecting water quality parameters every 10 minutes. The data are delivered to a web-based software that predicts algal blooms based on water quality parameters and maps algal distribution in large waterbodies. Based on the prediction, ultrasonic transmitters are activated to create a sound layer at the surface to prevent the algae from receiving sunlight (LG Sonic, 2020b). Figure 3-35 provides a visual representation of the MPC-Buoy system. There are no documented case studies in Florida. Case studies include a drinking water reservoir in Dominican Republic that treated a 2.7-square-mile reservoir to reduce approximately 87% chl *a*. The MPC-Buoy has been used in New Jersey to reduce algae concentrations in a raw water reservoir (LG Sonic, 2020a).

Material provided by vendor indicated that the MPC-Buoy eliminates up to 90% of algae with the use of specific ultrasonic sound waves, and that MPC-Buoy reduces TSS, BOD, and chemical composition in the reservoir. MPC-Buoy is capable of treating areas up to 1,600 feet in diameter (approximately 46 ac) (LG Sonic, 2020b). This technology does not create any residuals, which would reduce TSS in the reservoir discharge. Materials provided by the vendor indicates that the technology is safe for wildlife (LG Sonic, 2020a).

The energy required to power the device is approximately 5 to 20 watts, which is supplied by the onboard solar panels. Technology includes three 195-watt peak solar panels that provide power year-round, with an energy-saving program applied during periods of low sun radiation. Cost information provided by the vendor estimates a capital cost of $9,000,000 to treat the entire C-43 reservoir (LG Sonic, 2020b). Annual costs include 15-minute water quality data collection from 16 different monitoring points for an approximate cost of $50,000 annually (Eiffert, 2020). This technology was retained for further evaluation given the available performance information and potential application as in-reservoir treatment.

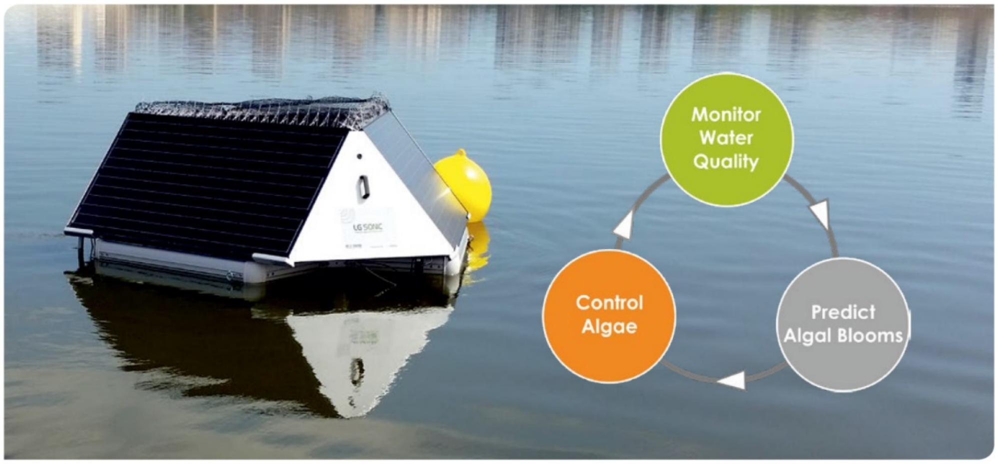


Figure 3-35. **MPC-Buoy Technology and Three-Step Process (LG Sonic, 2020)**

3.3.1.6 Aeration

Aeration is the process of passing air through a liquid to provide oxygen for a chemical or biological process or to physically remove water. The application to the C-43 WBSR would be for installation in the reservoir to destratify the reservoir water column when full, to oxidize organic matter through decomposition, and to nitrify ammonia for nitrogen removal.

The following technologies use aeration as the pollutant removal technology:

Air Diffusion Systems

Air Diffusion Systems' (ADS) technology includes a fine bubble aeration system for domestic and industrial installations. Information from ADS states that they have a clog-free design that requires minimal power input to provide aeration within the reservoir with little maintenance required. The fine bubble aerators create mixing and oxygen diffusion within the reservoir (ADS, 2020a). ADS case studies include applications in Havana, Florida and proposals for work in the St. Lucie River, Florida. Large reservoir system studies include Wisconsin, Massachusetts, Delaware, Maine, Illinois, and Colorado, with international work in India and Samoa.

Performance data provided by ADS indicate a 90% BOD reduction and 50% to 75% reduction of TN and TP. A proposal from ADS indicates the use of 96 disk modules for fine bubble aeration of the C-43 WBSR mixing approximately 29 MGD with a turnover of approximately 18 days. The 96 disks are paired with eight 25-horsepower (hp) compressors (ADS, 2020b). Figure 3-36 shows the proposed layout to treat the C-43 WBSR.

ADS technology is for in-reservoir treatment and does not produce residuals for maintenance. System lifespan is estimated at 20 years, and some systems have been fully functioning after 40 years of operation. Maintenance includes checks of compressors, air leak testing of supply piping and visual inspection of disc modules (ADS, 2020b). Assuming the 25-hp compressors are working 24-hours a day, the yearly cost of running eight 25-hp compressors is approximately $24,000 a year for electricity with a motor efficiency of 90% and a cost of $0.12 per kWH. Cost of an aeration system designed for the C-43 WBSR is approximately $3,886,000 including aeration discs, feeder tubing, and eight 25-hp compressors (Smith, 2020). This technology was retained based upon proven performance in other states, the general understanding of the benefits of aeration and the potential for scaling up.

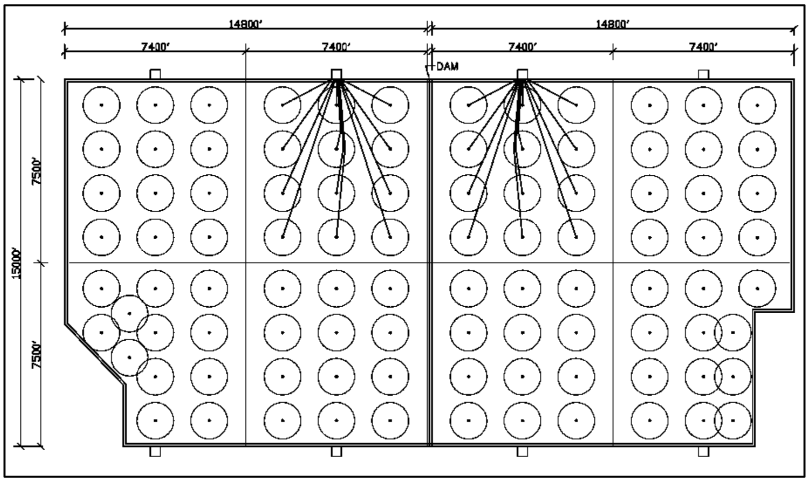


Figure 3-36. ADS Proposed System to Treat C-43 WBSR

3.3.1.7 Managed Recirculation

Managed recirculation is a novel concept where the intrinsic storage properties of the reservoir are utilized to improve water quality and minimize potential for algal bloom formation. The approach was introduced into the list of project technologies to consider through input from the Working Group. The C-43 WBSR can be expected to stratify during the storage period, with warmer, oxygenated water at the surface and cooler, deoxygenated water developing in bottom layers. Given the concern over the enriching effect of inorganic nitrogen (ammonia-N and nitrate-N) for algal blooms in the Caloosahatchee River and downstream estuary, there may be a conceptual opportunity to utilize the two stratified layers of water in the reservoir to naturally assimilate and transform nitrogen. The applicable concept would be to circulate water from the aerobic surface layer to the anaerobic bottom layer, thereby mimicking the two-step aerobic/anaerobic biologically-mediated process of nitrogen oxidation and reduction commonly applied in wastewater treatment systems (Rumbold, 2019). Because the concept relies on physical movement of water through the reservoir, significant pumping infrastructure would be required, and therefore is classified as a physical treatment technology.

Denitrification has previously been reported to naturally occur in reservoirs in other areas (e.g., Beaulieu et al., 2014). Rumbold (2019) have suggested that conditions in the reservoir could be managed to increase denitrification modeled after literature examples (e.g., Zhou et al., 2016).

The manipulated recirculation could encourage the ammonification-nitrification of dissolved organic nitrogen in the aerobic surface layer. Carbonaceous organic matter (CDOM) necessary to sustain the microbial community for this process is expected to be biologically available through photobleaching (Chen et al., 2015). Careful circulation of water from the lower to upper layers could provide a sustainable supply of CDOM.

The managed recirculation concept is in a very early stage of development as a concept. As a result, there are no Florida case studies and little way to project full-scale implementation feasibility and to estimate cost. However, manipulated recirculation has been retained for further consideration, given the potential savings in land acquisition cost and the incorporation of the natural phosphorus and nitrogen retention processes of the reservoir. In addition, nutrient assimilation properties of the reservoir during storage will be discussed in the feasibility study as it pertains to meeting treatment objectives.

3.3.2 Chemical Treatment Technologies

This section discusses chemical treatment technologies, which are further categorized into flocculation and coagulation. The following section provides summaries of each chemical treatment technology.

3.3.2.1 Flocculation/Coagulation

Flocculation is the process of binding particles together by hydrogen bonding or Van der Waal's forces to form larger particle flocs that are removed through hydrodynamic settling. Flocculation is achieved through mixing, which causes particles to collide and bond or by adding polymers which bind with the particle (Minnesota Rural Water Association, 2020). Coagulation is a process used to cause the destabilization and aggregation of smaller particles into larger particles. Water contaminants are primarily held in solution by electrical charges, and by adding charges to the water through chemical or electrical means, the contaminants aggregate and are capable of being removed. The neutralization of ion and particle charges allows contaminants to precipitate and be filtered out (Gerber Pumps International, Inc., 2020a). Coagulants are typically used when the pollutant to remove is a soluble pollutant that cannot be removed through physical technologies. However, coagulation and flocculation can be used as a predecessor for physical treatment to increase the particle size of the constituent of concern to allow physical filtration removal.

The following technologies use flocculation/coagulation as the pollutant removal technology:

Dredgeclear 53 (DEP Number 1392)

Dredgeclear 53 is a polymer used as a flocculant for North Palm Beach Waterway and interior residential canals. The polymer is not to exceed 20 mg/L when injected to protect fauna in the water. The supplier is the Village of North Palm Beach (permit #0176410-002) (DEP, 2020).

Optimer® 7193 PLUS (DEP Number 1394)

Optimer® 7193 PLUS is a cationic flocculant used in Lake Maggiore intended for freshwater lake introduction. The City of St. Petersburg used this polymer for lake dredging (permit #52-0207912-001) (DEP, 2020).

Ciba Krysalis FA/FC (DEP Number 1390, 1395 and 1396)

Ciba Krysalis is a polymer used as a flocculant, coagulant, retention aid, runnability aid, dewatering aid, process aid, viscosifier, and separation and clarification aid for use in the manufacture of paper, wastewater treatment, and mining in municipal, industrial, and extractive industries (Ciba Specialty Chemical Coporation, 2020). Ciba Krysalis FA has been used by Manatee County Port Authority in Tampa Bay (permit #0129291-013 EM). Ciba Krysalis FC has been used by Miami-Dade County in the Miami River (DEP, 2020).

FLOPAM™ EM 230 (DEP Number 1397)

FLOPAM™ EM 230 is a non-ionic flocculant for use in municipal, industrial, and extractive industries (SNF Floerger, 2012) (DEP, 2020).

All four flocculants were retained for further evaluation given their previous application in Florida and the general proven potential for coagulation and flocculation to remove nutrients.

Aluminum Sulfate (DEP Number 1398)

Alum (aluminum sulfate) is a cationic flocculant used generally for coagulation treatment and was investigated by SFWMD in Taylor Creek with the objective of confirming suitability for use in Class III freshwater systems. Watershed Technologies, LLC implemented the system (DEP, 2020). Alum addition is a process that has been used in many applications. Applications typically fall under one of three types of applications: sediment separation, injection into the inflow, and in-reservoir treatment.

On example of sediment separation is the Nutrient Reduction Facility, located in Lake County, which is a large-scale sediment separation facility that applies aluminum compounds for nutrient reduction. The process pumps water from Lake Apopka into the facility where alum is injected into the flow to bind with pollutants. The flow is then distributed into settling ponds where floc settles out of the flow. The clean water is collected at the opposite end of the settling ponds where it is returned to the lake. The Nutrient Reduction Facility has demonstrated the ability to treat up to 250 cfs while removing nearly two-thirds of the TP. The site requires extensive dewatering of the floc, requiring a large centrifuge to prepare the floc for transport off site. The estimated cost of the project was $7.3 million with an annual operating budget averaging approximately $1.5 million with alum as the primary expense (Florida Lake Management Society, 2010).

Other configurations of alum treatment systems inject alum into the flow based on a flow-proportioned basis. This ensures that the same dose of alum is added regardless of the discharge rate. A variable-speed chemical metering pump is used along with a flow meter to administer the dose of alum. Injection of alum is carefully monitored to ensure toxic concentrations of aluminum do not accumulate in the reservoir. Cost varies depending on the size of the metering pump and amount of alum needed for treatment (Bottcher et al., 2009).

Alum treatment is also achieved through in-reservoir application. This is usually preferred when a major source of phosphorus is from sediment phosphorus release within the reservoir. The longevity of in-reservoir treatment is important because legacy phosphorus release in the reservoir can lead to increased algal blooms. Longevity of phosphorus in the sediment is based on many water parameters but the average for deeper, stratified lakes, which resemble the characteristics of the C-43 WBSR, is approximately 21 years. Since 2000, Florida lakes treated with alum for phosphorus concentration reduction include Anderson Lake, Gatlin Lake, and Tyler Lake (Huser et al., 2016). Alum treatment was retained for further evaluation given the general proven experience of using alum as a nutrient removal technique.

ElectroCoagulation (DEP Number 1505)

ElectroCoagulation removes contaminants from the water by passing an electrical current through the water between an anode and cathode plate. The plates release charged metal ions that neutralize suspended particles and create dense flocs that settle rapidly. ElectroCoagulation is capable of removing multiple contaminants, hardness, color, heavy metals, organics, suspended and colloidal solids, fats, oil, bacteria, viruses, and more. Water is passed between metal plates that transmit the electricity through the water before the coagulated contaminants are filtered and removed. In Florida, ElectroCoagulation has been evaluated at Lake Jesup for the removal of TP and proposed for the St. Lucie River and Lake Okeechobee (Gerber Pumps International, Inc., 2016). There are many industrial applications nationwide.

The Lake Jesup case study report showed a nutrient removal performance of approximately 64% to 91% for TN and 87% to 99% TP (Gerber Pumps International, Inc., 2016). Algae removal has been achieved with ElectroCoagulation with a removal rate of approximately 99% (Gerber, 2020). To treat a flow of approximately 300 MGD, the vendor suggests using a total of 15 treatment units each processing 15,000 gpm (Gerber, 2020).

Residuals include TSS removed from the treated water with a 90% to 99% removal. The vendor states that the residuals are produced in a dry powder form, which simplifies removal and disposal (Gerber, 2020). Additionally, ElectroCoagulation produces approximately 83% less solids than alum treatment (Dole, 2019). The vendor suggests the residuals can be used for fertilizer or soil amendments (Gerber, 2020).

The vendor indicates the power consumption for the C-43 WBSR would be approximately 0.5 kWH per 1,000 gallons treated (Gerber, 2020). Given an approximate flow of 300 MGD, the daily power consumption would be approximately 150,000 kWH per day. A single 15,000-gpm ElectroCoagulation module is estimated to cost approximately $7,000,000 (Gerber, 2020). To treat approximately 300 MGD using 15 modules, the total capital cost would be approximately $105,000,000. The operational cost, assuming $0.12/kWH, would be approximately $6,570,000 per year at a straight line projection. Electrocoagulation was retained for further evaluation given its high throughput rate, high performance, and relatively small area requirement.

Phosphorus Free Water Solutions

Phosphorus Free Water Solutions (PFWS) proposes a variety of methods and chemical compounds for nutrient removal processes. The treatment technology is not described to protect the confidentiality of the process (PFWS, 2019). PFWS has partnered with SFWMD to conduct a demonstration project on

Lake Okeechobee. The information provided is from this demonstration project (PFWS, 2019). No additional case studies have been provided.

PFWS indicates that the technology can treat TP to 33 µg/L. PFWS states that the phosphorus removal is not based on percentage removal but removing phosphorus down to approximately 33 µg/L even with high concentrations present in the inflow. TN was also reduced by approximately 30% (PFWS, 2019). Residual management is not discussed in the report. However, sediment and algae removal are likely necessary for this technology. No discussion of the power needed to run the technology is discussed in the report.

PFWS estimates the approximate capital cost for a 350 cfs facility is $80 to $100 million. PFWS predicts an annual removal of 433,000 pounds of phosphorus per year, quoting a unit cost of approximately $175 per pound removed (PFWS, 2019). This technology was evaluated further given the relatively little information available on treatment process and lack of Florida case histories.

3.3.3 Biological Treatment Technologies

This section focuses on biological treatment technologies that are further categorized as bioremediation, advanced wastewater treatment, denitrifying bioreactors, wetlands treatment, and FWT. The following section provides summaries of each biological treatment technology. It is noted that treatment wetlands and FWT can be categorized under biological treatment technologies but have been described in the natural treatment alternatives in Section 3.2. Hybrid applications of constructed wetlands receiving chemical treatment compounds are included in this section.

3.3.3.1 Bioremediation

Bioremediation is the treatment of water through the seeding of microbes that feed on the nutrients for removal. Bioremediation introduces naturally occurring microbes in quantities and in environments that reduce the nutrient availability in the water. This reduction in nutrients prevents algae growth because the algae no longer has available nutrients with which to grow. Bioremediation techniques prepare a carefully selected microbial culture that is spread throughout the waterbody to minimize the nutrients present. This technology is typically spread within a lake, pond, or reservoir and is easily scalable to the appropriate size of the waterbody. The microbes are typically spread through release of a vessel or by spraying into the waterbody. To promote the survival of the introduced microbes, in low oxygen ponds, oxygenation is typically introduced along with the bioremediation technique to prevent the microbes from dying from low DO.

The following technologies use bioremediation as the pollutant removal technology:

Microbe-Lift (DEP Number 1473)

Microbe-Lift is a bioremediation product designed for use in ponds, lagoons, rivers, lakes, and industrial and municipal wastewater systems. The liquid contains a blend of aerobic and anaerobic microbial species to target multiple pollutants through biological oxidation of organic matter (SEEK Enterprises, Inc., 2020a). Case studies include applications in Jacksonville, Orlando, Captiva Island, and Fort Myers, Florida. The main applications have been in the treatment of golf course and natural ponds that are in need of nutrient and algae reduction (SEEK Enterprises, Inc., 2020b).

Materials provided by the supplier suggest ultimately up to 95% algae removal, with approximately 50% physical removal within a couple months of treatment (SEEK Enterprises, Inc., 2020c). One report supplied by the vendor indicated a 90% reduction in nitrates for an 11-acre freshwater lake located within a golf course (Kalogridis, 2014). Residuals are not present with this technology. Power is not required for this technology. Microorganisms are added to the pond water directly.

Materials supplied by the vendor provide an estimate for the cost to treat a 1-acre, 3- to 5-foot-deep pond for 2 years. After the first year of treatment, the pond required 3 gallons per acre of Microbe-Lift PBL product and 3 gallons per acre of Microbe-Lift SA product per month. Product cost was approximately $6,300 per acre for 2 years of maintenance. The total cost with labor and equipment included is approximately $12,300 (Elliott, 2020). Additional cost information is needed for treatment of a full reservoir and depth of approximately 17 feet.

BioCleaner Bio6 (DEP Number 1698)

BioCleaner Bio6 is a technology that combines bioremediation and aeration. The system uses a blower, aeration tubing, and biotube combined in a floating system to reduce sludge and nutrients in wastewater. Technology introduces a constant current through the biotube filled with microbes then feeding the microbes with enough oxygen to break down BOD and chemical oxygen demand (COD). The BioCleaner houses and introduces microbes into the water column to break down sludge in the system (BioCleaner, Inc., 2019a). Figure 3-37 provides a visual representation of the BioCleaner technology. BioCleaner has applications in commercial, agricultural, industrial and natural waterways. No projects have been implemented in Florida, but BioCleaner has projects in California and internationally in China, Philippines, and elsewhere.

Nutrient reduction is concentrated on treating BOD, COD, TSS, oil, and grease. No reduction performance data are presented. BioCleaner is designed for depths of 3 to 5 meters (10 to 17 feet) (BioCleaner, Inc., 2019b). The BioCleaner website states each BioCleaner is designed to treat 2,000 square meters (BioCleaner, 2020a), which would require approximately 20,000 units to treat the entire C-43 WBSR.

The microbes leave the biotube and enter the water column, feeding on the nutrients. There are no residuals produced by the BioCleaner. BioCleaner indicates that the microbes reduce or eliminate sludge build up in treatment areas reducing sludge production within the reservoir (BioCleaner, Inc., 2019b). Each biocleaner is equipped with a 2- or 3-hp blower (BioCleaner, Inc., 2019b). Assuming the blowers will run 24-hours per day, the total power needed is approximately 36 to 54 kWH per day per BioCleaner. No capital costs have been provided. Materials provided by the vendor approximate the maintenance costs at $2,600 per BioCleaner every 2 years. Additionally, the vendor estimates 5% of the media is lost per year, with a replacement cost of $3,000 (BioCleaner, Inc., 2020b). Given the media replacement cost, the initial cost to fill the entire biotube with media is approximately $60,000 per BioCleaner.

Figure 3-37. **BioCleaner Treatment Technology (BioCleaner, 2020a)**

Southern Algae Control (DEP Number 1858)

Southern Algae Control proposes the use of bioremediation microbes along with a proprietary polymer technology to reduce the available phosphorus and nitrogen for algae. The probiotic mixture is a blend of 10 microbes. The anionic polymer added to the microbial mixture targets the phosphates and nitrates to drop them below a 3-foot depth (Mikolay, 2019). Southern Algae Control proposes the construction of a treatment facilities to apply the product. A main treatment center consists of mixing tanks, pumping systems, compressors, air-drying system, and water filtration system (Mikolay, 2020). No completed case studies have been reported in Florida (Mikolay, 2019).

Nutrient reduction performance was tested by Bioscience, Inc. on St. Lucie Canal water. Testing indicated 50% COD removal, 33% phosphate removal, 52% ammonium removal, and an increase in nitrate. Testing was performed in bioreactors and results show the average performance of the three bioreactors (Bleam, 2019).

Materials provided by the vendor do not discuss any residuals. No discussion of the end product of the anionic polymer introduced with the microbes is provided, but this is presumed to be removed through passive sedimentation and decomposition. The treatment center will require power to run pumps, compressors, and air-drying system. No discussion of the energy needed to power a treatment center within the materials was provided. Cost of a treatment facility to process approximately 600 cfs for 24 hours a day, year-round is approximately $19,530,000 per year. The cost is approximately $138 per million gallons of water treated. This cost includes 24 hours a day, 7 days a week treatment service, certified laboratory analysis, monthly and annual reports, monitoring, and all required treatment (Mikolay, 2020).

Of the three bioremediation technologies, only Microbe-Lift was carried forward into further feasibility analysis primarily based on case study information. The other two were not retained, given the likely difficulty in scaling up and experience with large waterbodies.

Hybrid Wetlands Treatment Technology

Hybrid wetlands treatment technology (HWTT) includes design, construction, and operation of a facility that combines wetland and chemical treatment approaches to reduce phosphorus (DeBusk, 2009). The treatment uses chemical coagulants added to the front end of a wetland treatment system, containing one or more deep water zones to capture the resulting floc material. The passive treatment of the wetlands partnered with the active coagulant sorption results in the reduction of phosphorus. The coagulant used for the HWTT is aluminum sulfate or alum (SFWMD, 2009). Other forms of alum (e.g., polyaluminum chloride and sodium aluminate had been used in previous studies. Additional features of the technology include pumped recirculation of alum floc or reusing floc to extend the functional life of the coagulant for reduction of phosphorus in the water column or to minimize phosphorus remobilization from sediment. The reuse of the dried, stable floc helps reduce the residual management efforts. Case studies of the technology have occurred at multiple locations in the Northern Everglades in basins S-65D, S-65E, S-154, and S-191. DeBusk (2009) states the HWTT is effective at removing phosphorus and improving water quality at each system. A key recommendation was to use floating and submerged vegetation to reduce the nitrogen concentration. No specific flow rates were reported.

Residuals management was not discussed in detail, but floc will be collected in the deep zone of the wetlands. Residual management will be minimal given proper design of wetlands. Energy is needed to power the alum feed pump. Alum addition is highly dependent on the concentration and flow into the HWTT (DeBusk, 2009). Estimated operating costs range from $19 to $301 per pound of phosphorus removed, depending on the flow capacity and the phosphorus concentrations introduced. This technology was carried forward for further evaluation, given the strong performance data available and proven experience with both alum and wetland treatment.

3.3.3.2 Advanced Wastewater Treatment

Wastewater treatment systems use a multi-step process to treat wastewater removing nitrogen, phosphorus, TSS, and many more pollutants from a waste stream. The process begins with bar screening, which removes the large items from the influent to prevent clogging in the rest of the process system. Screening is followed by a secondary screening process designed to remove grit by flowing water over a grit chamber that removes grit from the water stream (Cole-Parmer, 2020). The next stage is the primary clarifier, which provides initial separation of solid organic matter from wastewater. This stage promotes settling of organics and solids to the bottom of the tank where they are removed from the system (Cole-Parmer, 2020). The next stage is aeration, which involves pumping air into the basin to encourage conversion of ammonia to nitrate and provide oxygen for bacteria to thrive and consume the nutrients. This stage is the bioremediation stage that relies on natural processes of bacteria to break down organics to remove them from the water (Cole-Parmer, 2020). Stage five is a secondary clarifier that further removes remaining organic sediment through settling. Low flow rates allow the fine particles to settle into a sludge that is removed (Cole-Parmer, 2020). Disinfection and chlorination follow the secondary clarifier. This stage involves adding chlorine to kill any remaining bacteria in the contact chamber. Some systems include sand filtration to remove the organics further before disinfection. It is important to remove the organics before adding chlorine to prevent chlorine-by-products. Additional ways to disinfect include ozone and ultraviolet disinfection (Cole-Parmer, 2020).

Wastewater treatment facilities that reduce nitrogen levels to less than 3 mg/L and less than 1 mg/L phosphorus are considered advanced wastewater treatment. There are many different approaches to treating the wastewater to desired levels. Some of the most widely used methods are the Bardenpho process, microfiltration, and reverse osmosis (Falk et al., 2013).

Extensive infrastructure would be required to implement an advanced wastewater treatment system. Generally, infrastructure for this type of facility would include power, piping, tank storage and reactor vessels, road access, treatment and administrative buildings, instrumentation and control, security and fencing, and residuals processing and storage. Administratively, it can be expected that this type of technology will require a significant labor requirement, with plant oversight, operation, maintenance, and related activities.

Biological Treatment to Ultra-low Concentrations

The Bardenpho process uses a combination of anaerobic, anoxic, and aerobic reactors to treat nitrogen and phosphorus. The 5-stage Bardenpho process begins with an aerobic tank, followed by an anoxic tank, aerobic tank, anoxic tank, another aerobic tank, and finally a clarifier to remove the nutrients that remain (Esfahani et al., 2018; Falk et al., 2013). Figure 3-38 illustrates the Bardenpho process. This technology was retained for further evaluation given the proven experience with removal of nutrients to low levels for high flow rates within range of the C-43 discharge.

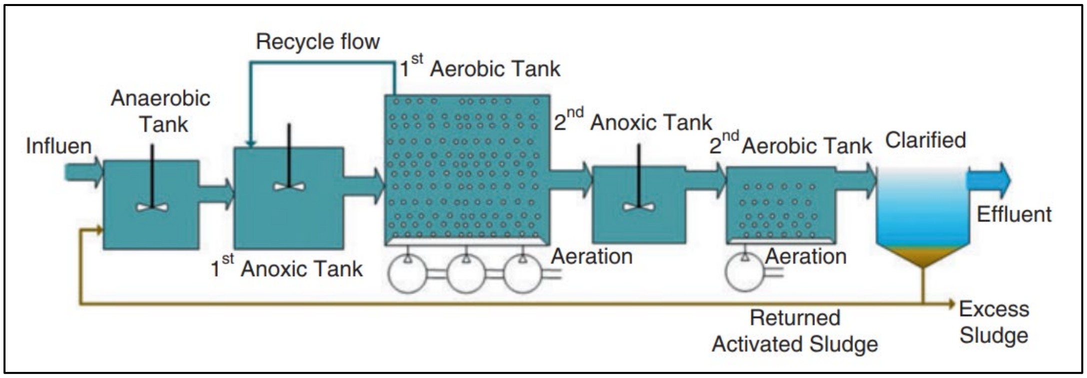


Figure 3-38. Illustration of the Bardenpho Process (Esfahani et al., 2018)

Membrane Filtration

Microfiltration is a method of membrane filtration. Membrane filtration removes particles by removing the pollutant particles through the filter medium because the particles are larger than the pores of the filter. Microfiltration is a method of membrane filtration that is used to remove particles in the 0.1- to 10-micron range but are not used to remove dissolved contaminants. Microfiltration uses a pressure on the membrane to drive the water through the physical barrier while removing the particles (WaterProfessionals, 2020). Typical nutrient concentrations from microfiltration with the Bardenpho process are approximately 3 mg/L nitrogen and less than 0.1 mg/L phosphorus (Falk et al., 2013).

Reverse osmosis is a process that uses a membrane to separate pollutants from the water to produce effluent that has very low concentrations of nitrogen and phosphorus. One of the issues with reverse osmosis is the brine residuals that are created that can be difficult to manage. Typical management strategies include evaporation ponds, concentration/crystallizers, and deep well injection (Falk et al., 2013). Typical nutrient concentrations after reverse osmosis are approximately 2 mg/L nitrogen and less than 0.02 mg/L phosphorus.

Residual Management and System Costs

Residual management is a key process with wastewater treatment facilities requiring land and power for effective implementation. Solids treatment requires gravity belt thickeners, anaerobic digestion with cogeneration, and centrifugation (Falk et al., 2013). Costs for the processes depend heavily on the influent concentration and the desired effluent nutrient concentrations. One cost estimate of a 10 MGD Bardenpho process facility is approximately $144 million, with an approximate annual cost of $2,350,000 per 10 MG treated. A facility that includes the Bardenpho process and microfiltration is approximately $153 million with operational costs of approximately $3,200,000 per 10 MG treated. Reverse osmosis is the most expensive process with a capital cost of $225 million with operational costs of approximately $4,990,000 per 10 MG treated (Falk et al., 2013).

3.3.3.3 Denitrifying Bioreactor

Denitrifying bioreactors remove nitrogen from the water column through natural processes of anaerobic denitrification. Bioreactors use a carbon source, like woodchips, and saturate the material to provide anaerobic conditions to encourage natural microbes to perform denitrification to remove nitrogen, mostly nitrate. Gravel is combined with the carbon source to promote hydraulic conductivity. Bioreactors typically use a geotextile or plastic lining to surround the media to prevent migration of soil particles into the media (City of Bonita Springs, 2019).

There are many case studies of bioreactors in Florida. One is for the treatment of nitrogen from stormwater collected from neighborhoods in Bonita Springs. This multi-phase project tested the treatment capability of a bioreactor with stormwater with hydraulic residencies varying from 0.5 to 1.1 days (City of Bonita Springs, 2019). Performance data indicated nitrate removal efficiencies of 77% to 98%. The influent concentration of nitrate averaged approximately 0.253 mg/L. The hydraulic residence times ranged from 0.5 day with an approximate flow of 82 gpm to 1.1 days with an approximate flow of 37 gpm per bioreactor (City of Bonita Springs, 2019). The estimated life span of the bioreactors is 20 years. After this time, new woodchips will have to be added to replenish the carbon source. The spent woodchips require disposal (City of Bonita Springs, 2019). This system uses natural processes and is a passive treatment system that requires no energy input. Cost information provided is for five bioreactors that receive up to 480 gpm. The cost of design and construction is approximately $801,000 (City of Bonita Springs, 2019). This system was not retained for further evaluation given the likely challenge of extrapolation to a scale appropriate to receive C-32 discharges.

3.3.4 DEP Technologies With No Response

The following technologies are currently on the DEP Accepted Water Technology Library but information was not provided on the product or approach despite efforts by J-Tech to contact the vendor or DEP reviewer. No response has been received for these following technologies as of the date of this report:

- FocalPoint High Performance Modular Biofiltration System – Biological Process (DEP Number 1478)
- Bioremediation and Oxidation of Nutrient Load for Both Proactive and Reactive Applications – Biological Process (DEP Number 1626)
- Integrated Onsite Stormwater Management Solutions (DEP Number 1678)
- HABolish – Physical and Chemical Process (DEP Number 1875)
- Omega Water Sciences – Biological Process (DEP Number 1882)

4.0 Discussion/Results (Top 25 to be Evaluated for the Study)

4.1 Treatment Technology Evaluation Technologies

The summary of available conventional and natural treatment technologies provided in Section 3.0 indicates that a wide range of approaches are available. All technologies are constrained to varying degrees by limitations on the scale of operation that will be necessary to provide effective treatment for the C-43 WBSR. For this preliminary review of the available technological approaches, the list of potentially applicable technologies was evaluated and reduced to 25 technologies recommended for further evaluation. Key criteria for this initial step included the following:

- General knowledge base.
- Performance within appropriate concentration ranges for the key water quality parameters.
- Scalable to flows within project range.
- Florida case studies.
- Availability of unit capital and operational cost information or preliminary estimates of full-scale cost.

A technology may be retained if four or more of these qualitative criteria were met. Table 4-1 summarizes the list, presented in alphabetical order.

Table 4-1. List of 25 Technologies Recommended for Further Evaluation

Technology	Justification for Further Evaluation
Advanced Wastewater Treatment	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available
Air Diffusion Systems (ADS)	▪ Aeration is a well-established technology ▪ Capable of achieving low TN and TP concentrations ▪ Can be scaled to large volume reservoirs ▪ No Florida case study but multiple case studies available other states ▪ Vendor has provided plans and costs to treat C-43
Aluminum Chloride	▪ Long history of application treating wastewater, stormwater and surface water ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available
Aluminum Sulfate	▪ Long history of application treating wastewater, stormwater and surface water ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available
AquaLutions®™	▪ Recent application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Vendor confident of capacity to function at high flows ▪ Florida case studies ▪ Cost information available

Technology	Justification for Further Evaluation
Aqua-Swirl®	▪ Common application treating stormwater ▪ Capable of achieving high TSS (algae) removal ▪ Vendor confident of capacity to configure function at high flows ▪ No documented Florida case studies provided ▪ Cost will need to be estimated specific to application
Bold & Gold	▪ Recent history of application treating stormwater ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost information available
Ciba Krysalis FA/FC	▪ Used to treat Miami River, Port Manatee, and Tampa Bay ▪ Capable of achieving high TSS (algae) removal ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Denitrifying Bioreactor	▪ Long history of application treating stormwater and groundwater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Downstream Defender®	▪ Recent history of application treating stormwater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of treating a stream of the total flow to reduce overall concentration ▪ Florida case study not available ▪ Cost will need to be estimated specific to application
Dredgeclear 53	▪ Used to treat North Palm Beach Waterway and interior residential canals ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
ElectroCoagulation	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations and remove algae ▪ Vendor confident of capacity to configure function at high flows ▪ Florida case studies ▪ Vendor has provided plans and costs to treat C-43
Floating Wetlands (Biohaven)	▪ Increasing application in Florida waters ▪ Capable of achieving measurable TN and TP concentrations ▪ Scaling to large reservoir areas may be difficult ▪ Florida case studies ▪ Cost information available
FLOPAMTM EM 230	▪ Used before to treat the Gator Sand Mine ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost information available
Hybrid Wetlands Treatment Technology (HWTT)	▪ Recent history of application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Unit cost data available based on flow
Managed Recirculation	▪ Experimental approach but based on reservoir circulation studies ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired volume ▪ Florida case study information unavailable ▪ Cost information unavailable

Technology	Justification for Further Evaluation
Microbe-Lift	▪ Recent history of application treating surface water ▪ Capacity to achieve low TN and TP concentrations not demonstrated ▪ Capacity to function at similarly large volumes not demonstrated ▪ Florida case studies ▪ Unit cost information available
MPC-Buoy	▪ Recent history of application treating surface water ▪ Capable of treating algae populations ▪ Capacity to function at similarly large volumes not demonstrated ▪ Florida case studies just beginning ▪ Unit cost information available
NutriGone™	▪ Recent history of application treating surface water ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Optimer 7194 Plus	▪ Used before to treat eutrophic Lake Maggiore ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies ▪ Cost will need to be estimated specific to application
Sand Filtration	▪ Long history of application treating wastewater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Unit cost data available based on flow
SciCLONE™	▪ Recent history of stormwater treatment ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ No Florida case study information available ▪ Cost information available
Southern Algae Control	▪ Long history of application treating wastewater ▪ Capable of achieving low TN and TP concentrations ▪ Capable of scaling treatment up to desired flow ▪ Florida case studies unavailable but Okeechobee applications investigated ▪ Vendor has provided plans and costs to treat C-43
StormPro®	▪ Long history of application treating wastewater ▪ Exhibits high removal rates of TSS, likely removal of algae ▪ Capable of scaling treatment up to desired flow ▪ No Florida case study information available
Treatment Wetlands	▪ Long history of application treating stormwater and groundwater ▪ Capable of achieving low TN and TP concentrations ▪ Proven capacity to function at high flows ▪ Florida case studies ▪ Cost information available

Note: Technologies are listed in alphabetical order

4.2 Technology Connectivity Matrix

The C-43 WBSR treatment system will be expected to provide cost-effective nutrient reduction and to ensure that water quality discharged from the C-43 WBSR will have improved water quality when returned to the Caloosahatchee River. As a consequence, three possible configurations are envisioned to connect the treatment system to the reservoir flow path to allow maximum improvement. First, water may be treated during the period of reservoir loading (“pre-storage”) with the objective of reducing nutrient loading to the reservoir to maintain water quality and minimizing the potential for algae growth during storage. Pre-storage flows would occur for relatively short duration (approximately 3 months) with high inflow rates (e.g., 1,500 cfs or less) expected. Second, water may be treated during storage ("in-reservoir") with the objective of complementing the natural nutrient reductions expected during storage while minimizing the potential for algal bloom development. Finally, water may be treated when being discharged from the reservoir ("post-storage") with the objective of removing nutrients, particulate matter and algae in the flow back to the River. Post-storage treatment would allow for monitoring of the water quality of the discharge to the river and would be sized for conceptually smaller flows (e.g., 450 cfs or less). From a practical perspective, a water quality treatment system could be connected to the system to allow pre-storage, in-reservoir, and post-storage treatment, thereby maximizing the year-round benefit. A system sized for treatment of a portion of the inflow during pre-storage and more comprehensive treatment during post-storage could provide a more efficient use of the technology, and conceptually be inoperative only during the storage period. However, a design providing pre-storage, in-reservoir, and post-storage may maximize treatment efficiencies. Table 4-2 provides a conceptual assignment for each of the 25 recommended technologies to the three alternative configurations.

Table 4-2. List of Technology Connectivity with the C-43 Reservoir System

Technology	Treatment Location		
	Pre-Storage	In-Reservoir	Post-Storage
Advanced Wastewater Treatment	X		X
Air Diffusion Systems		X	
Aluminum Chloride	X	X	X
Aluminum Sulfate	X		X
AquaLutions®™	X		X
Aqua-Swirl®	X		X
Bold & Gold	X		X
Ciba Krysalis FA/FC		X	
Denitrifying Bioreactor	X		X
Downstream Defender®	X		X
Dredgeclear 53		X	
ElectroCoagulation	X		X
Floating Treatment Wetlands		X	
FLOPAM™ EM 230		X	
Hybrid Wetlands Treatment Technology	X		X
Managed Recirculation		X	
Microbe-Lift		X	
MPC-Buoy		X	
NutriGone™	X		X
Optimer 7194 Plus		X	
Sand Filtration	X		X
SciCLONE™	X		X
Southern Algae Control	X		X
StormPro®	X		X
Treatment Wetlands	X		X

Note: Technologies are listed in alphabetical order

Table 4-3 summarizes the remaining technologies and reasons for not providing further evaluation. Reasons for excluding a technology from further evaluation generally include lack of available information, but consistently, many vendors were quick to point out that the technology was best suited for urban stormwater drainage or smaller-scale drainage situations.

Table 4-3. List of Technologies Not Recommended for Further Evaluation

Technology	Reason for No Further Evaluation
Aqua-Filter™	▪ Information provided by vendor indicates design flow rate is too low for application ▪ Designed for precise treatment of stormwater flows
Bio Clean Catch Basin Filter	▪ Designed as a catch basin insert, not applicable to C-43 WBSR
Debris Separating Baffle Box	▪ Information provided by vendor indicates design flow rate is too low for application ▪ Designed for precise treatment of stormwater flows
FocalPoint High Performance Modular Biofiltration System	▪ Vendor does not recommend this technology for C-43 WBSR application
HABolish	▪ Have not received information from vendor ▪ Website did not work and have not received information from DEP reviewer after multiple attempts
Hydro Dry Screen and Up-Flo Filter	▪ Vendor does not recommend this product for C-43 WBSR application
Integrated Onsite Stormwater Management Solutions	▪ DEP review documents are not available
Kraken Filter	▪ Vendor specified this technology is not applicable to C-43 WBSR
MagneGas (Oxidation)	▪ Information from the vendor indicates treatment of large flows would be too land intensive with 60 gpm needing a 40-foot tractor trailer size treatment system ▪ Performance data not consistent
Omega Water Sciences (Bioremediation)	▪ Have not received information from vendor ▪ DEP review documents are not available
Phosphorus Free Water Solutions (Bioremediation)	▪ Technology is not described in the material provided ▪ Case studies are limited to a demonstration project in the Okeechobee Lake, no indication of ability to treat flows designed for at the C-43 reservoir
PhosRedeem	▪ No specific product but have retrieved key reference ▪ Reached out to vendor multiple times with little information return
StormBasin	▪ Catch basin insert is not applicable for C-43 WBSR
StormSack™	▪ Catch basin insert is not applicable for C-43 WBSR

Note: Technologies are listed in alphabetical order

4.3 C-43 WBSR Water Quality Feasibility Study

The follow-on report will evaluate the 25 technologies for their potential use individually or combined to provide the greatest water quality improvement. The Final Feasibility Study will identify a minimum of three of the most cost-effective and technically feasible, conventional, and innovative biological, chemical, and physical water quality treatment technologies identified within this report. These technologies will be at a scale necessary (or ready to be scaled) for long-term pre-treatment, in-reservoir treatment, and/or post-treatment options that limit conditions suitable for blue-green algal bloom development and/or conditions that improve the quality of water leaving the C-43 WBSR to the Caloosahatchee River and its downstream estuarine ecosystem, while maintaining the current C-43 WBSR construction schedule and project purpose.

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Appendix B: Public Meeting Summary and Materials

C-43 West Basin Storage Reservoir Water Quality Feasibility Study

Public Meeting Minutes

September 27, 2019 2:00-4:00 PM

SW Florida Community Foundation Collaboratory

2031 Jackson Street, Suite 100, Fort Myers, FL 33901

Meeting Welcome

- The first of four public meetings for the C-43 West Basin Storage Reservoir (WBSR) Water Quality Feasibility Study (Study) began at 2:00 pm.
- Dave Fleming, Ingenuity Lab, gave a brief welcome and an overview of the meeting plan for the day.
- Drew Bartlett, Executive Director of the South Florida Water Management District (SFWMD), reviewed the importance of the Study that was the subject of the meeting and discussed how the Study is part of Governor Desantis' Executive Order issued in January 2019.
- Dave Fleming then discussed the format of the meeting and the plan for the day and introduced Georgia Vince, Project Manager for J-Tech, the consultant that is leading the Study efforts.

Understanding the Big Picture: Everglades Restoration and Scope of Feasibility Study

- Georgia Vince discussed the hydrologic changes that have historically occurred throughout south Florida and the greater Everglades and how those changes have affected the expansive mosaic of habitats.
- Georgia Vince discussed the graphic that shows the alteration of flows and the current system.
- Dave Fleming asked a question about the intent of Everglades restoration.
- Georgia Vince explained the graphic on the right of the slide shows the restoration targets for the quantity of flows. Everglades restoration also has targets for flow volume changes and water quality.
- Georgia Vince discussed the intent of the Comprehensive Everglades Restoration Plan (CERP) and that the plan outlined more than 60 individual projects to restore the timing, distribution, quantity, and quality of flows.
- Georgia Vince explained that the C-43 WBSR was one of the CERP projects and the purpose was to regulate the flow volumes to the Caloosahatchee Estuary by capturing and storing local basin runoff and Lake Okeechobee regulatory releases

during the wet season and releasing the stored freshwater to the Estuary during the dry season to help balance salinity levels.

- Georgia Vince reviewed subsequent efforts to CERP including SFWMD's Restoration Strategies and the Science Plan, Central Everglades Planning Project (CEPP), and CEPP Post Authorization Change Report (CEPP PACR), which was completed in 2018 and includes the A-2 Reservoir and stormwater treatment area (STA) components within the Everglades Agricultural Area. These storage and treatment facilities will also help to reduce flows to the northern estuaries.
- Georgia Vince reviewed some of the many other ongoing efforts led by the Florida Department of Environmental Protection (DEP) including the Red Tide Task Force, Blue-Green Algae Task Force, Agricultural Best Management Practices (BMP) regulations, basin management action plan (BMAP) update, and the DEP Library of Accepted Technologies for Water Issues.
- Georgia Vince also stated that DEP is participating in the Working Group that is providing input and feedback for the Study.

Meeting the Feasibility Study Working Group

- Dave Fleming asked the Working Group members to introduce themselves to the audience and indicated that they would be available to discuss the study and collect information in a networking session at the end of the presentation.
- Georgia Vince introduced Shawn Waldeck, J-Tech, who has been working on the C-43 WBSR since 2002 and is currently overseeing construction management of the reservoir.

Understanding the C-43 Reservoir Operations

- Shawn Waldeck provided an overview of the location of the C-43 WBSR including its location related to the Caloosahatchee River, Lake Okeechobee, Ortona and Franklin Locks, and Townsend Canal.
- Shawn Waldeck discussed the basic operation of the reservoir including the location of the inflow pump station on the Townsend Canal on the west side of the facility, and the interconnect between the two large cells.
- Shawn Waldeck then discussed how the reservoir will release water at two locations (one at each cell) into the outflow canal along the north boundary of the reservoir and west to the Townsend Canal, which ultimately will flow into the Caloosahatchee River.
- Dave Fleming asked how large the reservoir actually is and Shawn Waldeck replied that the reservoir is approximately 6 miles across and 3 miles tall. The storage capacity its 170,000 acre-feet.

- Shawn Waldeck reviewed the general operational plan which includes filling during the wet season, discharging during the dry season at a target rate of 400-450 cubic feet per second (cfs), which was identified as the minimum flows and levels (MFL) for the Caloosahatchee Estuary.
- Shawn Waldeck further described that the inflow pump station capacity is 1,500 cfs, and it would take about 2 to 4 months to fill the reservoir.

Understanding the C-43 Reservoir Study Constraints

- Dave Fleming described that all studies need to have clear goals and objectives and that the Study team has identified constraints to be aware of as they move forward to address the intent of the Executive Order.
- Georgia Vince reviewed several of the Study constraints including that the Study cannot affect the congressionally approved C-43 Reservoir project purposes, infrastructure, construction schedule, or operation. Project lands have not been specifically identified for the Study. The Study will focus on reviewed and accepted technologies included in the DEP Library of Accepted Technologies for Water Issues and that additional technologies would be discussed at the end of the meeting and at future meetings to capture input from the public.
- Georgia Vince also discussed that the C-43 Reservoir and the selected treatment component(s) alone are not intended to achieve compliance with the Caloosahatchee River and Estuary Total Maximum Daily Loads (TMDLs) and that there are other projects identified throughout the watershed related to that effort.
- Georgia Vince introduced two of the J-Tech team members, Jim Bays, of Jacobs Engineering, who will lead the alternative treatment technologies evaluation for the Study, and Chris Keller, with Wetland Solutions, Inc. who will lead the evaluation of wetland treatment systems.

Focusing on the Study: Technologies Presentations

Biological, Chemical, and Physical Treatment Technologies

- Jim Bays presented an overview of water quality technologies available for consideration in improving discharge water from the C-43 WBSR.
- Jim Bays discussed where in relation to the location to the reservoir and the Caloosahatchee River water quality treatment features could be implemented.
- Technologies reviewed included natural and conventional engineered technologies for treating water flowing into the reservoir, treatment

opportunities within the reservoir, and treatment opportunities for water leaving the reservoir.

- Jim Bays discussed that the broad spectrum of technologies allows tradeoffs in land area, performance, energy, waste products, and other factors to be compared. Physical (e.g., filtration, sedimentation), chemical (e.g., coagulation, flocculation, and adsorption), and biological (e.g., wetlands, floating wetland islands) technologies were briefly described.
- Jim Bays discussed the innovative technologies currently accepted by DEP and that these technologies will be reviewed and evaluated during the Study.
- Jim Bays explained that the technologies included in the Study will be evaluated based on performance, cost, physical and general requirements, and will be ranked during the project.

Wetland Treatment and STAs

- Chris Keller summarized the diverse array of water quality processes that occur in treatment wetland systems and related those back to the processes that occur in conventional biological, chemical, and physical treatment systems.
- Chris Keller described the wetland nitrogen and phosphorus cycles, highlighting the dominant pathways and processes responsible for net removal of nitrogen and phosphorus from surface waters.
- Chris Keller described the various types of wetland plant communities that have been used in wetland treatment systems: floating aquatic vegetation (FAV), emergent aquatic vegetation (EAV), submerged aquatic vegetation (SAV), and periphyton.
- Chris Keller noted that treatment wetlands, while they may not appear as such, are engineered to achieve specific outflow values based on known inflow values. The key differences between treatment wetlands and conventional systems are in land area requirements (larger for treatment wetlands), external energy and chemical inputs (lower for treatment wetlands), and cost-effectiveness (typically better for treatment wetlands).
- Chris Keller presented data from the 2007 C-43 WBSR Test Cell Water Quality Study showing that the total nitrogen concentration was reduced by 14% and total phosphorus by 74%. Natural processes (primarily microbial for nitrogen and physical settling for phosphorus) were responsible for the concentration decreases.
- Chris Keller summarized the recently completed C-43 Water Quality Treatment and Testing Project Phase 1 Mesocosm Study. The study focused on the use of EAV and SAV wetland systems to reduce dissolved organic nitrogen concentrations in water pumped from the Caloosahatchee River. The goals were

to evaluate performance differences attributable to plant community selection, antecedent soil nitrogen storages, and hydraulic loading rate. Overall, the mesocosms reduced total nitrogen by 23% on a concentration basis and 33% on a mass basis. More dissolved organic nitrogen was removed in the wet season (14%) than in the dry season (4%), while dissolved inorganic nitrogen was consistently and effectively removed (90%). Nitrogen performance was not different based on plant community type, but more phosphorus was removed by SAV than EAV.

- Chris Keller indicated that performance data from regional treatment wetland projects will be reviewed and incorporated into the Study. Members of the Working Group will be instrumental in locating and providing the regional data for review in the Study.

Engaging the Feasibility Study Working Group

- Following the presentations, the Working Group and the J-Tech team gathered with meeting attendees in the foyer of the Collaboratory to have an opportunity to discuss specific treatment technologies, and their potential to be included in the Study in a one-on-one format.
- Several informational sheets were available for the public including the C-43 WBSR fact sheet, the Caloosahatchee BMAP information sheet and the DEP Technology Database information sheet, which provided the details regarding submittal to the database for acceptance.
- AquaFiber, Phosphorus Free Solutions, and Powell Water Systems provided information and links useful to evaluating their potential as technologies to be applied to the WBSR Water Quality Feasibility Study.
- Other discussions and feedback from the audience included an overview of the project and potential solutions to a contingent of graduate students from the University of South Florida Graduate School of Engineering. Their class project will be to assess the effectiveness of different technologies for improving water quality in the C-43 and reservoir discharge.
- Other information exchanged included data compiled by the City of Sanibel regarding improved water quality in the Estuary and in wastewater and stormwater discharges, and with the Southwest Florida Clean Water Movement, which has been tracking water quality in the River and Estuary for over 30 years, and how that information can be incorporated into the Study.
- Valuable and important information and perspectives were shared between the Working Group and the public during this interactive one on one opportunity.

C-43 West Basin Storage Reservoir Water Quality Feasibility Study
Public Meeting Minutes

January 21, 2020 2:00-4:00 PM
Hendry County Extension Office
1085 Pratt Boulevard, LaBelle, FL 33976

Meeting Welcome

- Kim Fikoski, Project Manager with the South Florida Water Management District (SFWMD), stated that this is the second of four public meetings for the C-43 West Basin Storage Reservoir (WBSR) Water Quality Feasibility Study (Study).
- Mitchell Wills, Chairman of the Hendy County Commission welcomed participants to Hendry County.
- Drew Bartlett, Executive Director of the SFWMD, stated that Governor Desantis' Executive Order asked DEP to work with SFWMD to evaluate water quality treatment options for the C-43 WBSR. SFWMD created a team to evaluate all available options. He encouraged engagement by the local stakeholders in this discussion regarding additional water quality treatment for the C-43 Reservoir. He introduced Chauncey Goss, the Chairman of the SFWMD Governing Board.
- Kim stated that SFWMD and the Florida Department of Environmental Protection (DEP) initially met with the City of Sanibel and Lee County to discuss how to engage local stakeholder's input into the Study. This discussion lead to the formation of the Working Group who are part of the Study team. The Working Group members introduced themselves:
    - Roland Ottolini, Director Lee County Natural Resources
    - Shane Parker, Director Hendry County Public Works
    - Edward Smith, Director of Office of Ecosystem Projects, Florida Department of Environmental Protection
    - James Evans, Director of Natural Resources Department, City of Sanibel
    - Maya Robert, Environmental Resources Division Manager, City of Cape Coral
    - Kim noted Mike Cook, Asst. District Manager, Lehigh Acres MSID was unable to attend today's meeting

- Kim stated that the Working Group helps to provide information to the study consultant team, as well as review and comment on the Study throughout its development. She noted that the water quality treatment technology studies the team is reviewing for the Study are posted to the SFWMD website. If any applicable studies are missing, stakeholders can submit information through the website as a comment or they can follow up with a Working Group member.

- Kim asked the consultant team members of J-Tech - a joint venture of Jacobs Engineering and Tetra Tech, Inc. and Wetlands Solutions, Inc. (WSI) to introduced themselves.
    - Georgia Vince, Project Manager, J-Tech
    - Jim Bays, Technology Lead, J-Tech
    - Chris Keller, Wetland Treatment System Lead, WSI
    - Shawn Waldeck, C-43 WBSR Engineer, J-Tech

- Kim stated that the goals of this meeting are to provide an update on the literature search, identify any studies or information that is missing, ensure everyone understands the Study goals and constraints, and to answer questions. She noted that index cards were provided and will be collected later in the meeting for the Working Group and Study team to respond to.

Study Background

- Ed Smith, DEP, discussed the hydrologic changes that have historically occurred throughout south Florida and the greater Everglades. He discussed the graphic that shows the alteration of flows and the current system and noted that the changes have over drained the Everglades, which lead to the creation of the Comprehensive Everglades Restoration Plan (CERP) to restore historic flows. The C-43 WBSR is part of CERP. The reservoir is designed to store water in the wet season and then meter out the water in the dry season to help meet the minimum flows and levels (MFL). There is concern that storing the water in the reservoir could result in algae blooms within the reservoir.
- Governor Desantis' Executive Order issued in January 2019 directed DEP and SFWMD to improve the quality of water leaving the C-43 reservoir.
- The Governor’s Executive Order identified other initiatives needed to provide better protection of the state's waterbodies. DEP is leading several of those initiatives including the formation of the Blue-Green Algae Task Force and Harmful Algal Bloom (Red Tide) Task Force. The Blue-Green Algae Task Force made its first round of recommendations which included innovative technology grants that DEP is currently issuing, and they are about to begin their second round of recommendations. The Harmful Algal Bloom (Red Tide) Task Force, is meeting for the third time on January 23 to finalize their red tide recommendations.
- Ed also noted DEP, SFWMD, and the Florida Department of Agriculture and Consumer Services (FDACS) are looking for opportunities to improve agricultural best management practices (BMPs). DEP also has a Technology Library with information on technologies that DEP has reviewed and accepted. The Study team will be reviewing these technologies to determine if they will help with water quality treatment for the C-43 WBSR.

Study Objective

- Georgia Vince, J-Tech Project Manager, stated that the primary objective of the study is to identify opportunities to provide additional treatment and improve water quality leaving the C-43 Reservoir. To do this, the Study will evaluate pre-storage, in-reservoir, and/or post-storage treatment options to identify at a minimum three conceptual options to improve water quality. The Study team will evaluate options to ensure they are cost-effective and technically feasible. They will consider biological, chemical, and physical treatment options that are scalable and available for long-term use. In addition, any treatment technologies that are chosen must be compatible with the reservoir operations.
- Georgia reviewed the Study schedule. The Study is under development and the team is currently collecting information on treatment technologies. The Information Collection Summary Report is being drafted and will be finalized in March. The next step will be to evaluate the technologies. The Study will wrap up in October and a final meeting will be held in November.

C-43 Reservoir Operations

- Shawn Waldeck, J-Tech, stated the purpose of the C-43 WSBR is to capture excess Caloosahatchee basin runoff and Lake Okeechobee releases; improve quantity, timing and distribution of freshwater flows to the Caloosahatchee Estuary to help maintain proper salinity levels; and maintain water supply for existing legal users .
- The reservoir is a component of CERP and the Project Implementation Report was approved in 2010 and the project was authorized by Congress in 2014. A Project Partnership Agreement with the U.S. Army Corps of Engineers (USACE) was executed in June 2016 since this project is a 50/50 cost-share with USACE.
- Shawn provided an overview of the location of the C-43 WBSR, including its location related to the C-43 Canal, Lake Okeechobee, Ortona and Franklin Locks, and Townsend Canal.
- Flows from the river are directed down the Townsend Canal and into the reservoir. Water will go through the S470 pump station that is currently being constructed. The reservoir has two cells and a pump to transfer water from one cell to another. The two discharge structures are located on the north end of the reservoir. Water flows out of the reservoir into Townsend Canal and back into the Caloosahatchee River.
- The major constraints to the reservoir operations are the Lake Okeechobee operation schedule and the Caloosahatchee MFL. The reservoir will be filled during the wet season and discharge during the dry season to help modulate the salinity barrier in the river.
- Shawn reviewed the general operational plan which includes filling during the wet season, discharging during the dry season at a target rate of 450 cubic feet per second (cfs), which was identified as the MFL for the Caloosahatchee estuary, and an emergency discharge rate of 2,500 cfs.

Study Constraints

- Georgia reviewed several of the Study constraints including that the Study cannot affect the congressionally approved C-43 Reservoir project purposes, infrastructure, construction schedule, or operation. Project lands have not been specifically identified for the Study. The Study will focus on reviewed and accepted technologies included in the DEP Library for Water Issues, but will not be limited to those technologies, if other information is provided.
- The C-43 Reservoir and the selected treatment component(s) alone are not intended to achieve compliance with the Caloosahatchee River and Estuary Total Maximum Daily Loads (TMDLs). There are other projects identified throughout the watershed related to that effort.

Conventional and Innovative Treatment Technologies

- Jim Bays, J-Tech, stated that while the treatment focus is on nitrogen, they are also evaluating phosphorus and suspended solids (algae or suspended particles) removal. The technologies reviewed included natural and conventional engineered technologies that each have costs, benefits, and tradeoffs that should be considered.
- There are opportunities to treat the water flowing into the reservoir, water within the reservoir, and water leaving the reservoir. The goal is to have cleaner water leaving the reservoir than what came into it.
- Jim reviewed physical treatment technologies including filtration, sorption, dissolved air flotation (DAF), oxidation, and sonication. He presented an example of a physical/chemical project from AquaFiber from the DEP database. They had a pilot project on Lake Jesup that uses DAF with a chemical additional to remove algal solids and associated phosphorus and nitrogen. The pilot study ran for five years and there is a detailed report of the results. Jim noted that they are finding a wide range in the level of detail for each technology.
- Jim stated that chemical treatment options include coagulation and flocculation. He provide an example of electro-coagulation where an electric current is used to increase the settling of nutrients.
- Biological treatment options include bioremediation (use of microbes) or floating wetland islands and treatment wetlands. Jim provided an example of BioCleaner, which is a floating device on a waterbody that draws water into a media tube that has microbes that remove nutrients. The units are about 10 feet long so scaling up to the size of the reservoir may be an issue which is a factor that is being evaluated.
- The team is reviewing the 30 applicable technologies in the DEP database. There were also 8 unsolicited technologies that are being reviewed. Jim summarized the technologies based on the treatment type. Some of the technologies in the DEP database have Florida case study data.
- Jim noted that in-reservoir treatment typically includes aeration or adding chemicals to reduce algae growth and flocculate nutrients. The reservoir ecosystem

itself can also be used to retain nutrients and to use differences in oxygenation to remove nutrients. Jim provided examples including ultrasonication, algicide application, and biological treatment through artificial circulation in the reservoir.

- Jim presented a draft matrix of factors that will be used to evaluate each of the technologies. The factors include the process, Florida information, nutrient concentration, removal efficiency, area, flow, scale factor, power, residuals, and cost.
- The next step will be to summarize the performance of each of the technologies with a focus on technologies with Florida-specific information. They will estimate costs, estimate the physical requirements (land, power, day to day requirements), and the administrative requirements (permitting needs, regulations).

Wetland Treatment Technologies

- Chris Keller, WSI, stated that a lot of the treatment types that Jim described also occur naturally. Sedimentation occurs as water moves slowly through a natural system. Vegetation is covered with biofilm, which is a collection of microorganisms that can trap particles and provide biological processes that transforming nitrogen and phosphorus into other forms.
- Chris described the wetland nitrogen and phosphorus cycles. The nitrogen cycle coverts nitrogen to gas that goes into the atmosphere. The phosphorus cycle is different in that the phosphorus is taken up by vegetation that then dies and decomposes and turns into sediments.
- Chris described the various types of wetland plant communities that have been used in wetland treatment systems including floating aquatic vegetation (FAV), emergent aquatic vegetation (EAV), submerged aquatic vegetation (SAV), and periphyton. Treatment wetlands are engineered systems, although they may require a larger area and look different from conventional treatment options.
- Chris presented data from the 2007 C-43 WBSR Test Cell Water Quality Study. Water quality was measured in five-acre test cells. He presented data showing the nitrogen and phosphorus fractions. There was a net reduction of the total nitrogen (TN) concentration by 14% and total phosphorus (TP) concentration by 74%, which indicates that the reservoir itself provides some treatment.
- Chris summarized the results from the C-43 Water Quality Treatment and Testing Project Phase 1 Mesocosm Study, which was completed in July 2019. The objectives were to evaluate if the plant community type makes a difference in nutrient removal, if the soil type makes a difference, and how much water can flow through and still have nitrogen reductions. The focus of the study was on nitrogen, especially dissolved organic nitrogen (DON), which is the most abundant form in the C-43 watershed and the most difficult to remove. The final results showed that the mesocosms reduced TN by 23% on a concentration basis and 33% on a mass basis. DON was most (68%) of source water. More DON was removed in the wet season (14%) than in the dry season (4%). Dissolved inorganic nitrogen was

effectively removed at 90%. The nitrogen removal was not different based on plant community type, but more phosphorus was removed by SAV than EAV.

- Chris presented on results from the SFWMD Everglades Agricultural Area (EAA) stormwater treatment areas (STAs). The STAs were not designed or operated to remove nitrogen, but SFWMD had some monitoring data. He presented the differences in the EAA and C-43 basin water, in which the inflow TN concentrations are higher in the EAA. This is attributed to the soil type because the organic peat soils in the EAA store more organic nitrogen than the sandy soils in the C-43. There were some TN reductions with much higher TP reductions. SAV was used to help remove TP.
- Chris also presented regional filter marsh results from projects completed by the Working Group members within the Caloosahatchee watershed, which provide good examples for comparison to treatment of the reservoir. The TN inflow concentration were lower than in the EAA so a larger area for treatment or a different treatment process may be needed. The projects have a range of TN reductions from 6%-40% and TP reductions of 21%-84%.
- There was also a study by Lee County of three wet detention ponds that had TN removals in the range of 26%-50%.
- Chris presented examples of floating treatment wetlands from Lee County and Naples. There is a lot of literature about this treatment, but not many Florida-specific studies. These systems are typically small in footprint compared to the size of the waterbody, which makes it difficult to determine nutrient reductions. There is a possible interaction between the plant roots and algae in which there is something from the plant roots that controls algae, which is not well understood. The floating wetlands also shade the water column, which reduces light for algae.

Next Steps

- Kim noted that future public meetings will be held on March 25 and July 16. She reviewed the upcoming deliverables and provided a link to the Working Group website which was created to keep the public up to date on the study and to allow the public to submit via an email address on the webpage any pertinent studies missing from the studies collected to date. The webpage contains the C-43 reservoir fact Sheet and map, a copy of Governor Ron DeSantis' Executive Order 19-12, the Study Work Plan, and a link to all the studies that J-Tech will be evaluating including the DEP Technology Library. The webpage also contains the public meetings date/time/locations, PowerPoint presentations, meeting minutes, videos, and press releases. Upon their completion, the Information Collection Summary Report and the Study will also be available on the webpage.
- The Working Group webpage link is: https://www.sfwmd.gov/content/c43waterqualitystudy

Questions and Answers

- Following the presentations, the Working Group and J-Tech responded to questions and comments that were provided by the public on comment cards.

- Q: Is there any preference for natural system solutions such as natural wetlands?
- A: There is not, we are technology neutral at this point and all options are on the table. However, there will be constraints to implementing different technologies. It may be that too much land is needed for a natural system or a conventional technology produces too many residuals. The team is gathering information on technologies and will then evaluate them using a matrix. Some technology options are a combination of natural and conventional treatment.

- Q: Is there any consideration to prioritize or limit options that can alter the aquatic environment?
- A: Some technologies do include adding microbes or a chemical to the system. Right now there is no bias against those options but there will be a question moving forward about whether these are appropriate for the reservoir.

- Q: Will operations and maintenance (O&M) costs be considered?
- A: The next step will include a cost-benefit analysis of both the construction and O&M costs. O&M requirements are critical to understand because the reservoir will operation for years into the future so the treatment will also need to be long-term.

- Q: What role might aquifer storage and recovery (ASR) wells play in water quality treatment?
- A: ASR wells take surplus surface water, treat it as required for permit compliance, and then store it underground for subsequent recovery during dry periods. This technology has the potential to store and supply large volumes of water beneath a small surface footprint. This technology is on the list of options to be evaluated in the Study.

- Q: Without considering the current hydrologic limitations, what would be needed to help the nearby Orange River?
- A: There is no practicable way to move water from the reservoir to the Orange River. The Lehigh Acres Municipal Services Improvement District (LAMSID) is working on projects to treat water prior to entering tributaries that flow into the Caloosahatchee River. A pipe cannot be added to the C-43 reservoir to connect with LAMSID projects because, as noted in the discussion of Study constraints, the conceptual projects proposed by the Study cannot affect the Congressionally approved and authorized C-43 Reservoir project purpose, infrastructure, construction schedule, or operation.

- Q: Will the water quality monitoring include microcystin in the reservoir and discharge point?
- A: This will be determined as part of the reservoir operation plan that is currently being developed.

- Q: What nutrient reduction goals will the technologies be evaluated against?
- A: Per the Executive Order, the goal is to add stormwater treatment to the C-43 Reservoir to provide additional treatment and improve the quality of water leaving the reservoir. During the next phase of the Study, estimated concentrations will be determined to evaluate the treatment efficiencies of the different options. These results will be presented at a future meeting.

- Q: Is there any consideration for sediment and legacy nutrients in the nutrient budget?
- A: There will be work done to bracket the range of water quality concentrations and to what degree the sediment load may contribute and affect the system. This has not been considered in detail yet but will be as part of the next step.

- Q: The Coastal and Heartland National Estuary Partnership held a C-43 Water Quality Summit where several projects and concepts were discussed. The presentations and information are on the website. Has this information been reviewed?
- A: The information on completed projects with data on nutrient removal have been reviewed. There are more example projects that have been reviewed than what were presented today. All the evaluations will be summarized in the Information Collection Summary Report to be completed and available in mid-March. The website contains a link to all the studies currently under review. An email address on the website allows the public to submit any pertinent information not already under review.

- Q: Has the team reviewed all the statewide stormwater rule technologies?
- A: The team has reviewed the technologies in the DEP database and available reports. These likely overlap with the stormwater rule technologies.

- Q: Has the project received a DEP water quality certification and National Pollutant Discharge Elimination System (NPDES) permit?
- A: The reservoir has received a construction permit and an NPDES construction permit so erosion control BMPs are being implemented. The operation permit will be issued separately and will include the water quality certification.

- Q: Will offsite treatment projects be considered for the reservoir to meet water quality based effluent limits (WQBELs)?

- A: WQBELs are not applicable to the reservoir. These are for the EAA STAs. The water quality treatment will help to meet BMAP water quality treatment requirements.

- Q: Are there any plans for a reservoir north of Lake Okeechobee to slow and clean water before it reaches the lake?
- A: There is a plan underway for treatment north of the Lake, but this is not part of the C-43 WBSR project. Additional information is on the SFWMD website.

- Q: Would it be more cost effective to store and clean water closer to the source of major water inlets in Kissimmee than at the Caloosahatchee River?
- A: It is always better to treat at the source. There needs to be storage and treatment on all sides of the lake, which is currently being implemented by numerous CERP projects.
  It is important to note the C-43 WBSR is not just for storing water from Lake Okeechobee, but also for storing Caloosahatchee watershed runoff.

- Following the question and answer session, there was a time for open discussion between the public and the Working Group and Study consultant team members.

C-43 West Basin Storage Reservoir Water Quality Feasibility Study
Public Meeting Minutes

March 25, 2020 6:00 PM – 8:00 PM
Webinar

Meeting Welcome

Drew Bartlett, Executive Director of the South Florida Water Management District (SFWMD), welcomed everyone to the C-43 West Basin Storage Reservoir Water Quality Feasibility Study public meeting. This is the third public meeting. Drew stated that he is very proud of SFWMD staff for pulling together and holding this meeting even though we are not in person. This project is critical to the C-43 Reservoir and Caloosahatchee River. SFWMD will continue to do what is needed, which is why we are holding this meeting to provide information to the public in a timely manner so that the next steps can be taken to provide good quality and quantity of water to the river. Drew thanked the Working Group members for their work in narrowing down the options to 10 technologies to present tonight. This meeting has been set up to be as interactive as possible, and SFWMD staff are available by phone for any additional discussions.

Georgia Vince, J-Tech Project Manager, provided a welcome and introduced herself as supporting the SFWMD on this important project. She stated we are excited to bring you this virtual public meeting via Zoom technology and look forward to an interactive meeting with the participants, using this technology.

Georgia stated that there will be opportunities for a few questions at the end of each section of the presentation and asked that you keep your questions pertinent to the topic that was just presented.

If you called in only and are not on the web press *9 to raise and lower hand and *6 to mute or unmute OR - you will be able to provide feedback via our project email address which will be provided later

Georgia stated that at the end of the presentation we will be utilizing another program called “Menti” to obtain input and feedback from Zoom participants and there will be a second question and answer session at the end of the meeting where you can type in your questions regarding the information presented today.

You can access Menti from a separate internet browser window or from your smart phone and the website address and code will be provided during that section of the presentation.

Georgia explained that the C-43 Reservoir water quality study is being supported by several municipal entities within the region. The following are our working group members and introduced them:

SFWMD lead is Kim Fikoski, Project Manager
FDEP representative is Edward Smith, Director – Office of Water Policy and Ecosystem Restoration
Hendry County - Shane Parker, Public Works Director
Lee County - Roland Ottolini, Director of Natural Resources
City of Cape Coral - Maya Robert, Environmental Resources Division Manager
City of Sanibel - James Evans, Director of Natural Resources
Lehigh Acres Municipal Services Improvement District - Michael Cook, Assistant District Manager

The Consultant team leading the study efforts is J-Tech, a joint venture between Jacobs Engineering and Tetra Tech. You will be hearing from the consulting team today during the presentation including Shawn Waldeck and Jim Bays of J-Tech, and Chris Keller with Wetland Solutions Inc.

The purpose of today's meeting includes an overview of our Study goals and objectives, an update on our Information Collection Summary Report and key findings, and to obtain input for the Study.

Study Background

In January of 2019, Governor DeSantis signed an executive order for greater protection of Florida's environment and water quality. It included efforts to reduce harmful algae blooms and specific to today's topic, it included a directive to study additional WQ treatment opportunities for water leaving the C-43 West Basin Storage Reservoir.

DEP is leading many of the efforts outlined in the executive order including Harmful Algae Bloom Task Force, Blue Green Algae Task Force, Caloosahatchee Basin Management Action Plan update adopted January 2020, and Agricultural BMP assessments with the Dept of Agriculture and Consumer Services. DEP is also serving on the Working Group for THIS study and is managing the Technology Library which is accessible on their website.

The primary objective of the Study is to identify opportunities to provide additional treatment and improve water quality leaving the C-43 Reservoir. During the study we will identify and evaluate treatment technologies that may be implemented with the reservoir project, with the ultimate goal being identifying three alternatives.

The study will evaluate:

- ✓ Pre-treatment (Prior To Entering Reservoir)
- ✓ In-reservoir treatment
- ✓ Post Storage treatment
- ✓ Will Ensure the technology is cost-effective and technically feasible
- ✓ Will Use conventional and/or innovative treatment methods
- ✓ Will Consider biological, chemical and physical water quality treatment technologies
- ✓ Must be Scalable and "available" for long term operation
- ✓ MUST BE Compatible with the objectives of the C-43 Reservoir Project

The working group and consultant team have identified some constraints that we will need to keep in mind as this study moves forward.

- The identified alternatives cannot affect the congressionally approved C-43 WBSR project purposes, benefits, infrastructure, construction schedule, or operation;
- Available project lands have not been specifically identified for the Study;
- The C-43 WBSR and the selected treatment component(s) are not intended to achieve compliance with the Caloosahatchee River and Estuary Total Maximum Daily Loads (TMDLs)

The Information Collection Summary Report will be available on the project website on April 3rd, and the final public meeting will be held on July 16th. The final Feasibility Study with recommendations will be submitted in October to the SFWMD.

QUESTIONS

- Q: Could you talk about the status of the reservoir itself in terms of construction and whether there is water in it?
- A: This is a good transition to the next part of the presentation on the reservoir and its operations.

Georgia introduced Shawn Waldeck, J-Tech Construction Manager for C-43 Reservoir, to discuss some of the important details about the Reservoir.

C-43 West Basin Storage Reservoir Operations

Shawn Waldeck stated that the C-43 Reservoir is a component of the Comprehensive Everglades Restoration Plan (CERP). The project is funded by annual Florida legislative appropriations and the U.S. Army Corps of Engineers will credit eligible project costs. The purpose of the reservoir is to capture excess basin runoff and Lake Okeechobee releases to store water to improve the quantity, timing, and distribution of discharges to the Caloosahatchee Estuary. Another purpose of the project is to maintain water supply for existing users.

Shawn provided an overview of the location of the C-43 Reservoir including its location related to the C-43 River/Canal, Lake Okeechobee, Ortona and Franklin Locks, and Townsend Canal. This is a 10,500 acre project that will provide above-ground storage. Flows from the river will be directed down the Townsend Canal and into the reservoir. When the river and estuary call for it, water that is stored will be discharged through the Townsend Canal and back into the river and estuary.

The reservoir has two cells that are about equal size. Water is drawn through a large pump station into the reservoir. When discharges are needed, water is discharged from each cell to the perimeter canals into the Townsend Canal and back into the Caloosahatchee River.

The major constraints to the reservoir operations are the Lake Okeechobee operation schedule and the Caloosahatchee Minimum Flow and Level (MFL) that was established at 457 cubic feet per second (cfs). The reservoir will be filled during the wet season and discharge during the dry season to help maintain the salinity levels in the estuary. The discharges and inflows will be based on flows at the Franklin Lock.

The inflow capacity for the reservoir is 1,500 cfs, which equates to about 3 inches per day. In an emergency, the reservoir can discharge up to 2,500 cfs but normal discharges are to meet MFLs. Shawn noted that the reservoir construction contract was issued in June 2019 and the contract substantial completion date is December 2023.

QUESTIONS

- Q: Will the planned toll road have any impact or influence on this project?
- A: The footprint of the reservoir has been designated as not a viable location for the toll road so there will be no impacts.

- Q: Where is the MFL of 457 cfs measured?
- A: The flows are measured at the Franklin Lock.

- Q: What situation would be considered an emergency?
- A: The reservoir is an above ground impoundment that is surrounded by a dam. When flood conditions are approaching, water can be evacuated quickly from the reservoir to protect not only the reservoir itself but everyone around the reservoir.

- Q: How high are the finished walls and how high will the water level be?
- A: The dams will be about 35 feet above the existing ground surface. The water in the reservoir will appear to be half full even though it is full because there needs to be room in the reservoir for storm events and to contain waves in the event of a high wind event. The height of the water will be about 25 feet deep in the northwest corner and about 15–20 feet deep in the southeast corner due to elevation differences.

- Q: Are the reservoir walls just earthen dam or is there steel inside?
- A: They are earthen walls with a cutoff wall that reaches a clay layer, which makes the reservoir like a big bathtub. The clay layer is why the reservoir was sited here because it helps to reduce water loss.

- Q: Are there are going to be any criteria set before the reservoir is built for incoming water quality and for water quality in the releases into the river? If so, will these criteria be set in conjunction with the construction?
- A: This is the purpose of the Study. The authorized CERP project did not include any additional water quality requirements. The Study will identify options to improve water quality coming into the reservoir, within the reservoir, and leaving the reservoir.

- Q: Are there any federal water quality standards that would apply for the reservoir operation?
- A: There are no standards that are part of the authorized project.

Treatment Technologies: Physical, Chemical, and Biological

Jim Bays, J-Tech, stated that while the treatment focus is on nitrogen, they are also evaluating phosphorus and suspended solids (algae or suspended particles) removal. The different parameters for each nutrient require different types of treatment. Nitrogen exists in multiple forms which vary in their availability to algae, including organic Nitrogen, inorganic nitrogen including ammonia, and nitrate. Phosphorus occurs in dissolved and particulate forms which have different mechanisms of treatment.

For this project, because we face area and operational constraints, we are considering the spectrum of natural and conventional treatment systems. Natural systems utilize the same chemical and biological processes for treatment as conventional systems. Where conventional systems build tank-based treatment reactors of concrete, steel and move water and add compounds using electricity and chemicals: natural treatment systems are typically land-based systems that rely upon gravity flow and natural plant, soil and microbes to provide the media and biological habitat that sustains these processes at natural rates. As a result, fewer staff are required to operate and time in the field, maintenance and monitoring processes are reduced significantly, and fewer residuals are produced. This often means lower long-term unit operational costs per pound removed.

In the Information Collection Summary Report for this project, which will be available on April 3, 2020, we summarized the attributes of 33 technologies listed in the DEP's Library of 33 accepted water treatment technologies, which includes chemical, biological and physical methods of treatment. We also received suggestions from our Working Group members drawing from their knowledge and experience, other treatment professionals, submittals from vendors and suggestions from the public.

As we reviewed the different technologies, we described them by key attributes. These included:

- Whether Florida case studies were available, and whether the data was suitable for analysis
- Nutrient removal data and to what extent it could be used to scale up to treat large flows
- The general land area requirements and whether its features were compatible with the reservoir system and location
- If treatment residuals are produced and how they'd be managed
- What amount of energy is required?
- A schedule for implementation
- O&M requirements
- General costs for construction, O&M and cost benefit
- Regulatory constraints with the provision that the technology can't harm the environment.

Treatment Technology Highlights

Chris Keller, Wetlands Solutions, reviewed the constructed treatment wetlands technology.

Constructed Treatment Wetlands are large created marshes that are designed to naturally improve water quality. They are commonly used in South Florida and you may have heard them referred to as Stormwater Treatment Areas or Filter Marshes. They reduce nutrient concentrations by consuming nitrogen and phosphorus for growth of wetland plants and as an energy source for microbial processes.

There are many successful applications of this technology in Florida and around the world. We are fortunate to have very robust operational data sets from large-scale systems in this region. General removal efficiencies range from 20-40% for total nitrogen, 75-90% for total phosphorus, and over 90% for suspended algal solids.

Treatment wetlands generally require large land areas and therefore have correspondingly large capital costs for land acquisition and construction. However, they typically have lower O&M costs than the conventional technologies that Jim will discuss. Most of the annual costs are associated with supplying electricity to operate the pump stations needed to route water to and from the wetlands.

Treatment wetlands accrete residuals in the form of new sediments which are made up of decomposing vegetative matter. The accretion rate is low and treatment wetlands typically have design lives of 30-50 years. Treatment wetlands can be used to treat water either before or after storage in the reservoir.

Sand Filtration involves the gravity separation of particles (such as algae and suspended solids) from the water by forcing water to drain through a bed of sand or similarly sized media. Sand Filtration is considered a passive or natural technology because, other than pumping, it does not require energy or chemical inputs. There are several applications of this technology in Florida with the largest currently under construction for a phosphate mining facility. General removal efficiencies range from 20-40% for total nitrogen, 25-50% for total phosphorus, and over 90% for suspended algal solids.

Like treatment wetlands, Sand Filtration generally requires a large land area and therefore is likely to have a correspondingly large capital cost for land acquisition and construction. Again, they typically have lower O&M costs than most conventional technologies. O&M costs for Sand Filtration include pumping and periodic replacement of the upper sand layer every 3-5 years. Sand Filtration can be used to treat water either before or after storage in the reservoir.

Aeration can be used to reduce algal populations through physical mixing and supplying dissolved oxygen to reduce stratification and minimize the release of nutrients from anaerobic sediments. There are several applications of aeration in lakes and reservoirs in Florida. Removal efficiencies range from 50-75% for total nitrogen and total phosphorus.

Because aeration is employed within the water storage reservoir, little additional land is needed for the blowers and controls. Aeration does not create any residuals that will require removal and disposal. Aeration has moderate capital and O&M costs with most of the O&M cost associated with electricity to run the blowers. O&M includes annual compressor and diffuser maintenance. This technology is applicable within the storage reservoir.

Hybrid Wetland Treatment Technology combines physical-chemical processes of coagulation with the natural settling and uptake processes that occur in treatment wetlands. A coagulant, such as alum, is dosed to bond with nutrient ions and form particles that can settle out in the wetland basins. There are several successful applications of this technology in Florida, mostly within the Northern Lake Okeechobee watershed. These are well-studied systems with robust operational data. Removal efficiencies range from 50-60% for total nitrogen, 80-90% for total phosphorus, and over 90% for suspended algal solids.

Because they are enhanced or intensified by adding chemicals, they require a reduced land area and reduced capital costs in comparison to constructed treatment wetlands. The requirement for chemical addition, however, increases their O&M costs in comparison to treatment wetlands. They do generate solids that require periodic removal and disposal. Hybrid wetlands can be used to treat water either before or after storage in the reservoir.

Coagulation treatments would require a more dedicated system to pull water offline for treatment. There are multiple applications in Florida that are well studied and built for fairly large flows. The removal efficiencies range from 50%–70% for TN, 50%–90% for TP, and greater than 90% for algae. These chemical processes react quickly so there is not much land needed for treatment, but land is needed for settling out solids and storing solids before disposal. There are O&M costs for power for the pumps and dosing mechanisms and to remove the residuals. This technology can be used for pre- or post-reservoir treatment, as well as in-reservoir to settle out nutrients.

MPC Buoys are an innovative approach to treating water during storage by the use of ultrasound emitted at wavelengths in the water that will disrupt the natural buoyancy of algal cells and prevent them from staying in the well-lit upper surface layers. This affects their growth and keeps algae from growing to bloom levels. For this product, the vendor has invented a floating buoy which supports the ultrasonic emitter that is solar powered. There are a limited number of case studies from the US, and much more from Europe. Case studies are just beginning in Florida.

Available data do indicate that a significant reduction of algae may be expected. Some data also indicate that other aquatic organisms may be affected by the ultrasound. A beneficial attribute of this technology is there is not additional area needed, since it is on the reservoir surface, there are no residual produced and capital costs limited to the buoy system, anchoring and supporting electronics. Operations are moderate, focusing on annual maintenance of the transducer and buoy. This approach treats the water during storage.

Electro-coagulation is another form of coagulant addition for nutrient control. The working principle is basically the same, where the charge of a particle is modified by addition of a metal ion to the solution, which allows particles to grow and settle. In this case, instead of a metal salt like alum, an electrical charge is added to the water through a metal electrode and the metal ions are released from metal plates. The system typically includes a sedimentation tank for collecting the coagulated solids.

There are few Florida case studies mostly consisting of pilot and bench scale tests, and there are limited performance data, but the technology has been in wide use across the world for decades for treatment of industrial wastewater. Available pertinent data indicate removals of 60-90% nitrogen, more than 90% phosphorus and 90% algae can be expected. Of all the offline treatment technologies we're discussing, this system will likely require the least land area, given the rapid treatment time (on the order of a few minutes) and the relatively smaller amount of solids produced.

Capital cost is relatively high, given the highly engineered flow, treatment, and solids handling facilities needed. O&M costs will be relatively high, given the higher electricity requirement, electrode replacement, pumps, chemical dosing, and air injection. The amount of residuals produced is less than what can be expected from the use of chemical coagulants, given that the only solid added is just the metal ion from the electrodes. This technology would be considered for pre- and post-storage .

A more passive treatment technology is the use of a phosphorus sorption media, where nutrients are bound chemically to surfaces of substrates such as sand, clay, or organic materials selected for their property. In Florida, an increasingly common application is the use of **Bold & Gold**, an engineered sorption media developed at UCF for stormwater and surface water applications. This material comes in a range of formulations, which can include sand, clays, iron and tire crumbs, all of which exhibit phosphorus sorption potential. There are a number of applications in Florida, and a number of publications and performance studies have been completed.

Nitrogen removal is typically high (on the order of 75-95%) and phosphorus is too (50-90%). Because of the high flow rates that the media can take, land area requirements are moderate and capital costs are too. Typically, these systems are built in vaults or shallow detention basins, but they may also be built into the berm of a basin and provide final polishing to water infiltrating from the basin. O&M costs are relatively high, given the cost of replacing and disposing of spent media, although on a relatively long interval. This technology could be applicable to pre and a post storage application

Nutrigone Biologically Activated Media (or BAM) product is a phosphorus sorption media combined with an organic carbon media designed to remove phosphorus and nitrogen when water is passed through it. Typically, it is designed as a flow-through filtration vault but can be designed as large basins. There are limited applications in Florida at this time. Available bench-scale studies indicate 90% removal of nitrogen and phosphorus but performance data are limited and varied. Because it is a filtration system with sorption media, this technology would require a moderate land area. The capital cost would be high because of the engineered media and O&M cost would be high because of the need to replace media frequently. The volume of spent media needing to be disposed of would be significant. But power costs would be limited to pumping requirements. This approach would be applicable to pre-storage and post-storage operational phases.

Aqua-Lutions is a combination of chemical addition to coagulate algal solids followed by dissolved air flotation to separate solids. The product is clear water with low nutrients. Several pilot studies have been conducted in Florida, the most notable being a 5-year study treating water from Lake Jesup in north-central Florida. Available data from that project and tests by the District have provided reliable performance data. Nutrient reductions of 65% total nitrogen, 90% phosphorus and 80% algae were achieved in that study. The treatment system operates within a relatively compact footprint. The capital and O&M costs are high, given the chemical and mechanical components.

As with other solid separation techniques, a large volume of solids is produced that must be dried and disposed of. In lieu of landfilling, because the residuals do contain nutrients, the vendor promotes their use for fertilizer pellets but they can be burned too. Another factor to consider is the power cost to operate the mechanical components, including pumps, air compressors, and solids management systems. This technology would be potentially suitable for pre and post-storage.

QUESTIONS

- Q: My question is about disposal of the material.

- A: This is a factor we are considering. Sometimes residuals can be reused as a land amendment or they may need to be disposed of in a landfill or burned. Residual disposal will be assessed further in the next phase of the project.

- Q: How long do you think it will take to get from the qualitative criteria to more detailed costs?
- A: We are going to get to that phase very soon. A preliminary assessment will be ready in June and the final report will be available in October 2020.

- Q: How many acres would be required for an STA?
- A: We will be going into the next phase of the project in the next few weeks where we develop standard inflows and datasets to further develop each alternatives to provide a fair basis of comparison. It will be this next phase where we will determine the size of an STA needed to provide treatment.

- Q: Why are we doing this now instead of before construction began? Some of the options presented would be have been easier to implement before construction like the media that could have been put into the berm.
- A: In the CERP project, this reservoir did not evaluate water quality. It became apparent in recent years that algal blooms are a problem in the river and estuary. At that time, the CERP project was already underway and did not include a water quality component and it just focused on quantity, timing, and distribution of water. Based on recent water quality information, the decision was made to address water quality outside of the federal program.

- Q: I would like to echo the thanks to SFWMD and DEP for moving forward with a water quality project on the reservoir. In evaluating the cost-benefit of these treatment options can you speak to the scalability of a treatment train approach.
- A: Our approach is to look at each technology individually to make comparison. These technologies can be combined and there may be a combination that is selected as a final configuration.

- Q: The three alternatives that you will identify will be three separate technologies and not three options that include a combination?
- A: We will have three technologies or projects that we recommend based on a series of criteria. The SFWMD will then move forward to the design phase to provide the necessary water quality treatment

- Q: Have you determined the fate of alum in the environmental from the HWTT?
- A: We are relying on literature prepared by existing studies of this technology. Floc is created and must be removed periodically. There have not been any findings of toxicity concerns in Florida or nationally. The U.S. Environmental Protection Agency released a new aluminum toxicity standard that we will consider.

Next Steps

Georgia Vince highlighted the upcoming milestones for the project. We look forward to all of you participating again at our July 16th meeting at 2pm.

Georgia Vince reviewed frequently asked questions that were discussed at previous meetings or sent to the project email address.

Georgia Vince directed participants to SFWMD.gov for the working groups webpage and project specific email address where additional comments and questions can be submitted. The email address will be active throughout the study period and it is C43waterquality@sfwmd.gov

Georgia Vince thanked the **Coastal and Heartland National Estuary Partnership** for allowing use of their Menti program. This is a unique interactive tool was used to collect input and feedback from the participants.

Menti Polling and Questions
Participants were asked to provide feedback on the Menti website. The participants can have the results emailed to them and the results will also be posted to the project website.
Please type in any questions you have related to the C-43 Storage Reservoir Project.

- Q: Will the operational plan allow recycling of water within the reservoir?
- A: Right now the reservoir allows flows in from one cell to another. Within the reservoir, the only option is to add aeration to help move water through the system.

- Q: Are there any ways that storage benefits can be increased by multiple fillings?
- A: The operation plan is to fill the reservoir once in the wet season and discharge once in the dry season. Evaluations will be made whether the reservoir is able to take in more water or let more out.

- Q: Now that you are aware of the water quality issue, could a filter marsh be constructed within part of the reservoir footprint?
- A: No. The reservoir must be constructed as authorized by Congress to receive the cost-share funding. Any filter marshes will have to be outside of the reservoir footprint.

- Q: How does the C-43 reservoir volume of water needed to be treated compare to the treatment options presented?
- A: The normal low water discharges will be in 457 cfs range. Any treatment would have to be sized to accommodate that flow to meet the demands of the river and estuary.

- Georgia noted that all questions submitted through Menti will be captured and will be responded to on website.

Please type in any question you have related to the technologies that are being evaluated for the Study.

- Q: Could you list the 10 one more time?
- A: Constructed treatment wetlands, sand filtration, aeration, HWTT, coagulation, ElectroCoagulation, MPC-Buoy, Bold & Gold, Nutrigone BAM, and Aqua-Lutions.

- Q: Is there more detail on the technologies on the website?
- A: Yes. The Information Collection Summary Report includes more details on the technology and information available in the literature and provided by vendors. This report will be available on April 3rd and the literature library is currently on the website.

- Q: What happens if the chosen technology stops doing what it says it will?
- A: We only want to present and select a short list of technologies that are robust and based on sound principles. When we get to final list, it will have a presumption of long-term application for this large-scale project. In the unlikely scenario that the technology does not operate as planned, contingencies will be built into the project.

- Q: Have you considered the use of floating treatment wetlands in the reservoir?
- A: Floating treatment wetlands were on the original list but did not make the shortlist because of the size of the reservoir and wind conditions. This technology would require a robust anchoring under these conditions, which would make it difficult to implement and would have greater uncertainty in the effectiveness. There are opportunities to look at floating wetlands as part of a constructed wetlands system or HWTT to provide polishing.

- Q: As nutrients are removed, will there be a discussion of how the chosen treatment might perform? For example, at 100 parts per billion (ppb) TP, you might remove 70% but will that removal be expected at 20 ppb?
- A: In the next phase of the Study, we will look at flows and nutrient concentrations coming into the reservoir, within the reservoir, and coming out of the reservoir to evaluate how the technologies perform under a range of concentrations. Some of the technologies could drop out because the nutrient concentrations are lower than what was found in previous studies.

Please types in any additional questions you may have about the Study.

- Q: Will the slides from this presentation be available online?
- A: Yes. The slides and the Menti questions and responses will be posted to the website.

- Q: How will this study tie into the CERP Plan?
- A: This is a separate study being pursued by SFWMD and FDEP.

- Q: Is there a possible use of aquifer storage and recovery (ASR) for nutrient reduction?
- A: We drilled some pilot wells for the CERP ASR Program to be co-located with the reservoir. Based on those data, ASR is not a good application in this location

- Q: When will it be published online?
- A: All items related to the Study are posted on the SFWMD Working Group website under priority projects. The Information Collection Summary Report will be posted on April 3rd.

- Q: When is the next public meeting?
- A: The next meeting is July 16th at 2:00 pm.

Meeting Close

Drew Bartlett thanked the team and the participants for a successful meeting. Georgia Vince thanked the attendees for their participation in our virtual public meeting on the C-43 Reservoir Feasibility Study.

C-43 West Basin Storage Reservoir Water Quality Feasibility Study
Public Meeting Minutes

July 16, 2020 2:00 PM – 4:00 PM
Webinar

Meeting Welcome

- Jennifer Reynolds, Director of Ecosystem Restoration and Capital Projects with the South Florida Water Management District (SFWMD), welcomed everyone to the C-43 West Basin Storage Reservoir Water Quality Feasibility Study (Study) public webinar. This Study is one of Governor DeSantis' key priority projects that he announced in his January 2019 Executive Order, which ensured protection of Florida's water quality. She stated that we kicked off this project on July 3, 2019. Today is the fourth public meeting. The three previous public meetings were held in September 2019, January 2020, and March 2020. The March 2020 public meeting was the first meeting SFWMD held via Zoom technology. She thanked the public for working with the SFWMD to use new technology and for participating in this project, and she thanked the Working Group members for their dedication and collaboration on the project. She stated that today is the final public meeting to present findings from the Preliminary Draft Feasibility Study. The project is due in October 2020, and the next public meeting will be held on November 5th to present the findings of the Final Feasibility Study and an update on the second phase of the project.
- Georgia Vince, J-Tech, welcomed everyone to the fourth public meeting, the second using Zoom technology. She provided information on how to ask questions throughout the presentation using Zoom. She also explained that Menti, a live polling program, will be used at the end of the presentation to obtain input from Zoom participants.
- Georgia covered the meeting goals and objectives. The focus of today's meeting is on the Preliminary Draft Feasibility Study that was completed on June 18th and to review the criteria evaluation and cost benefit analysis that was performed to identify the recommended alternatives.
- Georgia introduced the Working Group members from SFWMD, Florida Department of Environmental Protection (DEP), Hendry County, Lee County, City of Cape Coral, City of Sanibel, and Lehigh Acres Municipal Services Improvement District. Georgia also introduced the J-Tech consultant team members from Jacobs Engineering, Tetra Tech, and Wetland Solutions.

Study Background

- In January 2019, Governor DeSantis signed an Executive Order to provide greater protection for Florida's environment and water quality. This order included this C-43 West Basin Storage Reservoir Water Quality Feasibility Study.
- Georgia noted that the primary objective for this Study is to identify opportunities to provide additional treatment and improve water quality leaving the C-43 West Basin Storage Reservoir (WBSR). The study will evaluate pre-treatment, in-reservoir treatment, and post storage treatment options. These options must be cost-effective, technically feasible, scalable, and compatible with the objectives of the C-43 WBSR.
- Georgia reviewed the Study constraints including that the Study cannot affect the congressionally approved C-43 WBSR project purposes, infrastructure, construction schedule, or operation. In addition, project lands have not been specifically identified for the Study. This evaluation will be done during the next phase of the project.
- Georgia stated that that the C-43 WBSR and the selected treatment component(s) are not identified to achieve compliance with the Caloosahatchee River and Estuary Total Maximum Daily Loads (TMDLS). Instead they are to improve water quality of flows returned back to the Caloosahatchee River.
- Georgia presented the project schedule. The project began in July 2019, and the Information Collection and Summary Report was completed in April 2020. The Preliminary Draft Feasibility Study was recently completed, and it will be discussed today in detail.
- Georgia stated that the C-43 WBSR is a component of the Comprehensive Everglades Restoration Plan (CERP). The project is funded by annual Florida legislative appropriations, and the U.S. Army Corps of Engineers will credit eligible project costs. The reservoir is currently under construction with a completion target of December 2023.
- The purpose of the C-43 WBSR is capture excess basin runoff and Lake Okeechobee releases to store water to improve the quantity, timing, and distribution of discharges to the Caloosahatchee Estuary. Another purpose of the project is to maintain water supply for existing users.
- Georgia provided an overview of the location of the C-43 WBSR including its location related to the C-43 Canal, Lake Okeechobee, Ortona and Franklin Locks, and Townsend Canal. This is a 10,500-acre project that will provide above-ground storage.
- Flows from the river will be directed down the Townsend Canal and into the reservoir. When the river and estuary call for it, water that is stored will be discharged through the Townsend Canal and back into the river and estuary.

Water Quality Treatment Technologies

- Marcy Frick, J-Tech, provided details about the treatment technologies the consultant team studied for the project. The search for the appropriate treatment technologies focused on three primary water quality parameters including nitrogen, phosphorus, and total suspended solids (TSS). Nitrogen and phosphorus are nutrients that drive algae growth, and TSS include algae and organic matter. Nitrogen exists in multiple forms, which vary in their availability to algae, including organic nitrogen and inorganic nitrogen that includes ammonia and nitrate. Phosphorus occurs in dissolved and particulate forms, which have different mechanisms of treatment.
- Marcy stated that this project faces area and operational constraints, so the consultant team considered the spectrum of natural and conventional treatment systems for pre-treatment, in-reservoir treatment, or post-treatment. Natural systems use the same chemical and biological processes for treatment as conventional systems. Conventional systems build tank-based treatment reactors of concrete and steel and move water and compounds using electricity and chemicals, while natural systems are typically land-based and rely upon gravity flow and natural plant, soil, and microbes to provide the media and biological habitat that sustain these processes at natural rates. As a result, fewer staff are required to operate, and maintenance and monitoring processes are significantly reduced. Fewer residuals are also produced, so this often means lower long-term unit operational costs per pound of nutrient removed for natural systems.
- Marcy mentioned that the Information Collection Summary Report for this project was available on April 3rd. The consultant team summarized the attributes of 38 chemical, physical, and biological technologies. These technologies were from the DEP Technology Library, Working Group member experience, case studies, vendor submittals, and public input from past public meetings. As part of the Information Collection Summary Report, the consultant team eliminated 13 technologies from further evaluation that were not applicable to the C-43 WBSR and/or did not have enough information available for the study. The remaining 25 technologies were carried over for further evaluation in the Preliminary Draft Feasibility Study.
- Marcy reviewed the key attributes that were used to describe the different technologies. These included whether Florida case studies were available and whether data were suitable for analysis, nutrient removal data and the extent it could be used to scale up to treat large flows associated with the reservoir, general land requirements and whether its features were compatible with the reservoir system and location, if treatment residuals are produced and how they can be managed, energy requirements, implementation schedule, operations and maintenance (O&M) requirements, general costs (construction, O&M, and cost benefit), and regulatory constraints with the provision that the technology cannot harm the environment.

- Chris Keller, Wetland Solutions, covered four of the top 10 technologies that were evaluated further. The first, constructed treatment wetlands, are large created marshes designed to naturally improve water quality. They are commonly used in south Florida, and they may be referred to as Stormwater Treatment Areas (STAs in south Florida) or filter marshes (for regional projects). These wetlands reduce nutrient concentrations by consuming nitrogen and phosphorus for the growth of wetland plants and as an energy source for microbial processes and communities that live in the wetlands. Many successful applications of this technology exist in Florida and around the world. We have very robust operational data sets from large-scale systems in this region (south Florida). The general removal efficiencies range from 20–40% for total nitrogen (TN), 75–90% for total phosphorus (TP), and over 90% for suspended algal solids. Constraints for this technology are that treatment wetlands generally require large land areas and have correspondingly large capital costs for land acquisition and construction, but they typically have lower O&M costs than the conventional technologies. Most of the annual costs are associated with supplying electricity to operate the pump stations needed to route water to and from the wetlands. Treatment wetlands accrete residuals in the form of new sediments, which are made up of decomposing vegetative matter. The accretion rate is low, and treatment wetlands typically have design lives of 30–50 years. They can be used to treat water either before or after it is discharged from the reservoir.
- The second technology Chris discussed was sand filtration, which involves the gravity separation of particles, such as algae and suspended solids, from the water by forcing water to drain through a bed of sand or similarly sized media. Sand filtration is a passive or natural technology because, other than pumping to deliver water to the system, it does not require energy or chemical inputs. Several applications of this technology exist in Florida with the largest currently under construction for a phosphate mining facility in central Florida. General removal efficiencies range from 20–40% for TN, 25–50% for TP, and over 90% for suspended algal solids. Like treatment wetlands, sand filtration generally requires a large land area and is likely to have large capital costs for land acquisition and construction. It typically has lower O&M costs than most conventional technologies. O&M costs include pumping and periodic replacement of the upper sand layer every 3–5 years. Sand filtration can be used before or after water storage in the reservoir.
- Chris discussed aeration (air diffusion systems), the third technology. Aeration can be used to reduce algal populations through physical mixing and supplying dissolved oxygen to reduce stratification and minimize the release of nutrients from anaerobic sediments. Several applications of aeration in lakes and reservoirs exist in Florida. Removal efficiencies range from 50–75% for TN and TP. Because aeration is employed within the water storage reservoir, little additional land is needed for the

blowers and controls. Aeration does not create any residuals, and it has moderate capital and O&M costs. Most of the O&M cost is associated with electricity to run the blowers. O&M includes annual compressor and diffuser maintenance. This technology is applicable within the storage reservoir.

- The fourth technology Chris covered was hybrid wetland treatment technology (HWTT). This technology combines physico-chemical processes of coagulation with the natural settling and polishing processes that occur in treatment wetlands. A coagulant, such as alum, is dosed to bond with nutrient ions and forms particles that can settle out in the wetland basins. HWTT has been used in various places in Florida though most applications have taken place in the northern Lake Okeechobee Watershed. Robust operational data are available. HWTT can be easily scaled up for use in this situation. Removal efficiencies range from 50–60% for TN, 80–90% for TP, and over 90% for suspended algal solids. Because they are enhanced or intensified by adding chemicals, they require reduced land area and capital costs in comparison to constructed treatment wetlands. O&M costs are higher compared to treatment wetlands because HWTT systems require chemical addition. HWTTs do generate solids that require periodic removal and disposal, and they can be used to treat water either before or after storage in the reservoir.
- Jim Bays, J-Tech, discussed the remaining six of the top 10 technologies. Coagulant treatment (alum) is used to coagulate nutrients by particle charge neutralization and solids sedimentation in offline lagoons or potentially within a reservoir. This approach has a long, successful history in Florida and is well-studied with ample performance data, such as the Nutrient Reduction Facility in Lake County. Removal rates for nitrogen range between 50–70% and for phosphorus between 50–90%. Over 90% algal solids removal occurs. The land area requirement is relatively small and consists primarily of settling basins, chemical storage, and solids dewatering and drying facilities. The O&M cost is moderate to high, given the continuous need for chemicals. The removed floc requires dewatering and storage, which is the largest open concern over the long term. Power is required for pumps, dosing and mixing.
- Jim described MPC-Buoy, which is a new and innovative technology. It would be considered an “in-reservoir” treatment approach. It is a solar powered and remotely programmed ultrasonic emitter that reduces algal populations through sonic interference with cell flotation. It may impact zooplankton. It keeps algae in deeper water and minimizes their productivity. No case studies exist in Florida yet, but a significant research project is currently underway by the Florida Gulf Coast University. Limited performance data exist in the United States as most data come from Europe. The system has shown up to 90% removal of algae, and it would not require additional land area or produce residuals. The cost would be the lowest of all technologies, and maintenance would be moderate.
- Jim explained that ElectroCoagulation is another technology that was reviewed by the consulting team. It is the coagulation of nutrients by electrode particle charge

neutralization and solids sedimentation. The system is relatively new to Florida with limited Florida case studies. Studies have shown that this approach consistently has high removal of nitrogen, phosphorus, and algal solids. The system would be relatively compact with a small land area requirement but would have high capital and O&M costs. One benefit of this approach is that it produces less residuals compared to alum treatment, but it still generates solids that require disposal. Power requirements are high to operate the system, pumps, and air diffusers.

- Jim described Bold & Gold, which is a sorption media developed by the University of Central Florida, that uses a mix of sand, tire crumbs, and clay particles to sorb and filter nutrients in engineered basins. Over 200 applications exist in Florida, and performance data indicate potential TN removal of 75–90% and TP removal of 50–90%. The media beds are relatively small and require a moderate area. The spent media must be replaced periodically. O&M costs are relatively high because of the replacement costs, but other operational needs are minimal. This technology can be used to treat water either being discharged or prior to entering the reservoir.
- Another technology that the consulting team reviewed was Nutrigone Bioabsorptive Media (BAM). Jim mentioned that it combines the sorption of phosphorus and denitrification of nitrogen using natural media in engineered filtration beds. This technology is relatively new with limited Florida applications and performance data. The available data set indicates 90% TN and >90% TP removal. A moderate land area is required, and the system would have high capital and O&M costs. The latter is because the spent media must be replaced often (possibly every 1.5 years). Residuals must be disposed of and can be used for soil amendments.
- The final technology in the top 10 was Aqua-Lutions. Jim stated that it is a proprietary technology that combines coagulation of algae and particulate organic matter via chemical addition with dissolved air flotation using micro bubbles for solids separation. Several pilot studies were completed in Florida, and available performance data indicate removals of 65% TN, 90% TP, and 80% algae. It is a relatively compact facility, with high capital and O&M costs. Residuals are produced, but the vendor proposes to convert the algal solids to fertilizer pellets. This technology could be used for pre- and post-storage treatment.

First Round of Questions

- Georgia read through the list of questions received.

- Q: Where can I find studies on aluminum toxicity, or studies related to the HWTT, to the flora and fauna at the discharge site?
- A: (Jim Bays, J-Tech) This has been a common and frequent topic as alum technology has been implemented over the last 30 years. Studies by Harvey Harper from projects in central Florida are cited in our report and are available on the SFWMD project website. The HWTT technology also has reports summarized from

Watershed Technologies as they have implemented this technology for SFWMD over the last several years. Additional details are posted on the C-43 WBSR WQFS project website, and the link will be provided at the end of the presentation.

- Q: I remember in the first meeting an alternative was discussed where some type of absorption media was built into the walls of the reservoir itself. Did I miss that today or was it dropped from consideration?
- A: (Shawn Waldeck, J-Tech) We have to dismiss any alternatives that result in a reconfiguration of the authorized project for the reservoir. Therefore, this option had to be dropped from consideration.

- Q: If using a technology that provides reusable fertilizer, what would be the costs to produce the fertilizer and can the sales be used to offset bulk of costs?
- A: (Jim Bays, J-Tech) The vendor that developed this approach does have a partner for the management of residuals that would make residuals into fertilizer. This would offset the costs depending on the availability to use the solids as fertilizer, and this information is summarized in the report. It does help to defray some of the costs although there are significant capital costs with this technology.

- Q: Bill Mitsch from Florida Gulf Coast University has described a process he calls "wetaculture." It involves working with farmers to create incentives for "soaking" fields (using portions of property) as wetlands. Is this similar to the hybrid you described?
- A: (Chris Keller, WSI) The wetaculture concept is one that takes a land area and has it cycle over the years between some type of crop rotation and flooding fields to allow those lands to become wetlands. This approach uses internal recycling where nutrients are trapped in the sediments in the system by the wetlands so that crops can use the nutrients instead of applying additional fertilizer. This is not the same technology as the HWTT. HWTT combines alum treatment with wetland polishing.

- Q: Most of these systems have a residual. The last one proposes turning it into fertilizer. What is done with the residual on the other systems?
- A: (Jim Bays, J-Tech) This is the crux with using a chemical coagulant because it accumulates over time and does not disintegrate. Other facilities, like the NuRF in Lake County, have managed residuals for years. They have used it for soil amendments and soil addition in restoration projects. The material has also been proposed for use as a wetland subgrade for constructed wetlands since it has the ability to absorb phosphorus over time. Accumulated residuals will either be placed in a landfill or used as mentioned above. Generally speaking, the residuals are stockpiled and placed in landfills.

- Q: Why has the reservoir been exempted from meeting TMDL or Basin Management Action Plan (BMAP) requirements?

- A: (Marcy Frick, J-Tech) The purpose of the Study is to identify treatment for the reservoir and will not achieve reduction to meet the entire TMDL. The Study goal is to treat the water to ensure the quality is as good if not better than what is going into the reservoir to help improve water quality for the river and estuary downstream.

- Q: Do you have an acreage for the treatment marsh (STA) if that is the selected alternative?
- A: (Georgia Vince, J-Tech) An approximately 5,000-acre (ac) STA would be needed, and details on this will be discussed later in the presentation.

Water Quality Treatment Technologies, continued

- Chris discussed the technology criteria and ranking. He stated that obvious ranking criteria include cost and nutrient removal performance, and the Working Group suggested that the consultant team also include other attributes in the ranking methodology. With the help of the Working Group, the consultant team identified 10 additional attributes that were weighted and ranked for each of the top 10 technologies. He discussed the attributes and their weighting factors. Attributes that are more important to the success of the project were given a greater weight. The highest weight, which indicates the most important attribute, is a "5." The lowest weight, which indicates the least important attribute, is a "1." The most important (highest weighted) attributes were those related to the use of the technology at a similar scale to that required for the C-43 Reservoir and the team's confidence in the performance estimates provided by the vendors. Other attributes considered habitat value, land requirements, energy efficiency, and the complexity of routine O&M activities.
- Chris reviewed the scores for each attribute and for each technology, based on consensus of the Working Group and consultant team. Individual scores ranged from 0–2 with guidance for the scoring shown at the bottom of the slide. For example, scalability received a "2" if it had already been demonstrated at an adequate scale, but a score of "0" was assigned if it had not been demonstrated at an adequate scale. Total scores were weighted, summed, and then ranked from high to low. The highest score for the 10 technologies was given the top rank. Treatment wetlands scored a "54," which was the highest score. Alum treatment and HWTT tied for second place with a score of "35."
- Chris explained that the consultant team developed a consistent design criteria, so technologies could be sized, priced, and compared in the same way. The inflow and outflow water quality concentration goals were based on a review of historical water quality data in the C-43 and removal goals for each nutrient of concern.

These goals were to reduce TN from 1.5 to 1.0 milligrams per liter (mg/L), TP from 0.16 to 0.08 mg/L, and TSS from 20 to 10 mg/L. These were based on a flow of 457 cubic feet per second (cfs), which is equivalent to the Minimum Flow and Level (MFL) at S-79.

- Chris stated that each technology was sized to meet the minimum design criteria, and total masses removed over a 20-year planning period were combined with 20-year net present value (NPV) capital and O&M costs (excluding land and conveyance infrastructure) to develop cost-effectiveness values for TN, TP, and TSS. The lowest cost per pound received a score of “1,” and the highest cost per pound received a “10.” The other technologies were scaled in between.
- Chris showed a sector plot with each technology scored based on the attribute ranking and the TN cost-effectiveness ranking. The consultant team chose TN because it is the nutrient of primary concern in the C-43 Basin. Treatment wetlands had an attribute ranking of “1,” and they scored around a “3” for cost effectiveness. HWTT and alum treatment ranked “2.” He mentioned that the most cost-effective alternatives with the best attribute rankings were those found in the lower left corner of the sector plot. As one moves to the right on the plot, these technologies have higher dollar per pound N removal or cost effectiveness, so the consultant team used this plot to select technologies to move forward with.
- Per Chris, the consultant team looked to develop a short list of stand-alone or combined technologies that would provide the highest benefits. The Working Group was particularly interested in technologies that could be combined in series or in parallel. Series configuration is used when each technology provides treatment for a different parameter or when the lead technology transforms parameters into a form that is easily removed by the second technology. For example, technology one may be excellent at removing TN, while technology two is excellent at removing TP. Combining these technologies into a treatment train would provide adequate treatment for both nutrients. Parallel configurations are used more for low flows and peak flows.
- Chris stated that the consultant team looked at the compatibility of different technologies. Details and information on this evaluation are found in the Preliminary Draft Feasibility Report. He showed a table that ranked the compatibility of these technologies. For example, a treatment wetland could be followed by sand filtration or Bold and Gold. The ElectroCoagulation data reviewed by the consultant team indicated that it reduces all nutrients of concern in a relatively compact footprint, so no real benefit would be gained by combining it with other technologies.
- Jim stated that from the ranking criteria analysis, it was determined that STAs, alum, and HWTT technologies are the highest ranked technologies. However, the team considered other combinations of technologies such as the use of a treatment

wetland to treat a portion of the flow, and a Bold & Gold treatment bed to treat the remainder. Conceptually, this combination was sized as a 1,000-ac STA, which would treat 20% of the target flow, and 104 ac for Bold & Gold to treat the remainder. A sand filter was also considered as a replacement for the treatment wetland, which was estimated to be 200 ac, coupled with 104-ac Bold & Gold treatment. Finally, ElectroCoagulation was considered given its high removal capabilities.

- The consultant team calculated the cost benefit to estimate the total costs including the construction costs for treatment facility and water conveyance infrastructure and the annualized O&M costs for a 20-year period. The benefits of the systems would be estimated by their cumulative mass removal of nitrogen, phosphorus, and solids and then dividing that amount into the total for the 20-year period.
- Jim showed a table with the capital cost, annual O&M, and the NPV of the infrastructure cost (typically in millions). Capital costs ranged from $42 for alum treatment to $164 million for ElectroCoagulation. For operational costs, wetlands and sand filtration had the lowest O&M costs of $2–$3 million, and HWTTs ranged from $8–$9 million. Conveyance infrastructure cost was also included for pump stations, conveyance channels, and access roads to support the technologies. Capital and O&M costs were summed over a 20-year period and annualized. The NPV costs ranged from $109 million for alum treatment to $245 million for ElectroCoagulation treatment.
- Jim showed a comparison of the six alternatives compared by area, flow, and 20-year net present worth unit removal cost. The largest area requirement was for a full-scale STA at 5,000 ac, and the smallest area requirement was for alum treatment (50 ac). Electrocoagulation required 150 acres. Treated flows ranged from an average of 457 cfs for the STA, alum, and HWTT down to 325 cfs for the Bold &Gold alternative. The lowest treated flows were 229 cfs associated with ElectroCoagulation. These findings are because the technologies showed greater removal rates than those specified by the consultant team, and they would treat a commensurately smaller flow that would then be blended with bypass flow. TN ranged from $16/pound removed for alum treatment to $37/pound removed for ElectroCoagulation. TP ranged from $102/pound removed for alum treatment up to $231/pound removed for ElectroCoagulation. These figures were consistent with other studies and findings.
- Jim stated that based on these analyses, alum treatment was ranked first followed by HWTT, the combination of a treatment wetland with Bold & Gold, and the combination of sand filtration with Bold & Gold. This set of alternatives represents technologies with a proven track record, such as alum treatment and treatment

wetlands, but it is supplemented with relatively new technologies, such as HWTT and Bold & Gold.

Next Steps

- Georgia noted that the team is continuing to finalize the feasibility study, and the draft will available August 14th. The Final Water Quality Feasibility Study will be completed on October 16th. A final presentation on the Study results will be given at a public meeting held on November 5th.
- She reminded meeting attendees to visit www.SFWMD.gov for the Working Group's webpage and project information. Additional questions and comments can be submitted to C43waterquality@sfwmd.gov during the remainder of the study period.
- She then asked for questions on the criteria ranking and cost benefit analysis.

Second Round of Questions

- Q: How come STAs received a zero for land requirements? Does zero means that it requires land?
- A: (Written Response) Zero means it requires a high amount of land, so it received the lowest score for land requirements.

- Q: Do you have a written update to the September 2019 report? A draft report before the expected December 2020 final?
- A: (Written Response) The Information Collection Summary Report was finalized in early April, and it is posted to the project website. The Draft Feasibility Study will be ready in about one month for public review before the Study is finalized.

- Q: The difference in score from the second and third place (tie) and fourth place technology is one point. Is there enough sensitivity in the scoring to differentiate in the score and ranking?
- A: (Georgia Vince and Jim Bays, J-Tech) We did do a sensitivity analysis, which is part of the report, where we varied the highest ranked criteria. This analysis did not show a differentiation in the top four technologies. The combination of weights did not have an effect on where technologies were ranked.

- Q: Can you clarify how the 457 cfs was incorporated into the design criteria? Was it based on moving enough water out of the reservoir to meet the 457 cfs at S-79 through each of the treatment technology options?
- A: (Jim Bays, J-Tech) This is the typical rate of flow we are expecting to see discharged from the reservoir. The working hypothesis is that what is discharged has to be equal to or better than what is in the river, which drove our treatment goals. We needed to treat a substantial flow to meet design targets for treatment.

- Q: Did scalability include to have a technology that can sustain zero flows for several weeks?
- A: (Jim Bays, J-Tech) This was addressed and considered in review of the 10 technologies. There is case experience where the filtration media, wetlands, and sand filters can all be dry for periods of time, so they can treat the natural variation of flows. Technologies that are more chemically or electrically driven can be turned off. Technologies had to sustain zero flows to have gotten this far in the evaluation.

- Q: Were ancillary water quality impacts included in the ranking (sulfate, aluminum, etc.)?
- A: (Chris Keller, WSI) Yes and no. Ancillary water quality impacts and benefits were wrapped up in the habitat creation and value to wildlife attribute. If a particular technology had a negative impact then that would be reflected in those attributes. Other water quality parameters were not included in ranking as a standalone attribute.

- Q: Did the cost include the capital cost or only the O&M? The cost was set per pound of phosphorus or nitrogen removed? Or per gallons treated?
- A: (Chris Keller, WSI) The final costs were the NPVs that included the capital cost for the technology, infrastructure requirements to deliver water to that technology and deliver it back, and associated O&M costs for both conveyance and technology. The technologies were evaluated in terms of pounds of TN, TP, and TSS removed.

- Q: Is the cost determined based on the water quality conditions (initial concentrations) at the site?
- A: (Chris Keller, WSI) The starting inflow concentrations that were used for TN, TP, and TSS were based on a statistical evaluation of water quality data in the C-43 and represent average inflow conditions for the reservoir.

- Q: Did the cost benefit analysis of alum treatment assume that the floc would be removed?
- A: (Jim Bays, J-Tech) Yes, this is included in the O&M costs for both the alum treatment and HWTT. A cost estimate is included to pump the floc from settling basins to drying facilities. Therefore, costs for both extraction and processing and drying are included.

- Q: Did the cost include dealing with the residuals?
- A: (Jim Bays, J-Tech) Yes, as part of the O&M.

- Q: "Equal to or better" than the water quality that's already in the river" seems like a low bar. Since the water in the reservoir is coming from the river, what factors have been identified which are expected to worsen water quality in the reservoir?

- A: (Jim Bays, J-Tech) We are not certain what water quality changes will occur in the reservoir but there should be a retention of nutrients. Therefore, we are assuming a conservative case because water quality will likely be better. The design targets represent typical water quality in the river during the dry season when there would be a discharge from the reservoir. This is not a simple target to treat to so we set a somewhat challenging requirement for nutrient reductions.

- Q: How does the stagnant conditions of the reservoir affect algae in the reservoir vs. the river itself?
- A: (Jim Bays, J-Tech) Retention in the reservoir and retention of nutrients could result in algal production. This is reflected in the TSS goals that we asked the technologies to achieve.

Menti Polling and Questions

- Participants were asked to provide feedback on the Menti website. The participants can have the results emailed to them and the results will also be posted to the project website.

Please type in any question you have related to the technologies that were evaluated for the Study.

- Q: What is Bold and Gold made from? What are its ingredients.
- A: (Jim Bays, J-Tech) We are using the CTS mixture, which includes clay, tire crumbs and fine sand. All have sorption attributes that are good for nutrient removal and are made from local materials. The concept for this site is to use sands from the project area in this mix.

- Q: How difficult is to change out the Bold & Gold media?
- A: (Jim Bays, J-Tech) This would be a rebuild of the media layer by physically removing the media bed. That would be 5 feet of media depth for this project. The media would be removed using a machine and replaced with media created onsite. Implementation at this scale has not been done but has been done on smaller scales.

- Q: How are coagulants being used in other restoration projects?
- A: (Chris Keller, WSI) Coagulants are more frequently used in treatment and water quality projects than habitat restoration projects. The most common is alum which has been used in lake restoration projects. This ties into the question about why alum instead of another coagulant. Alum is more proven at these larger scales than other coagulants. There are other chemicals that go with the alum to help with buffering pH.

- Q: When do you anticipate DEP will certify the operation of the reservoir?
- A: (Ed Smith, DEP) DEP will certify the operation of the reservoir after the operational testing monitoring phase, which will be after construction is complete. This is part of all CERP projects. This would occur around 2024, and DEP will work with SFWMD to permit those operations through the CERP process.

- Q: Does alum change the physical, chemical, or biological conditions in the waterbody or downstream?
- A: (Ed Smith DEP) Alum has been permitted by DEP going back to the 1980s. It has shown very effective treatment and is easy to manage. The City of Tallahassee uses alum in several location and they have the oldest system since 1984. The city has managed the output and the pH to prevent problems with alum. There was one system that they had to scale back because it was removing too much nutrients. Alum is very effective and easy to monitor. Alum systems would get an Environmental Resource Permit (ERP) and also a National Pollutant Discharge Elimination System (NPDES) permit, which would have both a DEP and U.S. Environmental Protection Agency Region 4 oversight, which would require extensive monitoring.

- Q: Does this study take into account an increase in nutrients coming into the C-43 as there is more nutrient use in South Florida. Would increase of nutrients coming in slow the removal and the target cfs?
- A: (Jim Bays, J-Tech) The project cannot affect the flow going downstream to the estuary. We looked at a snapshot of water quality data from the last 10 years. We did not forecast any increases in nutrients. We did this for comparison purposes to compare the technologies as apples to apples. The sizing of these systems is based on flows and concentrations. If we see an increase, there may be a need for additional facilities and acreage for treatment. The benefit of alum is that it can treat more load and flows but there would be more residuals. There is the ability to scale up for flows and concentrations. It would not slow removal but may require a change in operations and additional features.

- Georgia stated that all the questions will be captured and written responses will be provided, which will be posted to the project website.

Please type in any questions you have related to the C-43 West Basin Storage Reservoir Project.

- Q: Have the dam safety issues been resolved with respect to material used?
- A: (Shawn Waldeck, J-Tech) As part of the project design, it went through U.S. Army Corps of Engineers and independent peer review for safety issues related to construction of the dam.

- Q: Don't think I understand why the question we're trying to answer today was not incorporated into the original study?
- A: (Georgia Vince, J-Tech) This question has come up before. This reservoir was designed to regulate flows to the river and estuary and a water quality component was not included at the time it went through the Project Implementation Report (PIR) process.

- Q: Will there be an opportunity to clarify and provide more information on a technology?
- A: (Georgia Vince, J-Tech) On the project website, there is detailed information on the projects including reports and our Information Collection Summary Report. Additional information can be sent to the team for consideration in the next draft.

- Q: Will the reservoir be operable if water exiting does not meet water quality standards?
- A: (Ed Smith, DEP) The reservoir is pulling water in from the C-43, holding it in the reservoir, and transferring it out. The waters are not separate from Waters of the US, so it falls under the water transfers rule, so this does not apply.

- Q: How will adaptive management be used in reservoir operations to mitigate water quality impacts?
- A: (Shawn Waldeck, J-Tech) One of the concepts is to use the reservoir during the dry and cooler seasons, so we can count on some degree of better water quality during that season for discharge. We can also recirculate water within the system, which is more expensive, to minimize impacts from discharges.

- Q: What is the deadline for comments.
- A: (Kim Fikoski, SFWMD) The website has an email address where we will continue to take comments or information up until the completion of the Study. We would appreciate any comments by mid/late August when we will be starting to work on finalizing the Study. On the Working Group website for the project, there is a lot of information for review. In the Work Plan, the contact information for the Working Group and J-Tech is included, so you can reach out directly, but we encourage everyone to use the email address.

Please types in any additional questions you may have about the Study.

- Q: Is there any chance ranking of alternatives will be revisited given input today?
- A: (Jim Bays, J-Tech) We would revisit the alternatives that were selected if we thought there would be a major change in the cost-benefit analysis. We conducted a sensitivity analysis on the cost-benefit based on information received. If there are new data available that we have not seen before, we would look at them, but it would have to be a fairly big change in the ranking to change results. There may be people who have concerns about how this ranking affects the project in the future.

Whatever is ranked #1 here is not necessarily the project that will be implemented. We will use the results from this Study in the next phase with other information on land availability, timing, other priorities, how things work together, etc. We would then determine the final project. SFWMD has budgeted to further evaluate the top alternatives and is looking to have one recommendation in early 2021, which could be one or a combination of technologies. This alternative would go forward with design, permitting, and construction to be done concurrently with completion of the reservoir.

- Q: Please clarify that the water transfer rule exempts discharge from Water Quality Based Effluent Limits (WQBELs)?
- A: (Ed Smith, DEP) The water in the reservoir is Waters of the US, so it would qualify under the water transfer rule. Water is simply being held for use at a later date.

- Q: Is the C-43 Reservoir draft operating manual available online?
- A: (Ed Smith, DEP) The draft manual should be in DEP's OCULUS system. If you cannot find it, you can email Ed Smith at DEP for a copy of the draft operations manual.

Final Remarks

- Georgia thanked the Coastal and Heartland National Estuary Partnership for allowing use of the Menti program. The team feels this tool is beneficial for collecting input and feedback from meeting participants. She mentioned that at the end of the Menti session, the participants can have the results of the session emailed to them by entering their email address. The Menti results will also be posted to the project website. Georgia stated that the team will provide answers to all questions on the project website, https://www.sfwmd.gov/content/c43waterqualitystudy.
- Drew Bartlett, Executive Director of the SFWMD, gave the closing remarks. He is grateful that the SFWMD is working with DEP and Governor DeSantis to bring resolution to the C-43 water quality issue, and he appreciates the work of J-Tech and Wetland Solutions. He thanked the Working Group partners and stated that the SFWMD will continue to engage with them. He stated that we will have the right amount of water and right quality of water going to the Caloosahatchee with the help of this project. He thanked everyone for their participation.

Appendix C: Water Quality Data

The following tables show the data used in the water quality evaluation.

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
1/26/2010 12:30	Grab	KJELDAHL NITROGEN, TOTAL	1.12
1/26/2010 12:30	Grab	NITRATE+NITRITE-N	0.085
1/26/2010 12:30	Grab	PHOSPHATE, TOTAL AS P	0.055
2/23/2010 10:15	Grab	KJELDAHL NITROGEN, TOTAL	1.23
2/23/2010 10:15	Grab	NITRATE+NITRITE-N	0.246
2/23/2010 10:15	Grab	PHOSPHATE, TOTAL AS P	0.059
3/23/2010 10:37	Grab	KJELDAHL NITROGEN, TOTAL	1.26
3/23/2010 10:37	Grab	NITRATE+NITRITE-N	0.334
3/23/2010 10:37	Grab	PHOSPHATE, TOTAL AS P	0.132
4/27/2010 11:05	Grab	KJELDAHL NITROGEN, TOTAL	1.34
4/27/2010 11:05	Grab	NITRATE+NITRITE-N	0.117
4/27/2010 11:05	Grab	PHOSPHATE, TOTAL AS P	0.139
5/4/2010 11:37	Grab	KJELDAHL NITROGEN, TOTAL	1.99
5/4/2010 11:37	Grab	NITRATE+NITRITE-N	0.256
5/4/2010 11:37	Grab	PHOSPHATE, TOTAL AS P	0.203
5/11/2010 11:01	Grab	KJELDAHL NITROGEN, TOTAL	1.36
5/11/2010 11:01	Grab	NITRATE+NITRITE-N	0.085
5/11/2010 11:01	Grab	PHOSPHATE, TOTAL AS P	0.099
5/18/2010 11:40	Grab	KJELDAHL NITROGEN, TOTAL	1.41
5/18/2010 11:40	Grab	NITRATE+NITRITE-N	0.07
5/18/2010 11:40	Grab	PHOSPHATE, TOTAL AS P	0.091
5/25/2010 11:50	Grab	KJELDAHL NITROGEN, TOTAL	1.3
5/25/2010 11:50	Grab	NITRATE+NITRITE-N	0.041
5/25/2010 11:50	Grab	PHOSPHATE, TOTAL AS P	0.088
6/1/2010 11:45	Grab	KJELDAHL NITROGEN, TOTAL	1.23
6/1/2010 11:45	Grab	NITRATE+NITRITE-N	0.007
6/1/2010 11:45	Grab	PHOSPHATE, TOTAL AS P	0.076
6/8/2010 11:22	Grab	KJELDAHL NITROGEN, TOTAL	1.25
6/8/2010 11:22	Grab	NITRATE+NITRITE-N	0.035
6/8/2010 11:22	Grab	PHOSPHATE, TOTAL AS P	0.102
6/15/2010 11:00	Grab	KJELDAHL NITROGEN, TOTAL	1.55
6/15/2010 11:00	Grab	NITRATE+NITRITE-N	0.027
6/15/2010 11:00	Grab	PHOSPHATE, TOTAL AS P	0.086
6/22/2010 12:08	Grab	KJELDAHL NITROGEN, TOTAL	1.36
6/22/2010 12:08	Grab	NITRATE+NITRITE-N	0.04
6/22/2010 12:08	Grab	PHOSPHATE, TOTAL AS P	0.082
6/29/2010 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.61
6/29/2010 10:40	Grab	NITRATE+NITRITE-N	0.019
6/29/2010 10:40	Grab	PHOSPHATE, TOTAL AS P	0.085
7/6/2010 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.48
7/6/2010 11:20	Grab	NITRATE+NITRITE-N	0.085
7/6/2010 11:20	Grab	PHOSPHATE, TOTAL AS P	0.103
7/13/2010 10:53	Grab	KJELDAHL NITROGEN, TOTAL	1.55

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/13/2010 10:53	Grab	NITRATE+NITRITE-N	0.163
7/13/2010 10:53	Grab	PHOSPHATE, TOTAL AS P	0.13
7/20/2010 10:44	Grab	KJELDAHL NITROGEN, TOTAL	1.48
7/20/2010 10:44	Grab	NITRATE+NITRITE-N	0.006
7/20/2010 10:44	Grab	PHOSPHATE, TOTAL AS P	0.079
7/27/2010 11:46	Grab	KJELDAHL NITROGEN, TOTAL	1.33
7/27/2010 11:46	Grab	NITRATE+NITRITE-N	0.007
7/27/2010 11:46	Grab	PHOSPHATE, TOTAL AS P	0.068
8/3/2010 11:07	Grab	KJELDAHL NITROGEN, TOTAL	1.19
8/3/2010 11:07	Grab	NITRATE+NITRITE-N	0.006
8/3/2010 11:07	Grab	PHOSPHATE, TOTAL AS P	0.064
8/10/2010 10:25	Grab	KJELDAHL NITROGEN, TOTAL	1.36
8/10/2010 10:25	Grab	NITRATE+NITRITE-N	0.012
8/10/2010 10:25	Grab	PHOSPHATE, TOTAL AS P	0.085
8/17/2010 10:54	Grab	KJELDAHL NITROGEN, TOTAL	1.22
8/17/2010 10:54	Grab	NITRATE+NITRITE-N	0.014
8/17/2010 10:54	Grab	PHOSPHATE, TOTAL AS P	0.077
8/24/2010 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.8
8/24/2010 11:20	Grab	NITRATE+NITRITE-N	0.102
8/24/2010 11:20	Grab	PHOSPHATE, TOTAL AS P	0.194
8/31/2010 11:11	Grab	KJELDAHL NITROGEN, TOTAL	1.57
8/31/2010 11:11	Grab	NITRATE+NITRITE-N	0.134
8/31/2010 11:11	Grab	PHOSPHATE, TOTAL AS P	0.157
9/7/2010 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.28
9/7/2010 11:54	Grab	NITRATE+NITRITE-N	0.097
9/7/2010 11:54	Grab	PHOSPHATE, TOTAL AS P	0.128
9/13/2010 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.22
9/13/2010 11:20	Grab	NITRATE+NITRITE-N	0.041
9/13/2010 11:20	Grab	PHOSPHATE, TOTAL AS P	0.132
9/21/2010 11:25	Grab	KJELDAHL NITROGEN, TOTAL	1.2
9/21/2010 11:25	Grab	NITRATE+NITRITE-N	0.257
9/21/2010 11:25	Grab	PHOSPHATE, TOTAL AS P	0.143
9/28/2010 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.17
9/28/2010 11:20	Grab	NITRATE+NITRITE-N	0.327
9/28/2010 11:20	Grab	PHOSPHATE, TOTAL AS P	0.126
10/5/2010 10:50	Grab	KJELDAHL NITROGEN, TOTAL	1.27
10/5/2010 10:50	Grab	NITRATE+NITRITE-N	0.398
10/5/2010 10:50	Grab	PHOSPHATE, TOTAL AS P	0.123
10/12/2010 11:05	Grab	KJELDAHL NITROGEN, TOTAL	1.21
10/12/2010 11:05	Grab	NITRATE+NITRITE-N	0.365
10/12/2010 11:05	Grab	PHOSPHATE, TOTAL AS P	0.124
10/19/2010 11:35	Grab	KJELDAHL NITROGEN, TOTAL	1.08
10/19/2010 11:35	Grab	NITRATE+NITRITE-N	0.012
10/19/2010 11:35	Grab	PHOSPHATE, TOTAL AS P	0.058
10/26/2010 11:28	Grab	KJELDAHL NITROGEN, TOTAL	1.12
10/26/2010 11:28	Grab	NITRATE+NITRITE-N	0.093
10/26/2010 11:28	Grab	PHOSPHATE, TOTAL AS P	0.092

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
11/2/2010 11:05	Grab	KJELDAHL NITROGEN, TOTAL	1.19
11/2/2010 11:05	Grab	NITRATE+NITRITE-N	0.252
11/2/2010 11:05	Grab	PHOSPHATE, TOTAL AS P	0.097
11/9/2010 11:58	Grab	KJELDAHL NITROGEN, TOTAL	1.16
11/9/2010 11:58	Grab	NITRATE+NITRITE-N	0.248
11/9/2010 11:58	Grab	PHOSPHATE, TOTAL AS P	0.093
11/16/2010 10:31	Grab	KJELDAHL NITROGEN, TOTAL	1.14
11/16/2010 10:31	Grab	NITRATE+NITRITE-N	0.142
11/16/2010 10:31	Grab	PHOSPHATE, TOTAL AS P	0.068
11/22/2010 11:35	Grab	KJELDAHL NITROGEN, TOTAL	1.08
11/22/2010 11:35	Grab	NITRATE+NITRITE-N	0.025
11/22/2010 11:35	Grab	PHOSPHATE, TOTAL AS P	0.049
11/30/2010 13:07	Grab	KJELDAHL NITROGEN, TOTAL	1.12
11/30/2010 13:07	Grab	NITRATE+NITRITE-N	0.05
11/30/2010 13:07	Grab	PHOSPHATE, TOTAL AS P	0.066
12/7/2010 11:30	Grab	KJELDAHL NITROGEN, TOTAL	1.17
12/7/2010 11:30	Grab	NITRATE+NITRITE-N	0.076
12/7/2010 11:30	Grab	PHOSPHATE, TOTAL AS P	0.089
12/14/2010 11:00	Grab	KJELDAHL NITROGEN, TOTAL	1.05
12/14/2010 11:00	Grab	NITRATE+NITRITE-N	0.06
12/14/2010 11:00	Grab	PHOSPHATE, TOTAL AS P	0.055
12/21/2010 12:11	Grab	KJELDAHL NITROGEN, TOTAL	1.06
12/21/2010 12:11	Grab	NITRATE+NITRITE-N	0.016
12/21/2010 12:11	Grab	PHOSPHATE, TOTAL AS P	0.066
12/28/2010 11:42	Grab	KJELDAHL NITROGEN, TOTAL	1.1
12/28/2010 11:42	Grab	NITRATE+NITRITE-N	0.024
12/28/2010 11:42	Grab	PHOSPHATE, TOTAL AS P	0.053
1/5/2011 11:21	Grab	KJELDAHL NITROGEN, TOTAL	1.07
1/5/2011 11:21	Grab	NITRATE+NITRITE-N	-0.005
1/5/2011 11:21	Grab	PHOSPHATE, TOTAL AS P	0.058
1/12/2011 11:57	Grab	KJELDAHL NITROGEN, TOTAL	1.08
1/12/2011 11:57	Grab	NITRATE+NITRITE-N	0.061
1/12/2011 11:57	Grab	PHOSPHATE, TOTAL AS P	0.074
1/19/2011 11:55	Grab	KJELDAHL NITROGEN, TOTAL	1.09
1/19/2011 11:55	Grab	NITRATE+NITRITE-N	0.095
1/19/2011 11:55	Grab	PHOSPHATE, TOTAL AS P	0.09
1/26/2011 12:02	Grab	KJELDAHL NITROGEN, TOTAL	1.11
1/26/2011 12:02	Grab	NITRATE+NITRITE-N	0.096
1/26/2011 12:02	Grab	PHOSPHATE, TOTAL AS P	0.088
2/2/2011 11:41	Grab	KJELDAHL NITROGEN, TOTAL	1.31
2/2/2011 11:41	Grab	NITRATE+NITRITE-N	0.022
2/2/2011 11:41	Grab	PHOSPHATE, TOTAL AS P	0.071
2/9/2011 11:59	Grab	KJELDAHL NITROGEN, TOTAL	1.17
2/9/2011 11:59	Grab	NITRATE+NITRITE-N	0.074
2/9/2011 11:59	Grab	PHOSPHATE, TOTAL AS P	0.08
2/16/2011 11:40	Grab	KJELDAHL NITROGEN, TOTAL	1.26
2/16/2011 11:40	Grab	NITRATE+NITRITE-N	0.111

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/16/2011 11:40	Grab	PHOSPHATE, TOTAL AS P	0.079
2/23/2011 11:30	Grab	KJELDAHL NITROGEN, TOTAL	1.14
2/23/2011 11:30	Grab	NITRATE+NITRITE-N	0.063
2/23/2011 11:30	Grab	PHOSPHATE, TOTAL AS P	0.076
3/2/2011 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.11
3/2/2011 11:54	Grab	NITRATE+NITRITE-N	0.073
3/2/2011 11:54	Grab	PHOSPHATE, TOTAL AS P	0.069
3/9/2011 11:23	Grab	KJELDAHL NITROGEN, TOTAL	1.1
3/9/2011 11:23	Grab	NITRATE+NITRITE-N	0.129
3/9/2011 11:23	Grab	PHOSPHATE, TOTAL AS P	0.08
3/16/2011 11:24	Grab	KJELDAHL NITROGEN, TOTAL	1.29
3/16/2011 11:24	Grab	NITRATE+NITRITE-N	-0.005
3/16/2011 11:24	Grab	PHOSPHATE, TOTAL AS P	0.091
3/23/2011 11:50	Grab	KJELDAHL NITROGEN, TOTAL	1.13
3/23/2011 11:50	Grab	NITRATE+NITRITE-N	0.011
3/23/2011 11:50	Grab	PHOSPHATE, TOTAL AS P	0.08
3/30/2011 11:36	Grab	KJELDAHL NITROGEN, TOTAL	1.11
3/30/2011 11:36	Grab	NITRATE+NITRITE-N	0.023
3/30/2011 11:36	Grab	PHOSPHATE, TOTAL AS P	0.071
4/6/2011 11:40	Grab	KJELDAHL NITROGEN, TOTAL	1.13
4/6/2011 11:40	Grab	NITRATE+NITRITE-N	0.02
4/6/2011 11:40	Grab	PHOSPHATE, TOTAL AS P	0.093
4/13/2011 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.21
4/13/2011 11:54	Grab	NITRATE+NITRITE-N	0.018
4/13/2011 11:54	Grab	PHOSPHATE, TOTAL AS P	0.101
4/20/2011 12:56	Grab	KJELDAHL NITROGEN, TOTAL	1.18
4/20/2011 12:56	Grab	NITRATE+NITRITE-N	-0.005
4/20/2011 12:56	Grab	PHOSPHATE, TOTAL AS P	0.078
4/27/2011 12:42	Grab	KJELDAHL NITROGEN, TOTAL	1.25
4/27/2011 12:42	Grab	NITRATE+NITRITE-N	-0.005
4/27/2011 12:42	Grab	PHOSPHATE, TOTAL AS P	0.091
5/4/2011 11:58	Grab	KJELDAHL NITROGEN, TOTAL	1.23
5/4/2011 11:58	Grab	NITRATE+NITRITE-N	-0.005
5/4/2011 11:58	Grab	PHOSPHATE, TOTAL AS P	0.094
5/11/2011 11:08	Grab	KJELDAHL NITROGEN, TOTAL	1.22
5/11/2011 11:08	Grab	NITRATE+NITRITE-N	-0.005
5/11/2011 11:08	Grab	PHOSPHATE, TOTAL AS P	0.093
5/18/2011 12:22	Grab	KJELDAHL NITROGEN, TOTAL	1.13
5/18/2011 12:22	Grab	NITRATE+NITRITE-N	0.016
5/18/2011 12:22	Grab	PHOSPHATE, TOTAL AS P	0.118
5/25/2011 11:46	Grab	KJELDAHL NITROGEN, TOTAL	1.58
5/25/2011 11:46	Grab	NITRATE+NITRITE-N	-0.005
5/25/2011 11:46	Grab	PHOSPHATE, TOTAL AS P	0.098
6/1/2011 12:26	Grab	KJELDAHL NITROGEN, TOTAL	1.45
6/1/2011 12:26	Grab	NITRATE+NITRITE-N	-0.005
6/1/2011 12:26	Grab	PHOSPHATE, TOTAL AS P	0.144
6/8/2011 11:37	Grab	KJELDAHL NITROGEN, TOTAL	1.4

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/8/2011 11:37	Grab	NITRATE+NITRITE-N	-0.005
6/8/2011 11:37	Grab	PHOSPHATE, TOTAL AS P	0.123
6/15/2011 11:58	Grab	KJELDAHL NITROGEN, TOTAL	1.4
6/15/2011 11:58	Grab	NITRATE+NITRITE-N	-0.005
6/15/2011 11:58	Grab	PHOSPHATE, TOTAL AS P	0.139
6/22/2011 12:03	Grab	KJELDAHL NITROGEN, TOTAL	1.47
6/22/2011 12:03	Grab	NITRATE+NITRITE-N	-0.005
6/22/2011 12:03	Grab	PHOSPHATE, TOTAL AS P	0.073
6/29/2011 12:11	Grab	KJELDAHL NITROGEN, TOTAL	1.48
6/29/2011 12:11	Grab	NITRATE+NITRITE-N	0.008
6/29/2011 12:11	Grab	PHOSPHATE, TOTAL AS P	0.173
7/6/2011 11:57	Grab	KJELDAHL NITROGEN, TOTAL	1.54
7/6/2011 11:57	Grab	NITRATE+NITRITE-N	0.018
7/6/2011 11:57	Grab	PHOSPHATE, TOTAL AS P	0.197
7/13/2011 12:11	Grab	KJELDAHL NITROGEN, TOTAL	1.42
7/13/2011 12:11	Grab	NITRATE+NITRITE-N	0.057
7/13/2011 12:11	Grab	PHOSPHATE, TOTAL AS P	0.212
7/20/2011 13:10	Grab	KJELDAHL NITROGEN, TOTAL	1.42
7/20/2011 13:10	Grab	NITRATE+NITRITE-N	0.045
7/20/2011 13:10	Grab	PHOSPHATE, TOTAL AS P	0.222
7/27/2011 12:03	Grab	KJELDAHL NITROGEN, TOTAL	1.49
7/27/2011 12:03	Grab	NITRATE+NITRITE-N	0.025
7/27/2011 12:03	Grab	PHOSPHATE, TOTAL AS P	0.212
8/3/2011 12:00	Grab	KJELDAHL NITROGEN, TOTAL	1.68
8/3/2011 12:00	Grab	NITRATE+NITRITE-N	0.031
8/3/2011 12:00	Grab	PHOSPHATE, TOTAL AS P	0.27
8/10/2011 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.5
8/10/2011 11:54	Grab	NITRATE+NITRITE-N	0.016
8/10/2011 11:54	Grab	PHOSPHATE, TOTAL AS P	0.364
8/17/2011 11:58	Grab	KJELDAHL NITROGEN, TOTAL	1.3
8/17/2011 11:58	Grab	NITRATE+NITRITE-N	0.069
8/17/2011 11:58	Grab	PHOSPHATE, TOTAL AS P	0.25
8/24/2011 11:42	Grab	KJELDAHL NITROGEN, TOTAL	1.23
8/24/2011 11:42	Grab	NITRATE+NITRITE-N	0.012
8/24/2011 11:42	Grab	PHOSPHATE, TOTAL AS P	0.154
8/31/2011 12:18	Grab	KJELDAHL NITROGEN, TOTAL	1.33
8/31/2011 12:18	Grab	NITRATE+NITRITE-N	0.12
8/31/2011 12:18	Grab	PHOSPHATE, TOTAL AS P	0.18
9/7/2011 11:29	Grab	KJELDAHL NITROGEN, TOTAL	1.25
9/7/2011 11:29	Grab	NITRATE+NITRITE-N	0.208
9/7/2011 11:29	Grab	PHOSPHATE, TOTAL AS P	0.185
9/14/2011 12:13	Grab	KJELDAHL NITROGEN, TOTAL	1.36
9/14/2011 12:13	Grab	NITRATE+NITRITE-N	-0.005
9/14/2011 12:13	Grab	PHOSPHATE, TOTAL AS P	0.132
9/21/2011 11:23	Grab	KJELDAHL NITROGEN, TOTAL	1.37
9/21/2011 11:23	Grab	NITRATE+NITRITE-N	0.039
9/21/2011 11:23	Grab	PHOSPHATE, TOTAL AS P	0.144

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/28/2011 12:01	Grab	KJELDAHL NITROGEN, TOTAL	1.22
9/28/2011 12:01	Grab	NITRATE+NITRITE-N	0.253
9/28/2011 12:01	Grab	PHOSPHATE, TOTAL AS P	0.208
10/5/2011 11:36	Grab	KJELDAHL NITROGEN, TOTAL	1.41
10/5/2011 11:36	Grab	NITRATE+NITRITE-N	0.129
10/5/2011 11:36	Grab	PHOSPHATE, TOTAL AS P	0.199
10/12/2011 12:02	Grab	KJELDAHL NITROGEN, TOTAL	1.26
10/12/2011 12:02	Grab	NITRATE+NITRITE-N	0.197
10/12/2011 12:02	Grab	PHOSPHATE, TOTAL AS P	0.173
10/19/2011 12:10	Grab	KJELDAHL NITROGEN, TOTAL	1.14
10/19/2011 12:10	Grab	NITRATE+NITRITE-N	0.289
10/19/2011 12:10	Grab	PHOSPHATE, TOTAL AS P	0.115
10/26/2011 11:30	Grab	KJELDAHL NITROGEN, TOTAL	1.23
10/26/2011 11:30	Grab	NITRATE+NITRITE-N	0.219
10/26/2011 11:30	Grab	PHOSPHATE, TOTAL AS P	0.106
11/2/2011 12:50	Grab	KJELDAHL NITROGEN, TOTAL	1.33
11/2/2011 12:50	Grab	NITRATE+NITRITE-N	0.366
11/2/2011 12:50	Grab	PHOSPHATE, TOTAL AS P	0.103
11/9/2011 12:04	Grab	KJELDAHL NITROGEN, TOTAL	1.36
11/9/2011 12:04	Grab	NITRATE+NITRITE-N	0.333
11/9/2011 12:04	Grab	PHOSPHATE, TOTAL AS P	0.109
11/16/2011 11:55	Grab	KJELDAHL NITROGEN, TOTAL	1.26
11/16/2011 11:55	Grab	NITRATE+NITRITE-N	0.362
11/16/2011 11:55	Grab	PHOSPHATE, TOTAL AS P	0.127
11/22/2011 11:32	Grab	KJELDAHL NITROGEN, TOTAL	1.32
11/22/2011 11:32	Grab	NITRATE+NITRITE-N	0.345
11/22/2011 11:32	Grab	PHOSPHATE, TOTAL AS P	0.129
11/30/2011 12:12	Grab	KJELDAHL NITROGEN, TOTAL	1.1
11/30/2011 12:12	Grab	NITRATE+NITRITE-N	0.364
11/30/2011 12:12	Grab	PHOSPHATE, TOTAL AS P	0.122
12/7/2011 12:12	Grab	KJELDAHL NITROGEN, TOTAL	1.18
12/7/2011 12:12	Grab	NITRATE+NITRITE-N	0.374
12/7/2011 12:12	Grab	PHOSPHATE, TOTAL AS P	0.133
12/14/2011 12:17	Grab	KJELDAHL NITROGEN, TOTAL	1.07
12/14/2011 12:17	Grab	NITRATE+NITRITE-N	0.419
12/14/2011 12:17	Grab	PHOSPHATE, TOTAL AS P	0.146
12/21/2011 11:16	Grab	KJELDAHL NITROGEN, TOTAL	1.27
12/21/2011 11:16	Grab	NITRATE+NITRITE-N	0.367
12/21/2011 11:16	Grab	PHOSPHATE, TOTAL AS P	0.106
12/28/2011 11:25	Grab	KJELDAHL NITROGEN, TOTAL	1.28
12/28/2011 11:25	Grab	NITRATE+NITRITE-N	0.243
12/28/2011 11:25	Grab	PHOSPHATE, TOTAL AS P	0.113
1/4/2012 12:11	Grab	KJELDAHL NITROGEN, TOTAL	1.32
1/4/2012 12:11	Grab	NITRATE+NITRITE-N	0.288
1/4/2012 12:11	Grab	PHOSPHATE, TOTAL AS P	0.135
1/11/2012 12:16	Grab	KJELDAHL NITROGEN, TOTAL	1.26
1/11/2012 12:16	Grab	NITRATE+NITRITE-N	0.151

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
1/11/2012 12:16	Grab	PHOSPHATE, TOTAL AS P	0.1
1/18/2012 11:33	Grab	KJELDAHL NITROGEN, TOTAL	1.34
1/18/2012 11:33	Grab	NITRATE+NITRITE-N	0.127
1/18/2012 11:33	Grab	PHOSPHATE, TOTAL AS P	0.098
1/25/2012 12:06	Grab	KJELDAHL NITROGEN, TOTAL	1.23
1/25/2012 12:06	Grab	NITRATE+NITRITE-N	0.092
1/25/2012 12:06	Grab	PHOSPHATE, TOTAL AS P	0.072
2/1/2012 10:32	Grab	KJELDAHL NITROGEN, TOTAL	1.28
2/1/2012 10:32	Grab	NITRATE+NITRITE-N	0.064
2/1/2012 10:32	Grab	PHOSPHATE, TOTAL AS P	0.085
2/8/2012 11:23	Grab	KJELDAHL NITROGEN, TOTAL	1.2
2/8/2012 11:23	Grab	NITRATE+NITRITE-N	0.105
2/8/2012 11:23	Grab	PHOSPHATE, TOTAL AS P	0.083
2/15/2012 11:53	Grab	KJELDAHL NITROGEN, TOTAL	1.22
2/15/2012 11:53	Grab	NITRATE+NITRITE-N	0.075
2/15/2012 11:53	Grab	PHOSPHATE, TOTAL AS P	0.086
2/22/2012 11:49	Grab	KJELDAHL NITROGEN, TOTAL	1.34
2/22/2012 11:49	Grab	NITRATE+NITRITE-N	-0.005
2/22/2012 11:49	Grab	PHOSPHATE, TOTAL AS P	0.072
2/29/2012 11:17	Grab	KJELDAHL NITROGEN, TOTAL	1.38
2/29/2012 11:17	Grab	NITRATE+NITRITE-N	-0.005
2/29/2012 11:17	Grab	PHOSPHATE, TOTAL AS P	0.083
3/7/2012 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.28
3/7/2012 11:20	Grab	NITRATE+NITRITE-N	0.031
3/7/2012 11:20	Grab	PHOSPHATE, TOTAL AS P	0.104
3/14/2012 11:26	Grab	KJELDAHL NITROGEN, TOTAL	1.45
3/14/2012 11:26	Grab	NITRATE+NITRITE-N	-0.005
3/14/2012 11:26	Grab	PHOSPHATE, TOTAL AS P	0.091
3/21/2012 10:53	Grab	KJELDAHL NITROGEN, TOTAL	1.34
3/21/2012 10:53	Grab	NITRATE+NITRITE-N	-0.005
3/21/2012 10:53	Grab	PHOSPHATE, TOTAL AS P	0.078
3/28/2012 10:59	Grab	KJELDAHL NITROGEN, TOTAL	1.29
3/28/2012 10:59	Grab	NITRATE+NITRITE-N	0.005
3/28/2012 10:59	Grab	PHOSPHATE, TOTAL AS P	0.094
4/4/2012 11:19	Grab	KJELDAHL NITROGEN, TOTAL	1.24
4/4/2012 11:19	Grab	NITRATE+NITRITE-N	-0.005
4/4/2012 11:19	Grab	PHOSPHATE, TOTAL AS P	0.083
4/11/2012 12:40	Grab	KJELDAHL NITROGEN, TOTAL	1.3
4/11/2012 12:40	Grab	NITRATE+NITRITE-N	-0.005
4/11/2012 12:40	Grab	PHOSPHATE, TOTAL AS P	0.085
4/18/2012 12:20	Grab	KJELDAHL NITROGEN, TOTAL	1.17
4/18/2012 12:20	Grab	NITRATE+NITRITE-N	-0.005
4/18/2012 12:20	Grab	PHOSPHATE, TOTAL AS P	0.079
4/25/2012 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.31
4/25/2012 11:54	Grab	NITRATE+NITRITE-N	-0.005
4/25/2012 11:54	Grab	PHOSPHATE, TOTAL AS P	0.069
5/2/2012 11:36	Grab	KJELDAHL NITROGEN, TOTAL	1.28

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/2/2012 11:36	Grab	NITRATE+NITRITE-N	0.009
5/2/2012 11:36	Grab	PHOSPHATE, TOTAL AS P	0.06
5/9/2012 12:14	Grab	KJELDAHL NITROGEN, TOTAL	1.23
5/9/2012 12:14	Grab	NITRATE+NITRITE-N	-0.005
5/9/2012 12:14	Grab	PHOSPHATE, TOTAL AS P	0.059
5/15/2012 12:00	Grab	KJELDAHL NITROGEN, TOTAL	1.31
5/15/2012 12:00	Grab	NITRATE+NITRITE-N	-0.005
5/15/2012 12:00	Grab	PHOSPHATE, TOTAL AS P	0.081
5/23/2012 11:27	Grab	KJELDAHL NITROGEN, TOTAL	1.2
5/23/2012 11:27	Grab	NITRATE+NITRITE-N	-0.005
5/23/2012 11:27	Grab	PHOSPHATE, TOTAL AS P	0.072
5/30/2012 12:13	Grab	KJELDAHL NITROGEN, TOTAL	1.4
5/30/2012 12:13	Grab	NITRATE+NITRITE-N	-0.005
5/30/2012 12:13	Grab	PHOSPHATE, TOTAL AS P	0.106
6/6/2012 12:37	Grab	KJELDAHL NITROGEN, TOTAL	1.61
6/6/2012 12:37	Grab	NITRATE+NITRITE-N	-0.005
6/6/2012 12:37	Grab	PHOSPHATE, TOTAL AS P	0.183
6/13/2012 12:05	Grab	KJELDAHL NITROGEN, TOTAL	1.35
6/13/2012 12:05	Grab	NITRATE+NITRITE-N	-0.005
6/13/2012 12:05	Grab	PHOSPHATE, TOTAL AS P	0.071
6/21/2012 11:48	Grab	KJELDAHL NITROGEN, TOTAL	1.33
6/21/2012 11:48	Grab	NITRATE+NITRITE-N	-0.005
6/21/2012 11:48	Grab	PHOSPHATE, TOTAL AS P	0.095
6/27/2012 10:51	Grab	KJELDAHL NITROGEN, TOTAL	1.22
6/27/2012 10:51	Grab	NITRATE+NITRITE-N	0.045
6/27/2012 10:51	Grab	PHOSPHATE, TOTAL AS P	0.108
7/3/2012 11:10	Grab	KJELDAHL NITROGEN, TOTAL	1.28
7/3/2012 11:10	Grab	NITRATE+NITRITE-N	0.008
7/3/2012 11:10	Grab	PHOSPHATE, TOTAL AS P	0.085
7/10/2012 11:55	Grab	KJELDAHL NITROGEN, TOTAL	1.31
7/10/2012 11:55	Grab	NITRATE+NITRITE-N	0.005
7/10/2012 11:55	Grab	PHOSPHATE, TOTAL AS P	0.061
7/18/2012 11:52	Grab	KJELDAHL NITROGEN, TOTAL	1.26
7/18/2012 11:52	Grab	NITRATE+NITRITE-N	-0.005
7/18/2012 11:52	Grab	PHOSPHATE, TOTAL AS P	0.094
7/25/2012 10:46	Grab	KJELDAHL NITROGEN, TOTAL	1.24
7/25/2012 10:46	Grab	NITRATE+NITRITE-N	0.023
7/25/2012 10:46	Grab	PHOSPHATE, TOTAL AS P	0.095
8/1/2012 11:55	Grab	KJELDAHL NITROGEN, TOTAL	1.28
8/1/2012 11:55	Grab	NITRATE+NITRITE-N	0.007
8/1/2012 11:55	Grab	PHOSPHATE, TOTAL AS P	0.079
8/8/2012 9:42	Grab	KJELDAHL NITROGEN, TOTAL	1.37
8/8/2012 9:42	Grab	NITRATE+NITRITE-N	-0.005
8/8/2012 9:42	Grab	PHOSPHATE, TOTAL AS P	0.078
8/15/2012 11:28	Grab	KJELDAHL NITROGEN, TOTAL	1.28
8/15/2012 11:28	Grab	NITRATE+NITRITE-N	0.011
8/15/2012 11:28	Grab	PHOSPHATE, TOTAL AS P	0.105

Table C-1. S-78 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
8/22/2012 10:38	Grab	KJELDAHL NITROGEN, TOTAL	1.32
8/22/2012 10:38	Grab	NITRATE+NITRITE-N	0.005
8/22/2012 10:38	Grab	PHOSPHATE, TOTAL AS P	0.12
8/29/2012 11:42	Grab	KJELDAHL NITROGEN, TOTAL	1.25
8/29/2012 11:42	Grab	NITRATE+NITRITE-N	0.409
8/29/2012 11:42	Grab	PHOSPHATE, TOTAL AS P	0.129
9/5/2012 13:09	Grab	KJELDAHL NITROGEN, TOTAL	1.65
9/5/2012 13:09	Grab	NITRATE+NITRITE-N	0.102
9/5/2012 13:09	Grab	PHOSPHATE, TOTAL AS P	0.165
9/12/2012 10:30	Grab	KJELDAHL NITROGEN, TOTAL	1.52
9/12/2012 10:30	Grab	NITRATE+NITRITE-N	0.133
9/12/2012 10:30	Grab	PHOSPHATE, TOTAL AS P	0.144
9/19/2012 12:53	Grab	KJELDAHL NITROGEN, TOTAL	1.58
9/19/2012 12:53	Grab	NITRATE+NITRITE-N	0.269
9/19/2012 12:53	Grab	PHOSPHATE, TOTAL AS P	0.159
9/26/2012 10:46	Grab	KJELDAHL NITROGEN, TOTAL	1.85
9/26/2012 10:46	Grab	NITRATE+NITRITE-N	0.021
9/26/2012 10:46	Grab	PHOSPHATE, TOTAL AS P	0.226
10/3/2012 11:11	Grab	KJELDAHL NITROGEN, TOTAL	1.91
10/3/2012 11:11	Grab	NITRATE+NITRITE-N	0.009
10/3/2012 11:11	Grab	PHOSPHATE, TOTAL AS P	0.18
10/10/2012 10:46	Grab	KJELDAHL NITROGEN, TOTAL	2.07
10/10/2012 10:46	Grab	NITRATE+NITRITE-N	0.073
10/10/2012 10:46	Grab	PHOSPHATE, TOTAL AS P	0.15
10/17/2012 10:45	Grab	KJELDAHL NITROGEN, TOTAL	1.8
10/17/2012 10:45	Grab	NITRATE+NITRITE-N	0.017
10/17/2012 10:45	Grab	PHOSPHATE, TOTAL AS P	0.106
10/24/2012 11:13	Grab	KJELDAHL NITROGEN, TOTAL	1.67
10/24/2012 11:13	Grab	NITRATE+NITRITE-N	0.018
10/24/2012 11:13	Grab	PHOSPHATE, TOTAL AS P	0.097
11/1/2012 11:19	Grab	KJELDAHL NITROGEN, TOTAL	1.65
11/1/2012 11:19	Grab	NITRATE+NITRITE-N	0.075
11/1/2012 11:19	Grab	PHOSPHATE, TOTAL AS P	0.106
11/7/2012 10:24	Grab	KJELDAHL NITROGEN, TOTAL	1.38
11/7/2012 10:24	Grab	NITRATE+NITRITE-N	0.062
11/7/2012 10:24	Grab	PHOSPHATE, TOTAL AS P	0.076
11/14/2012 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.32
11/14/2012 10:40	Grab	NITRATE+NITRITE-N	0.079
11/14/2012 10:40	Grab	PHOSPHATE, TOTAL AS P	0.075
11/20/2012 10:08	Grab	KJELDAHL NITROGEN, TOTAL	1.46
11/20/2012 10:08	Grab	NITRATE+NITRITE-N	0.07
11/20/2012 10:08	Grab	PHOSPHATE, TOTAL AS P	0.095
11/28/2012 11:05	Grab	KJELDAHL NITROGEN, TOTAL	1.29
11/28/2012 11:05	Grab	NITRATE+NITRITE-N	0.057
11/28/2012 11:05	Grab	PHOSPHATE, TOTAL AS P	0.069
12/5/2012 10:28	Grab	KJELDAHL NITROGEN, TOTAL	1.37
12/5/2012 10:28	Grab	NITRATE+NITRITE-N	0.084

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
12/5/2012 10:28	Grab	PHOSPHATE, TOTAL AS P	0.077
12/12/2012 10:43	Grab	KJELDAHL NITROGEN, TOTAL	1.42
12/12/2012 10:43	Grab	NITRATE+NITRITE-N	0.109
12/12/2012 10:43	Grab	PHOSPHATE, TOTAL AS P	0.09
12/19/2012 11:00	Grab	KJELDAHL NITROGEN, TOTAL	1.46
12/19/2012 11:00	Grab	NITRATE+NITRITE-N	0.186
12/19/2012 11:00	Grab	PHOSPHATE, TOTAL AS P	0.135
12/27/2012 10:24	Grab	KJELDAHL NITROGEN, TOTAL	1.28
12/27/2012 10:24	Grab	NITRATE+NITRITE-N	0.102
12/27/2012 10:24	Grab	PHOSPHATE, TOTAL AS P	0.065
1/3/2013 10:03	Grab	KJELDAHL NITROGEN, TOTAL	1.26
1/3/2013 10:03	Grab	NITRATE+NITRITE-N	0.104
1/3/2013 10:03	Grab	PHOSPHATE, TOTAL AS P	0.067
1/9/2013 10:22	Grab	KJELDAHL NITROGEN, TOTAL	1.23
1/9/2013 10:22	Grab	NITRATE+NITRITE-N	0.099
1/9/2013 10:22	Grab	PHOSPHATE, TOTAL AS P	0.064
1/16/2013 10:21	Grab	KJELDAHL NITROGEN, TOTAL	1.36
1/16/2013 10:21	Grab	NITRATE+NITRITE-N	0.236
1/16/2013 10:21	Grab	PHOSPHATE, TOTAL AS P	0.097
1/23/2013 10:58	Grab	KJELDAHL NITROGEN, TOTAL	1.35
1/23/2013 10:58	Grab	NITRATE+NITRITE-N	0.128
1/23/2013 10:58	Grab	PHOSPHATE, TOTAL AS P	0.098
1/30/2013 12:22	Grab	KJELDAHL NITROGEN, TOTAL	1.19
1/30/2013 12:22	Grab	NITRATE+NITRITE-N	0.005
1/30/2013 12:22	Grab	PHOSPHATE, TOTAL AS P	0.061
2/6/2013 10:33	Grab	KJELDAHL NITROGEN, TOTAL	1.14
2/6/2013 10:33	Grab	NITRATE+NITRITE-N	-0.005
2/6/2013 10:33	Grab	PHOSPHATE, TOTAL AS P	0.043
2/13/2013 10:04	Grab	KJELDAHL NITROGEN, TOTAL	1.19
2/13/2013 10:04	Grab	NITRATE+NITRITE-N	-0.005
2/13/2013 10:04	Grab	PHOSPHATE, TOTAL AS P	0.054
2/21/2013 11:06	Grab	KJELDAHL NITROGEN, TOTAL	1.37
2/21/2013 11:06	Grab	NITRATE+NITRITE-N	0.205
2/21/2013 11:06	Grab	PHOSPHATE, TOTAL AS P	0.081
2/27/2013 10:36	Grab	KJELDAHL NITROGEN, TOTAL	1.17
2/27/2013 10:36	Grab	NITRATE+NITRITE-N	0.028
2/27/2013 10:36	Grab	PHOSPHATE, TOTAL AS P	0.066
3/6/2013 10:37	Grab	KJELDAHL NITROGEN, TOTAL	1.2
3/6/2013 10:37	Grab	NITRATE+NITRITE-N	0.052
3/6/2013 10:37	Grab	PHOSPHATE, TOTAL AS P	0.066
3/13/2013 11:11	Grab	KJELDAHL NITROGEN, TOTAL	1.21
3/13/2013 11:11	Grab	NITRATE+NITRITE-N	0.005
3/13/2013 11:11	Grab	PHOSPHATE, TOTAL AS P	0.063
3/20/2013 10:30	Grab	KJELDAHL NITROGEN, TOTAL	1.09
3/20/2013 10:30	Grab	NITRATE+NITRITE-N	-0.005
3/20/2013 10:30	Grab	PHOSPHATE, TOTAL AS P	0.053
3/27/2013 10:38	Grab	KJELDAHL NITROGEN, TOTAL	1.11

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
3/27/2013 10:38	Grab	NITRATE+NITRITE-N	0.011
3/27/2013 10:38	Grab	PHOSPHATE, TOTAL AS P	0.078
4/3/2013 10:53	Grab	KJELDAHL NITROGEN, TOTAL	1.1
4/3/2013 10:53	Grab	NITRATE+NITRITE-N	0.01
4/3/2013 10:53	Grab	PHOSPHATE, TOTAL AS P	0.046
4/10/2013 11:14	Grab	KJELDAHL NITROGEN, TOTAL	1.25
4/10/2013 11:14	Grab	NITRATE+NITRITE-N	-0.005
4/10/2013 11:14	Grab	PHOSPHATE, TOTAL AS P	0.064
4/17/2013 9:36	Grab	KJELDAHL NITROGEN, TOTAL	1.1
4/17/2013 9:36	Grab	NITRATE+NITRITE-N	-0.005
4/17/2013 9:36	Grab	PHOSPHATE, TOTAL AS P	0.067
4/24/2013 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.2
4/24/2013 10:40	Grab	NITRATE+NITRITE-N	0.024
4/24/2013 10:40	Grab	PHOSPHATE, TOTAL AS P	0.119
5/1/2013 10:23	Grab	KJELDAHL NITROGEN, TOTAL	1.28
5/1/2013 10:23	Grab	NITRATE+NITRITE-N	0.005
5/1/2013 10:23	Grab	PHOSPHATE, TOTAL AS P	0.078
5/8/2013 11:33	Grab	KJELDAHL NITROGEN, TOTAL	1.2
5/8/2013 11:33	Grab	NITRATE+NITRITE-N	0.007
5/8/2013 11:33	Grab	PHOSPHATE, TOTAL AS P	0.08
5/15/2013 10:33	Grab	KJELDAHL NITROGEN, TOTAL	1.28
5/15/2013 10:33	Grab	NITRATE+NITRITE-N	-0.005
5/15/2013 10:33	Grab	PHOSPHATE, TOTAL AS P	0.078
5/22/2013 12:39	Grab	KJELDAHL NITROGEN, TOTAL	1.47
5/22/2013 12:39	Grab	NITRATE+NITRITE-N	0.005
5/22/2013 12:39	Grab	PHOSPHATE, TOTAL AS P	0.108
5/29/2013 10:55	Grab	KJELDAHL NITROGEN, TOTAL	1.45
5/29/2013 10:55	Grab	NITRATE+NITRITE-N	0.057
5/29/2013 10:55	Grab	PHOSPHATE, TOTAL AS P	0.071
6/5/2013 10:10	Grab	KJELDAHL NITROGEN, TOTAL	1.28
6/5/2013 10:10	Grab	NITRATE+NITRITE-N	0.095
6/5/2013 10:10	Grab	PHOSPHATE, TOTAL AS P	0.069
6/12/2013 10:04	Grab	KJELDAHL NITROGEN, TOTAL	1.38
6/12/2013 10:04	Grab	NITRATE+NITRITE-N	0.152
6/12/2013 10:04	Grab	PHOSPHATE, TOTAL AS P	0.149
6/19/2013 10:38	Grab	KJELDAHL NITROGEN, TOTAL	1.43
6/19/2013 10:38	Grab	NITRATE+NITRITE-N	0.064
6/19/2013 10:38	Grab	PHOSPHATE, TOTAL AS P	0.179
6/26/2013 10:22	Grab	KJELDAHL NITROGEN, TOTAL	1.68
6/26/2013 10:22	Grab	NITRATE+NITRITE-N	0.08
6/26/2013 10:22	Grab	PHOSPHATE, TOTAL AS P	0.231
7/3/2013 10:47	Grab	KJELDAHL NITROGEN, TOTAL	1.44
7/3/2013 10:47	Grab	NITRATE+NITRITE-N	0.147
7/3/2013 10:47	Grab	PHOSPHATE, TOTAL AS P	0.172
7/10/2013 10:30	Grab	KJELDAHL NITROGEN, TOTAL	1.59
7/10/2013 10:30	Grab	NITRATE+NITRITE-N	0.076
7/10/2013 10:30	Grab	PHOSPHATE, TOTAL AS P	0.154

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/17/2013 10:18	Grab	KJELDAHL NITROGEN, TOTAL	1.72
7/17/2013 10:18	Grab	NITRATE+NITRITE-N	0.09
7/17/2013 10:18	Grab	PHOSPHATE, TOTAL AS P	0.168
7/24/2013 10:44	Grab	KJELDAHL NITROGEN, TOTAL	1.63
7/24/2013 10:44	Grab	NITRATE+NITRITE-N	0.134
7/24/2013 10:44	Grab	PHOSPHATE, TOTAL AS P	0.125
7/31/2013 10:14	Grab	KJELDAHL NITROGEN, TOTAL	1.52
7/31/2013 10:14	Grab	NITRATE+NITRITE-N	0.045
7/31/2013 10:14	Grab	PHOSPHATE, TOTAL AS P	0.126
8/7/2013 11:23	Grab	KJELDAHL NITROGEN, TOTAL	1.69
8/7/2013 11:23	Grab	NITRATE+NITRITE-N	0.05
8/7/2013 11:23	Grab	PHOSPHATE, TOTAL AS P	0.138
8/14/2013 10:55	Grab	KJELDAHL NITROGEN, TOTAL	1.5
8/14/2013 10:55	Grab	NITRATE+NITRITE-N	0.033
8/14/2013 10:55	Grab	PHOSPHATE, TOTAL AS P	0.09
8/21/2013 11:03	Grab	KJELDAHL NITROGEN, TOTAL	1.46
8/21/2013 11:03	Grab	NITRATE+NITRITE-N	0.053
8/21/2013 11:03	Grab	PHOSPHATE, TOTAL AS P	0.086
8/28/2013 11:09	Grab	KJELDAHL NITROGEN, TOTAL	1.24
8/28/2013 11:09	Grab	NITRATE+NITRITE-N	0.067
8/28/2013 11:09	Grab	PHOSPHATE, TOTAL AS P	0.084
9/4/2013 10:19	Grab	KJELDAHL NITROGEN, TOTAL	1.43
9/4/2013 10:19	Grab	NITRATE+NITRITE-N	0.042
9/4/2013 10:19	Grab	PHOSPHATE, TOTAL AS P	0.131
9/11/2013 10:01	Grab	KJELDAHL NITROGEN, TOTAL	1.28
9/11/2013 10:01	Grab	NITRATE+NITRITE-N	0.07
9/11/2013 10:01	Grab	PHOSPHATE, TOTAL AS P	0.081
9/18/2013 10:43	Grab	KJELDAHL NITROGEN, TOTAL	1.28
9/18/2013 10:43	Grab	NITRATE+NITRITE-N	0.071
9/18/2013 10:43	Grab	PHOSPHATE, TOTAL AS P	0.115
9/25/2013 10:20	Grab	KJELDAHL NITROGEN, TOTAL	1.65
9/25/2013 10:20	Grab	NITRATE+NITRITE-N	0.072
9/25/2013 10:20	Grab	PHOSPHATE, TOTAL AS P	0.136
10/2/2013 10:25	Grab	KJELDAHL NITROGEN, TOTAL	1.28
10/2/2013 10:25	Grab	NITRATE+NITRITE-N	0.047
10/2/2013 10:25	Grab	PHOSPHATE, TOTAL AS P	0.08
10/9/2013 11:08	Grab	KJELDAHL NITROGEN, TOTAL	1.23
10/9/2013 11:08	Grab	NITRATE+NITRITE-N	0.059
10/9/2013 11:08	Grab	PHOSPHATE, TOTAL AS P	0.07
10/16/2013 10:58	Grab	KJELDAHL NITROGEN, TOTAL	1.21
10/16/2013 10:58	Grab	NITRATE+NITRITE-N	0.054
10/16/2013 10:58	Grab	PHOSPHATE, TOTAL AS P	0.084
10/23/2013 9:51	Grab	KJELDAHL NITROGEN, TOTAL	1.21
10/23/2013 9:51	Grab	NITRATE+NITRITE-N	0.052
10/23/2013 9:51	Grab	PHOSPHATE, TOTAL AS P	0.103
10/30/2013 10:00	Grab	KJELDAHL NITROGEN, TOTAL	1.22
10/30/2013 10:00	Grab	NITRATE+NITRITE-N	0.082

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
10/30/2013 10:00	Grab	PHOSPHATE, TOTAL AS P	0.105
11/6/2013 10:04	Grab	KJELDAHL NITROGEN, TOTAL	1.15
11/6/2013 10:04	Grab	NITRATE+NITRITE-N	0.064
11/6/2013 10:04	Grab	PHOSPHATE, TOTAL AS P	0.062
11/14/2013 10:17	Grab	KJELDAHL NITROGEN, TOTAL	1.19
11/14/2013 10:17	Grab	NITRATE+NITRITE-N	0.124
11/14/2013 10:17	Grab	PHOSPHATE, TOTAL AS P	0.071
11/20/2013 10:56	Grab	KJELDAHL NITROGEN, TOTAL	1.19
11/20/2013 10:56	Grab	NITRATE+NITRITE-N	0.094
11/20/2013 10:56	Grab	PHOSPHATE, TOTAL AS P	0.063
11/26/2013 11:17	Grab	KJELDAHL NITROGEN, TOTAL	1.2
11/26/2013 11:17	Grab	NITRATE+NITRITE-N	0.097
11/26/2013 11:17	Grab	PHOSPHATE, TOTAL AS P	0.074
12/4/2013 10:10	Grab	KJELDAHL NITROGEN, TOTAL	1.12
12/4/2013 10:10	Grab	NITRATE+NITRITE-N	0.11
12/4/2013 10:10	Grab	PHOSPHATE, TOTAL AS P	0.078
12/11/2013 9:56	Grab	KJELDAHL NITROGEN, TOTAL	1.06
12/11/2013 9:56	Grab	NITRATE+NITRITE-N	0.138
12/11/2013 9:56	Grab	PHOSPHATE, TOTAL AS P	0.057
12/18/2013 11:23	Grab	KJELDAHL NITROGEN, TOTAL	1.09
12/18/2013 11:23	Grab	NITRATE+NITRITE-N	0.257
12/18/2013 11:23	Grab	PHOSPHATE, TOTAL AS P	0.095
12/23/2013 10:36	Grab	KJELDAHL NITROGEN, TOTAL	1.08
12/23/2013 10:36	Grab	NITRATE+NITRITE-N	0.115
12/23/2013 10:36	Grab	PHOSPHATE, TOTAL AS P	0.045
12/31/2013 10:20	Grab	KJELDAHL NITROGEN, TOTAL	1.09
12/31/2013 10:20	Grab	NITRATE+NITRITE-N	0.137
12/31/2013 10:20	Grab	PHOSPHATE, TOTAL AS P	0.054
1/8/2014 12:23	Grab	KJELDAHL NITROGEN, TOTAL	1.14
1/8/2014 12:23	Grab	NITRATE+NITRITE-N	0.167
1/8/2014 12:23	Grab	PHOSPHATE, TOTAL AS P	0.07
1/15/2014 9:48	Grab	KJELDAHL NITROGEN, TOTAL	1.08
1/15/2014 9:48	Grab	NITRATE+NITRITE-N	0.103
1/15/2014 9:48	Grab	PHOSPHATE, TOTAL AS P	0.051
1/22/2014 9:58	Grab	KJELDAHL NITROGEN, TOTAL	1.09
1/22/2014 9:58	Grab	NITRATE+NITRITE-N	0.166
1/22/2014 9:58	Grab	PHOSPHATE, TOTAL AS P	0.046
1/29/2014 11:04	Grab	KJELDAHL NITROGEN, TOTAL	1.08
1/29/2014 11:04	Grab	NITRATE+NITRITE-N	0.113
1/29/2014 11:04	Grab	PHOSPHATE, TOTAL AS P	0.055
2/5/2014 10:48	Grab	KJELDAHL NITROGEN, TOTAL	1.21
2/5/2014 10:48	Grab	NITRATE+NITRITE-N	0.105
2/5/2014 10:48	Grab	PHOSPHATE, TOTAL AS P	0.072
2/12/2014 10:19	Grab	KJELDAHL NITROGEN, TOTAL	1.09
2/12/2014 10:19	Grab	NITRATE+NITRITE-N	0.119
2/12/2014 10:19	Grab	PHOSPHATE, TOTAL AS P	0.067
2/19/2014 9:58	Grab	KJELDAHL NITROGEN, TOTAL	1.36

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/19/2014 9:58	Grab	NITRATE+NITRITE-N	0.254
2/19/2014 9:58	Grab	PHOSPHATE, TOTAL AS P	0.145
2/26/2014 10:03	Grab	KJELDAHL NITROGEN, TOTAL	1.17
2/26/2014 10:03	Grab	NITRATE+NITRITE-N	0.071
2/26/2014 10:03	Grab	PHOSPHATE, TOTAL AS P	0.086
3/5/2014 10:47	Grab	KJELDAHL NITROGEN, TOTAL	1.11
3/5/2014 10:47	Grab	NITRATE+NITRITE-N	0.114
3/5/2014 10:47	Grab	PHOSPHATE, TOTAL AS P	0.094
3/12/2014 10:09	Grab	KJELDAHL NITROGEN, TOTAL	1.18
3/12/2014 10:09	Grab	NITRATE+NITRITE-N	0.061
3/12/2014 10:09	Grab	PHOSPHATE, TOTAL AS P	0.1
3/19/2014 10:09	Grab	KJELDAHL NITROGEN, TOTAL	1
3/19/2014 10:09	Grab	NITRATE+NITRITE-N	0.084
3/19/2014 10:09	Grab	PHOSPHATE, TOTAL AS P	0.073
3/26/2014 12:28	Grab	KJELDAHL NITROGEN, TOTAL	1.12
3/26/2014 12:28	Grab	NITRATE+NITRITE-N	0.065
3/26/2014 12:28	Grab	PHOSPHATE, TOTAL AS P	0.075
4/2/2014 10:16	Grab	KJELDAHL NITROGEN, TOTAL	1.24
4/2/2014 10:16	Grab	NITRATE+NITRITE-N	0.06
4/2/2014 10:16	Grab	PHOSPHATE, TOTAL AS P	0.06
4/9/2014 9:12	Grab	KJELDAHL NITROGEN, TOTAL	1.09
4/9/2014 9:12	Grab	NITRATE+NITRITE-N	0.013
4/9/2014 9:12	Grab	PHOSPHATE, TOTAL AS P	0.061
4/16/2014 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.11
4/16/2014 10:40	Grab	NITRATE+NITRITE-N	0.02
4/16/2014 10:40	Grab	PHOSPHATE, TOTAL AS P	0.088
4/23/2014 9:41	Grab	KJELDAHL NITROGEN, TOTAL	1.04
4/23/2014 9:41	Grab	NITRATE+NITRITE-N	0.064
4/23/2014 9:41	Grab	PHOSPHATE, TOTAL AS P	0.066
4/30/2014 10:48	Grab	KJELDAHL NITROGEN, TOTAL	1.14
4/30/2014 10:48	Grab	NITRATE+NITRITE-N	0.006
4/30/2014 10:48	Grab	PHOSPHATE, TOTAL AS P	0.058
5/7/2014 10:03	Grab	KJELDAHL NITROGEN, TOTAL	1.14
5/7/2014 10:03	Grab	NITRATE+NITRITE-N	-0.005
5/7/2014 10:03	Grab	PHOSPHATE, TOTAL AS P	0.085
5/14/2014 9:44	Grab	KJELDAHL NITROGEN, TOTAL	1.08
5/14/2014 9:44	Grab	NITRATE+NITRITE-N	0.057
5/14/2014 9:44	Grab	PHOSPHATE, TOTAL AS P	0.078
5/21/2014 10:48	Grab	KJELDAHL NITROGEN, TOTAL	1.05
5/21/2014 10:48	Grab	NITRATE+NITRITE-N	0.013
5/21/2014 10:48	Grab	PHOSPHATE, TOTAL AS P	0.051
5/28/2014 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.03
5/28/2014 10:40	Grab	NITRATE+NITRITE-N	-0.005
5/28/2014 10:40	Grab	PHOSPHATE, TOTAL AS P	0.052
6/4/2014 11:17	Grab	NITRATE+NITRITE-N	0.018
6/4/2014 11:17	Grab	PHOSPHATE, TOTAL AS P	0.102
6/4/2014 11:17	Grab	TOTAL NITROGEN	0.98

Table C-1. S-78 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
6/11/2014 10:41	Grab	NITRATE+NITRITE-N	-0.005
6/11/2014 10:41	Grab	PHOSPHATE, TOTAL AS P	0.076
6/11/2014 10:41	Grab	TOTAL NITROGEN	0.99
6/18/2014 11:05	Grab	NITRATE+NITRITE-N	0.009
6/18/2014 11:05	Grab	PHOSPHATE, TOTAL AS P	0.091
6/18/2014 11:05	Grab	TOTAL NITROGEN	1.13
6/25/2014 10:38	Grab	NITRATE+NITRITE-N	-0.005
6/25/2014 10:38	Grab	PHOSPHATE, TOTAL AS P	0.057
6/25/2014 10:38	Grab	TOTAL NITROGEN	1.12
7/2/2014 10:08	Grab	NITRATE+NITRITE-N	0.013
7/2/2014 10:08	Grab	PHOSPHATE, TOTAL AS P	0.08
7/2/2014 10:08	Grab	TOTAL NITROGEN	1.07
7/9/2014 10:22	Grab	NITRATE+NITRITE-N	0.013
7/9/2014 10:22	Grab	PHOSPHATE, TOTAL AS P	0.092
7/9/2014 10:22	Grab	TOTAL NITROGEN	0.99
7/16/2014 10:09	Grab	NITRATE+NITRITE-N	0.085
7/16/2014 10:09	Grab	PHOSPHATE, TOTAL AS P	0.074
7/16/2014 10:09	Grab	TOTAL NITROGEN	1.42
7/23/2014 11:30	Grab	NITRATE+NITRITE-N	0.134
7/23/2014 11:30	Grab	PHOSPHATE, TOTAL AS P	0.226
7/23/2014 11:30	Grab	TOTAL NITROGEN	1.94
7/30/2014 10:21	Grab	NITRATE+NITRITE-N	0.147
7/30/2014 10:21	Grab	PHOSPHATE, TOTAL AS P	0.16
7/30/2014 10:21	Grab	TOTAL NITROGEN	1.57
8/6/2014 10:53	Grab	NITRATE+NITRITE-N	0.119
8/6/2014 10:53	Grab	PHOSPHATE, TOTAL AS P	0.232
8/6/2014 10:53	Grab	TOTAL NITROGEN	1.76
8/13/2014 10:15	Grab	NITRATE+NITRITE-N	0.094
8/13/2014 10:15	Grab	PHOSPHATE, TOTAL AS P	0.144
8/13/2014 10:15	Grab	TOTAL NITROGEN	1.41
8/20/2014 11:11	Grab	NITRATE+NITRITE-N	0.025
8/20/2014 11:11	Grab	PHOSPHATE, TOTAL AS P	0.114
8/20/2014 11:11	Grab	TOTAL NITROGEN	1.42
8/27/2014 9:19	Grab	NITRATE+NITRITE-N	0.081
8/27/2014 9:19	Grab	PHOSPHATE, TOTAL AS P	0.129
8/27/2014 9:19	Grab	TOTAL NITROGEN	1.51
9/3/2014 10:34	Grab	NITRATE+NITRITE-N	0.118
9/3/2014 10:34	Grab	PHOSPHATE, TOTAL AS P	0.179
9/3/2014 10:34	Grab	TOTAL NITROGEN	1.68
9/10/2014 10:30	Grab	NITRATE+NITRITE-N	0.139
9/10/2014 10:30	Grab	PHOSPHATE, TOTAL AS P	0.118
9/10/2014 10:30	Grab	TOTAL NITROGEN	1.56
9/17/2014 10:25	Grab	NITRATE+NITRITE-N	0.149
9/17/2014 10:25	Grab	PHOSPHATE, TOTAL AS P	0.19
9/17/2014 10:25	Grab	TOTAL NITROGEN	1.38
9/24/2014 10:22	Grab	NITRATE+NITRITE-N	0.236
9/24/2014 10:22	Grab	PHOSPHATE, TOTAL AS P	0.124

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/24/2014 10:22	Grab	TOTAL NITROGEN	1.58
10/1/2014 10:37	Grab	NITRATE+NITRITE-N	0.216
10/1/2014 10:37	Grab	PHOSPHATE, TOTAL AS P	0.181
10/1/2014 10:37	Grab	TOTAL NITROGEN	1.63
10/8/2014 10:45	Grab	NITRATE+NITRITE-N	0.273
10/8/2014 10:45	Grab	PHOSPHATE, TOTAL AS P	0.169
10/8/2014 10:45	Grab	TOTAL NITROGEN	1.63
10/15/2014 11:53	Grab	NITRATE+NITRITE-N	0.326
10/15/2014 11:53	Grab	PHOSPHATE, TOTAL AS P	0.138
10/15/2014 11:53	Grab	TOTAL NITROGEN	1.54
10/22/2014 10:53	Grab	NITRATE+NITRITE-N	0.45
10/22/2014 10:53	Grab	PHOSPHATE, TOTAL AS P	0.154
10/22/2014 10:53	Grab	TOTAL NITROGEN	1.77
10/29/2014 10:20	Grab	NITRATE+NITRITE-N	0.204
10/29/2014 10:20	Grab	PHOSPHATE, TOTAL AS P	0.108
10/29/2014 10:20	Grab	TOTAL NITROGEN	1.53
11/5/2014 10:54	Grab	NITRATE+NITRITE-N	0.04
11/5/2014 10:54	Grab	PHOSPHATE, TOTAL AS P	0.075
11/5/2014 10:54	Grab	TOTAL NITROGEN	1.2
11/12/2014 10:06	Grab	NITRATE+NITRITE-N	0.072
11/12/2014 10:06	Grab	PHOSPHATE, TOTAL AS P	0.08
11/12/2014 10:06	Grab	TOTAL NITROGEN	1.24
11/19/2014 10:12	Grab	NITRATE+NITRITE-N	0.063
11/19/2014 10:12	Grab	PHOSPHATE, TOTAL AS P	0.058
11/19/2014 10:12	Grab	TOTAL NITROGEN	1.16
11/26/2014 10:35	Grab	NITRATE+NITRITE-N	0.056
11/26/2014 10:35	Grab	PHOSPHATE, TOTAL AS P	0.056
11/26/2014 10:35	Grab	TOTAL NITROGEN	1.04
12/3/2014 10:35	Grab	NITRATE+NITRITE-N	0.11
12/3/2014 10:35	Grab	PHOSPHATE, TOTAL AS P	0.069
12/3/2014 10:35	Grab	TOTAL NITROGEN	1.28
12/10/2014 10:13	Grab	NITRATE+NITRITE-N	0.193
12/10/2014 10:13	Grab	PHOSPHATE, TOTAL AS P	0.063
12/10/2014 10:13	Grab	TOTAL NITROGEN	1.35
12/17/2014 11:09	Grab	NITRATE+NITRITE-N	0.102
12/17/2014 11:09	Grab	PHOSPHATE, TOTAL AS P	0.057
12/17/2014 11:09	Grab	TOTAL NITROGEN	1.34
12/23/2014 10:33	Grab	NITRATE+NITRITE-N	0.083
12/23/2014 10:33	Grab	PHOSPHATE, TOTAL AS P	0.068
12/23/2014 10:33	Grab	TOTAL NITROGEN	1.31
12/30/2014 9:52	Grab	NITRATE+NITRITE-N	0.084
12/30/2014 9:52	Grab	PHOSPHATE, TOTAL AS P	0.065
12/30/2014 9:52	Grab	TOTAL NITROGEN	1.25
1/7/2015 11:22	Grab	NITRATE+NITRITE-N	0.153
1/7/2015 11:22	Grab	PHOSPHATE, TOTAL AS P	0.09
1/7/2015 11:22	Grab	TOTAL NITROGEN	1.25
1/14/2015 10:55	Grab	NITRATE+NITRITE-N	0.142

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
1/14/2015 10:55	Grab	PHOSPHATE, TOTAL AS P	0.059
1/14/2015 10:55	Grab	TOTAL NITROGEN	1.16
1/21/2015 10:21	Grab	NITRATE+NITRITE-N	0.121
1/21/2015 10:21	Grab	PHOSPHATE, TOTAL AS P	0.052
1/21/2015 10:21	Grab	TOTAL NITROGEN	1
1/28/2015 10:26	Grab	NITRATE+NITRITE-N	0.07
1/28/2015 10:26	Grab	PHOSPHATE, TOTAL AS P	0.051
1/28/2015 10:26	Grab	TOTAL NITROGEN	1.11
2/4/2015 11:08	Grab	NITRATE+NITRITE-N	0.062
2/4/2015 11:08	Grab	PHOSPHATE, TOTAL AS P	0.066
2/4/2015 11:08	Grab	TOTAL NITROGEN	1.19
2/11/2015 11:01	Grab	NITRATE+NITRITE-N	0.041
2/11/2015 11:01	Grab	PHOSPHATE, TOTAL AS P	0.056
2/11/2015 11:01	Grab	TOTAL NITROGEN	1.08
2/18/2015 10:39	Grab	NITRATE+NITRITE-N	0.03
2/18/2015 10:39	Grab	PHOSPHATE, TOTAL AS P	0.062
2/18/2015 10:39	Grab	TOTAL NITROGEN	1.06
2/25/2015 10:12	Grab	NITRATE+NITRITE-N	0.022
2/25/2015 10:12	Grab	PHOSPHATE, TOTAL AS P	0.071
2/25/2015 10:12	Grab	TOTAL NITROGEN	1.1
3/4/2015 10:53	Grab	NITRATE+NITRITE-N	0.055
3/4/2015 10:53	Grab	PHOSPHATE, TOTAL AS P	0.079
3/4/2015 10:53	Grab	TOTAL NITROGEN	1.11
3/11/2015 10:20	Grab	NITRATE+NITRITE-N	0.097
3/11/2015 10:20	Grab	PHOSPHATE, TOTAL AS P	0.093
3/11/2015 10:20	Grab	TOTAL NITROGEN	1.16
3/18/2015 10:29	Grab	NITRATE+NITRITE-N	0.144
3/18/2015 10:29	Grab	PHOSPHATE, TOTAL AS P	0.104
3/18/2015 10:29	Grab	TOTAL NITROGEN	1.22
3/25/2015 10:08	Grab	NITRATE+NITRITE-N	0.098
3/25/2015 10:08	Grab	PHOSPHATE, TOTAL AS P	0.091
3/25/2015 10:08	Grab	TOTAL NITROGEN	1.14
4/1/2015 10:27	Grab	NITRATE+NITRITE-N	0.148
4/1/2015 10:27	Grab	PHOSPHATE, TOTAL AS P	0.093
4/1/2015 10:27	Grab	TOTAL NITROGEN	1.26
4/8/2015 10:29	Grab	NITRATE+NITRITE-N	0.039
4/8/2015 10:29	Grab	PHOSPHATE, TOTAL AS P	0.089
4/8/2015 10:29	Grab	TOTAL NITROGEN	1.12
4/15/2015 11:35	Grab	NITRATE+NITRITE-N	0.037
4/15/2015 11:35	Grab	PHOSPHATE, TOTAL AS P	0.082
4/15/2015 11:35	Grab	TOTAL NITROGEN	1.08
4/22/2015 10:15	Grab	NITRATE+NITRITE-N	0.27
4/22/2015 10:15	Grab	PHOSPHATE, TOTAL AS P	0.133
4/22/2015 10:15	Grab	TOTAL NITROGEN	1.61
4/29/2015 10:37	Grab	NITRATE+NITRITE-N	0.238
4/29/2015 10:37	Grab	PHOSPHATE, TOTAL AS P	0.134
4/29/2015 10:37	Grab	TOTAL NITROGEN	1.45

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/6/2015 10:33	Grab	NITRATE+NITRITE-N	0.113
5/6/2015 10:33	Grab	PHOSPHATE, TOTAL AS P	0.117
5/6/2015 10:33	Grab	TOTAL NITROGEN	1.39
5/13/2015 10:48	Grab	NITRATE+NITRITE-N	0.038
5/13/2015 10:48	Grab	PHOSPHATE, TOTAL AS P	0.101
5/13/2015 10:48	Grab	TOTAL NITROGEN	1.33
5/20/2015 10:14	Grab	NITRATE+NITRITE-N	0.031
5/20/2015 10:14	Grab	PHOSPHATE, TOTAL AS P	0.095
5/20/2015 10:14	Grab	TOTAL NITROGEN	1.58
5/27/2015 11:29	Grab	NITRATE+NITRITE-N	0.113
5/27/2015 11:29	Grab	PHOSPHATE, TOTAL AS P	0.092
5/27/2015 11:29	Grab	TOTAL NITROGEN	1.4
6/3/2015 10:21	Grab	NITRATE+NITRITE-N	0.055
6/3/2015 10:21	Grab	PHOSPHATE, TOTAL AS P	0.079
6/3/2015 10:21	Grab	TOTAL NITROGEN	1.31
6/10/2015 10:13	Grab	NITRATE+NITRITE-N	0.024
6/10/2015 10:13	Grab	PHOSPHATE, TOTAL AS P	0.082
6/10/2015 10:13	Grab	TOTAL NITROGEN	1.2
6/17/2015 10:15	Grab	NITRATE+NITRITE-N	0.054
6/17/2015 10:15	Grab	PHOSPHATE, TOTAL AS P	0.106
6/17/2015 10:15	Grab	TOTAL NITROGEN	1.29
6/24/2015 9:30	Grab	NITRATE+NITRITE-N	0.007
6/24/2015 9:30	Grab	PHOSPHATE, TOTAL AS P	0.101
6/24/2015 9:30	Grab	TOTAL NITROGEN	1.21
7/1/2015 10:05	Grab	NITRATE+NITRITE-N	0.009
7/1/2015 10:05	Grab	PHOSPHATE, TOTAL AS P	0.169
7/1/2015 10:05	Grab	TOTAL NITROGEN	1.11
7/8/2015 11:26	Grab	NITRATE+NITRITE-N	0.016
7/8/2015 11:26	Grab	PHOSPHATE, TOTAL AS P	0.17
7/8/2015 11:26	Grab	TOTAL NITROGEN	1.54
7/15/2015 10:00	Grab	NITRATE+NITRITE-N	0.009
7/15/2015 10:00	Grab	PHOSPHATE, TOTAL AS P	0.134
7/15/2015 10:00	Grab	TOTAL NITROGEN	0.92
7/29/2015 9:26	Grab	NITRATE+NITRITE-N	0.021
7/29/2015 9:26	Grab	PHOSPHATE, TOTAL AS P	0.111
7/29/2015 9:26	Grab	TOTAL NITROGEN	1.09
8/5/2015 11:39	Grab	NITRATE+NITRITE-N	0.01
8/5/2015 11:39	Grab	PHOSPHATE, TOTAL AS P	0.116
8/5/2015 11:39	Grab	TOTAL NITROGEN	1.31
8/12/2015 12:25	Grab	NITRATE+NITRITE-N	0.018
8/12/2015 12:25	Grab	PHOSPHATE, TOTAL AS P	0.124
8/12/2015 12:25	Grab	TOTAL NITROGEN	1.33
8/19/2015 10:40	Grab	NITRATE+NITRITE-N	0.145
8/19/2015 10:40	Grab	PHOSPHATE, TOTAL AS P	0.124
8/19/2015 10:40	Grab	TOTAL NITROGEN	1.36
8/26/2015 10:08	Grab	NITRATE+NITRITE-N	0.03
8/26/2015 10:08	Grab	PHOSPHATE, TOTAL AS P	0.181

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
8/26/2015 10:08	Grab	TOTAL NITROGEN	1.99
9/2/2015 10:45	Grab	NITRATE+NITRITE-N	0.173
9/2/2015 10:45	Grab	PHOSPHATE, TOTAL AS P	0.092
9/2/2015 10:45	Grab	TOTAL NITROGEN	1.62
9/9/2015 9:57	Grab	NITRATE+NITRITE-N	0.21
9/9/2015 9:57	Grab	PHOSPHATE, TOTAL AS P	0.089
9/9/2015 9:57	Grab	TOTAL NITROGEN	1.57
9/16/2015 10:29	Grab	NITRATE+NITRITE-N	0.112
9/16/2015 10:29	Grab	PHOSPHATE, TOTAL AS P	0.131
9/16/2015 10:29	Grab	TOTAL NITROGEN	1.48
9/23/2015 9:50	Grab	NITRATE+NITRITE-N	0.137
9/23/2015 9:50	Grab	PHOSPHATE, TOTAL AS P	0.136
9/23/2015 9:50	Grab	TOTAL NITROGEN	1.77
9/30/2015 9:40	Grab	NITRATE+NITRITE-N	0.257
9/30/2015 9:40	Grab	PHOSPHATE, TOTAL AS P	0.147
9/30/2015 9:40	Grab	TOTAL NITROGEN	1.59
10/7/2015 10:11	Grab	NITRATE+NITRITE-N	0.366
10/7/2015 10:11	Grab	PHOSPHATE, TOTAL AS P	0.158
10/7/2015 10:11	Grab	TOTAL NITROGEN	1.62
10/14/2015 10:35	Grab	NITRATE+NITRITE-N	0.386
10/14/2015 10:35	Grab	PHOSPHATE, TOTAL AS P	0.15
10/14/2015 10:35	Grab	TOTAL NITROGEN	1.55
10/21/2015 9:27	Grab	NITRATE+NITRITE-N	0.434
10/21/2015 9:27	Grab	PHOSPHATE, TOTAL AS P	0.14
10/21/2015 9:27	Grab	TOTAL NITROGEN	1.63
10/28/2015 11:18	Grab	NITRATE+NITRITE-N	0.128
10/28/2015 11:18	Grab	PHOSPHATE, TOTAL AS P	0.094
10/28/2015 11:18	Grab	TOTAL NITROGEN	1.33
11/4/2015 10:01	Grab	NITRATE+NITRITE-N	0.131
11/4/2015 10:01	Grab	PHOSPHATE, TOTAL AS P	0.113
11/4/2015 10:01	Grab	TOTAL NITROGEN	1.57
11/10/2015 9:40	Grab	NITRATE+NITRITE-N	0.236
11/10/2015 9:40	Grab	PHOSPHATE, TOTAL AS P	0.113
11/10/2015 9:40	Grab	TOTAL NITROGEN	1.49
11/18/2015 9:51	Grab	NITRATE+NITRITE-N	0.181
11/18/2015 9:51	Grab	PHOSPHATE, TOTAL AS P	0.1
11/18/2015 9:51	Grab	TOTAL NITROGEN	1.39
11/24/2015 10:37	Grab	NITRATE+NITRITE-N	0.27
11/24/2015 10:37	Grab	PHOSPHATE, TOTAL AS P	0.102
11/24/2015 10:37	Grab	TOTAL NITROGEN	1.34
12/2/2015 9:29	Grab	NITRATE+NITRITE-N	0.377
12/2/2015 9:29	Grab	PHOSPHATE, TOTAL AS P	0.084
12/2/2015 9:29	Grab	TOTAL NITROGEN	1.58
12/9/2015 10:06	Grab	NITRATE+NITRITE-N	0.206
12/9/2015 10:06	Grab	PHOSPHATE, TOTAL AS P	0.088
12/9/2015 10:06	Grab	TOTAL NITROGEN	1.34
12/21/2015 10:40	Grab	NITRATE+NITRITE-N	0.161

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
12/21/2015 10:40	Grab	PHOSPHATE, TOTAL AS P	0.151
12/21/2015 10:40	Grab	TOTAL NITROGEN	1.45
1/4/2016 11:56	Grab	NITRATE+NITRITE-N	0.14
1/4/2016 11:56	Grab	PHOSPHATE, TOTAL AS P	0.114
1/4/2016 11:56	Grab	TOTAL NITROGEN	1.38
1/19/2016 10:47	Grab	NITRATE+NITRITE-N	0.43
1/19/2016 10:47	Grab	PHOSPHATE, TOTAL AS P	0.092
1/19/2016 10:47	Grab	TOTAL NITROGEN	1.78
2/1/2016 11:11	Grab	NITRATE+NITRITE-N	0.922
2/1/2016 11:11	Grab	PHOSPHATE, TOTAL AS P	0.202
2/1/2016 11:11	Grab	TOTAL NITROGEN	2.36
2/15/2016 9:44	Grab	NITRATE+NITRITE-N	0.154
2/15/2016 9:44	Grab	PHOSPHATE, TOTAL AS P	0.155
2/15/2016 9:44	Grab	TOTAL NITROGEN	1.67
2/29/2016 10:41	Grab	NITRATE+NITRITE-N	0.046
2/29/2016 10:41	Grab	PHOSPHATE, TOTAL AS P	0.116
2/29/2016 10:41	Grab	TOTAL NITROGEN	1.73
3/14/2016 11:13	Grab	NITRATE+NITRITE-N	0.043
3/14/2016 11:13	Grab	PHOSPHATE, TOTAL AS P	0.074
3/14/2016 11:13	Grab	TOTAL NITROGEN	1.17
3/28/2016 9:30	Grab	NITRATE+NITRITE-N	0.084
3/28/2016 9:30	Grab	PHOSPHATE, TOTAL AS P	0.09
3/28/2016 9:30	Grab	TOTAL NITROGEN	1.16
4/11/2016 10:14	Grab	NITRATE+NITRITE-N	0.114
4/11/2016 10:14	Grab	PHOSPHATE, TOTAL AS P	0.092
4/11/2016 10:14	Grab	TOTAL NITROGEN	1.26
4/25/2016 11:26	Grab	NITRATE+NITRITE-N	0.072
4/25/2016 11:26	Grab	PHOSPHATE, TOTAL AS P	0.091
4/25/2016 11:26	Grab	TOTAL NITROGEN	1.15
5/9/2016 11:35	Grab	NITRATE+NITRITE-N	0.15
5/9/2016 11:35	Grab	PHOSPHATE, TOTAL AS P	0.116
5/9/2016 11:35	Grab	TOTAL NITROGEN	1.38
5/23/2016 9:32	Grab	NITRATE+NITRITE-N	0.187
5/23/2016 9:32	Grab	PHOSPHATE, TOTAL AS P	0.186
5/23/2016 9:32	Grab	TOTAL NITROGEN	1.42
6/7/2016 10:10	Grab	NITRATE+NITRITE-N	0.064
6/7/2016 10:10	Grab	PHOSPHATE, TOTAL AS P	0.116
6/7/2016 10:10	Grab	TOTAL NITROGEN	1.44
6/20/2016 10:01	Grab	NITRATE+NITRITE-N	0.122
6/20/2016 10:01	Grab	PHOSPHATE, TOTAL AS P	0.188
6/20/2016 10:01	Grab	TOTAL NITROGEN	1.91
7/5/2016 11:01	Grab	NITRATE+NITRITE-N	0.095
7/5/2016 11:01	Grab	PHOSPHATE, TOTAL AS P	0.15
7/5/2016 11:01	Grab	TOTAL NITROGEN	1.66
7/18/2016 10:01	Grab	NITRATE+NITRITE-N	0.085
7/18/2016 10:01	Grab	PHOSPHATE, TOTAL AS P	0.12
7/18/2016 10:01	Grab	TOTAL NITROGEN	1.4

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
8/1/2016 10:26	Grab	NITRATE+NITRITE-N	0.085
8/1/2016 10:26	Grab	PHOSPHATE, TOTAL AS P	0.16
8/1/2016 10:26	Grab	TOTAL NITROGEN	1.48
8/15/2016 12:09	Grab	NITRATE+NITRITE-N	0.132
8/15/2016 12:09	Grab	PHOSPHATE, TOTAL AS P	0.12
8/15/2016 12:09	Grab	TOTAL NITROGEN	1.36
9/12/2016 9:32	Grab	KJELDAHL NITROGEN, TOTAL	1.38
9/12/2016 9:32	Grab	NITRATE+NITRITE-N	0.257
9/12/2016 9:32	Grab	PHOSPHATE, TOTAL AS P	0.126
9/12/2016 9:32	Grab	TOTAL NITROGEN	1.57
9/26/2016 10:11	Grab	NITRATE+NITRITE-N	0.131
9/26/2016 10:11	Grab	PHOSPHATE, TOTAL AS P	0.102
9/26/2016 10:11	Grab	TOTAL NITROGEN	1.26
10/10/2016 11:33	Grab	KJELDAHL NITROGEN, TOTAL	1.56
10/10/2016 11:33	Grab	NITRATE+NITRITE-N	0.172
10/10/2016 11:33	Grab	PHOSPHATE, TOTAL AS P	0.121
10/10/2016 11:33	Grab	TOTAL NITROGEN	1.8
10/24/2016 10:04	Grab	NITRATE+NITRITE-N	0.082
10/24/2016 10:04	Grab	PHOSPHATE, TOTAL AS P	0.05
10/24/2016 10:04	Grab	TOTAL NITROGEN	1.09
11/7/2016 10:13	Grab	KJELDAHL NITROGEN, TOTAL	1.01
11/7/2016 10:13	Grab	NITRATE+NITRITE-N	0.101
11/7/2016 10:13	Grab	PHOSPHATE, TOTAL AS P	0.055
11/7/2016 10:13	Grab	TOTAL NITROGEN	1.13
11/21/2016 10:03	Grab	NITRATE+NITRITE-N	0.121
11/21/2016 10:03	Grab	PHOSPHATE, TOTAL AS P	0.07
11/21/2016 10:03	Grab	TOTAL NITROGEN	1.34
12/7/2016 10:35	Grab	NITRATE+NITRITE-N	0.145
12/7/2016 10:35	Grab	PHOSPHATE, TOTAL AS P	0.074
12/7/2016 10:35	Grab	TOTAL NITROGEN	1.11
1/5/2017 10:55	Grab	KJELDAHL NITROGEN, TOTAL	0.98
1/5/2017 10:55	Grab	NITRATE+NITRITE-N	0.164
1/5/2017 10:55	Grab	PHOSPHATE, TOTAL AS P	0.068
1/5/2017 10:55	Grab	TOTAL NITROGEN	1.07
1/11/2017 10:18	Grab	NITRATE+NITRITE-N	0.18
1/11/2017 10:18	Grab	PHOSPHATE, TOTAL AS P	0.076
1/11/2017 10:18	Grab	TOTAL NITROGEN	1.13
1/19/2017 9:40	Grab	PHOSPHATE, TOTAL AS P	0.08
1/25/2017 10:12	Grab	NITRATE+NITRITE-N	0.128
1/25/2017 10:12	Grab	PHOSPHATE, TOTAL AS P	0.067
1/25/2017 10:12	Grab	TOTAL NITROGEN	1.06
2/1/2017 9:45	Grab	NITRATE+NITRITE-N	0.205
2/1/2017 9:45	Grab	PHOSPHATE, TOTAL AS P	0.083
2/1/2017 9:45	Grab	TOTAL NITROGEN	1.16
2/8/2017 10:34	Grab	NITRATE+NITRITE-N	0.153
2/8/2017 10:34	Grab	PHOSPHATE, TOTAL AS P	0.086
2/8/2017 10:34	Grab	TOTAL NITROGEN	1.2

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/15/2017 10:11	Grab	NITRATE+NITRITE-N	0.093
2/15/2017 10:11	Grab	PHOSPHATE, TOTAL AS P	0.069
2/15/2017 10:11	Grab	TOTAL NITROGEN	1.06
2/22/2017 9:07	Grab	NITRATE+NITRITE-N	0.091
2/22/2017 9:07	Grab	PHOSPHATE, TOTAL AS P	0.072
2/22/2017 9:07	Grab	TOTAL NITROGEN	1.03
3/1/2017 10:02	Grab	NITRATE+NITRITE-N	0.079
3/1/2017 10:02	Grab	PHOSPHATE, TOTAL AS P	0.072
3/1/2017 10:02	Grab	TOTAL NITROGEN	1.01
3/8/2017 10:10	Grab	NITRATE+NITRITE-N	0.138
3/8/2017 10:10	Grab	PHOSPHATE, TOTAL AS P	0.078
3/8/2017 10:10	Grab	TOTAL NITROGEN	1.09
3/15/2017 13:09	Grab	NITRATE+NITRITE-N	0.087
3/15/2017 13:09	Grab	PHOSPHATE, TOTAL AS P	0.083
3/15/2017 13:09	Grab	TOTAL NITROGEN	1.14
3/22/2017 9:39	Grab	NITRATE+NITRITE-N	0.246
3/22/2017 9:39	Grab	PHOSPHATE, TOTAL AS P	0.089
3/22/2017 9:39	Grab	TOTAL NITROGEN	1.28
3/29/2017 9:28	Grab	NITRATE+NITRITE-N	0.03
3/29/2017 9:28	Grab	PHOSPHATE, TOTAL AS P	0.068
3/29/2017 9:28	Grab	TOTAL NITROGEN	1.08
4/5/2017 10:04	Grab	NITRATE+NITRITE-N	-0.005
4/5/2017 10:04	Grab	PHOSPHATE, TOTAL AS P	0.07
4/5/2017 10:04	Grab	TOTAL NITROGEN	1.11
4/12/2017 9:30	Grab	NITRATE+NITRITE-N	0.239
4/12/2017 9:30	Grab	PHOSPHATE, TOTAL AS P	0.082
4/12/2017 9:30	Grab	TOTAL NITROGEN	1.34
4/19/2017 10:16	Grab	NITRATE+NITRITE-N	0.067
4/19/2017 10:16	Grab	PHOSPHATE, TOTAL AS P	0.083
4/19/2017 10:16	Grab	TOTAL NITROGEN	1.34
4/26/2017 9:44	Grab	NITRATE+NITRITE-N	0.044
4/26/2017 9:44	Grab	PHOSPHATE, TOTAL AS P	0.085
4/26/2017 9:44	Grab	TOTAL NITROGEN	1.22
5/3/2017 9:38	Grab	NITRATE+NITRITE-N	-0.005
5/3/2017 9:38	Grab	PHOSPHATE, TOTAL AS P	0.074
5/3/2017 9:38	Grab	TOTAL NITROGEN	1.25
5/10/2017 10:50	Grab	NITRATE+NITRITE-N	-0.005
5/10/2017 10:50	Grab	PHOSPHATE, TOTAL AS P	0.089
5/10/2017 10:50	Grab	TOTAL NITROGEN	1.39
5/17/2017 10:23	Grab	NITRATE+NITRITE-N	0.006
5/17/2017 10:23	Grab	PHOSPHATE, TOTAL AS P	0.087
5/17/2017 10:23	Grab	TOTAL NITROGEN	1.41
5/24/2017 10:18	Grab	NITRATE+NITRITE-N	0.048
5/24/2017 10:18	Grab	PHOSPHATE, TOTAL AS P	0.083
5/24/2017 10:18	Grab	TOTAL NITROGEN	1.24
5/31/2017 10:09	Grab	NITRATE+NITRITE-N	-0.005
5/31/2017 10:09	Grab	PHOSPHATE, TOTAL AS P	0.054

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/31/2017 10:09	Grab	TOTAL NITROGEN	1.1
6/7/2017 10:11	Grab	NITRATE+NITRITE-N	0.082
6/7/2017 10:11	Grab	PHOSPHATE, TOTAL AS P	0.091
6/7/2017 10:11	Grab	TOTAL NITROGEN	1.24
6/14/2017 10:35	Grab	NITRATE+NITRITE-N	0.187
6/14/2017 10:35	Grab	PHOSPHATE, TOTAL AS P	0.31
6/14/2017 10:35	Grab	TOTAL NITROGEN	1.8
6/21/2017 10:42	Grab	NITRATE+NITRITE-N	0.145
6/21/2017 10:42	Grab	PHOSPHATE, TOTAL AS P	0.287
6/21/2017 10:42	Grab	TOTAL NITROGEN	1.79
6/28/2017 10:48	Grab	NITRATE+NITRITE-N	0.074
6/28/2017 10:48	Grab	PHOSPHATE, TOTAL AS P	0.221
6/28/2017 10:48	Grab	TOTAL NITROGEN	1.4
7/6/2017 9:44	Grab	NITRATE+NITRITE-N	0.011
7/6/2017 9:44	Grab	PHOSPHATE, TOTAL AS P	0.215
7/6/2017 9:44	Grab	TOTAL NITROGEN	1.52
7/12/2017 10:03	Grab	NITRATE+NITRITE-N	0.027
7/12/2017 10:03	Grab	PHOSPHATE, TOTAL AS P	0.226
7/12/2017 10:03	Grab	TOTAL NITROGEN	1.56
7/19/2017 9:56	Grab	NITRATE+NITRITE-N	0.31
7/19/2017 9:56	Grab	PHOSPHATE, TOTAL AS P	0.281
7/19/2017 9:56	Grab	TOTAL NITROGEN	1.85
7/26/2017 10:11	Grab	NITRATE+NITRITE-N	0.033
7/26/2017 10:11	Grab	PHOSPHATE, TOTAL AS P	0.179
7/26/2017 10:11	Grab	TOTAL NITROGEN	1.52
8/2/2017 9:49	Grab	NITRATE+NITRITE-N	0.118
8/2/2017 9:49	Grab	PHOSPHATE, TOTAL AS P	0.204
8/2/2017 9:49	Grab	TOTAL NITROGEN	1.67
8/9/2017 10:14	Grab	NITRATE+NITRITE-N	0.279
8/9/2017 10:14	Grab	PHOSPHATE, TOTAL AS P	0.192
8/9/2017 10:14	Grab	TOTAL NITROGEN	1.82
8/14/2017 9:36	Grab	NITRATE+NITRITE-N	0.233
8/14/2017 9:36	Grab	PHOSPHATE, TOTAL AS P	0.214
8/14/2017 9:36	Grab	TOTAL NITROGEN	1.71
8/21/2017 10:16	Grab	NITRATE+NITRITE-N	0.16
8/21/2017 10:16	Grab	PHOSPHATE, TOTAL AS P	0.162
8/21/2017 10:16	Grab	TOTAL NITROGEN	1.55
8/28/2017 10:03	Grab	NITRATE+NITRITE-N	0.225
8/28/2017 10:03	Grab	PHOSPHATE, TOTAL AS P	0.15
8/28/2017 10:03	Grab	TOTAL NITROGEN	1.54
9/5/2017 11:11	Grab	NITRATE+NITRITE-N	0.14
9/5/2017 11:11	Grab	PHOSPHATE, TOTAL AS P	0.116
9/5/2017 11:11	Grab	TOTAL NITROGEN	1.44
9/13/2017 12:05	Grab	NITRATE+NITRITE-N	0.095
9/13/2017 12:05	Grab	PHOSPHATE, TOTAL AS P	0.272
9/13/2017 12:05	Grab	TOTAL NITROGEN	1.32
9/18/2017 10:33	Grab	NITRATE+NITRITE-N	0.02

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/18/2017 10:33	Grab	PHOSPHATE, TOTAL AS P	0.483
9/18/2017 10:33	Grab	TOTAL NITROGEN	1.81
9/25/2017 9:54	Grab	NITRATE+NITRITE-N	0.04
9/25/2017 9:54	Grab	PHOSPHATE, TOTAL AS P	0.246
9/25/2017 9:54	Grab	TOTAL NITROGEN	1.75
10/2/2017 10:51	Grab	NITRATE+NITRITE-N	0.028
10/2/2017 10:51	Grab	PHOSPHATE, TOTAL AS P	0.235
10/2/2017 10:51	Grab	TOTAL NITROGEN	2.26
10/9/2017 10:28	Grab	NITRATE+NITRITE-N	0.094
10/9/2017 10:28	Grab	PHOSPHATE, TOTAL AS P	0.189
10/9/2017 10:28	Grab	TOTAL NITROGEN	1.93
10/16/2017 10:16	Grab	NITRATE+NITRITE-N	0.08
10/16/2017 10:16	Grab	PHOSPHATE, TOTAL AS P	0.117
10/16/2017 10:16	Grab	TOTAL NITROGEN	2.61
10/23/2017 10:24	Grab	NITRATE+NITRITE-N	0.099
10/23/2017 10:24	Grab	PHOSPHATE, TOTAL AS P	0.139
10/23/2017 10:24	Grab	TOTAL NITROGEN	1.67
10/30/2017 10:15	Grab	NITRATE+NITRITE-N	0.22
10/30/2017 10:15	Grab	PHOSPHATE, TOTAL AS P	0.124
10/30/2017 10:15	Grab	TOTAL NITROGEN	1.55
11/6/2017 10:50	Grab	NITRATE+NITRITE-N	0.138
11/6/2017 10:50	Grab	PHOSPHATE, TOTAL AS P	0.109
11/6/2017 10:50	Grab	TOTAL NITROGEN	1.39
11/13/2017 10:33	Grab	NITRATE+NITRITE-N	0.116
11/13/2017 10:33	Grab	PHOSPHATE, TOTAL AS P	0.114
11/13/2017 10:33	Grab	TOTAL NITROGEN	1.36
11/20/2017 10:38	Grab	NITRATE+NITRITE-N	0.131
11/20/2017 10:38	Grab	PHOSPHATE, TOTAL AS P	0.116
11/20/2017 10:38	Grab	TOTAL NITROGEN	1.35
11/27/2017 10:05	Grab	NITRATE+NITRITE-N	0.173
11/27/2017 10:05	Grab	PHOSPHATE, TOTAL AS P	0.134
11/27/2017 10:05	Grab	TOTAL NITROGEN	1.42
12/4/2017 9:45	Grab	NITRATE+NITRITE-N	0.216
12/4/2017 9:45	Grab	PHOSPHATE, TOTAL AS P	0.124
12/4/2017 9:45	Grab	TOTAL NITROGEN	1.32
12/11/2017 9:44	Grab	NITRATE+NITRITE-N	0.181
12/11/2017 9:44	Grab	PHOSPHATE, TOTAL AS P	0.111
12/11/2017 9:44	Grab	TOTAL NITROGEN	1.28
12/18/2017 10:15	Grab	NITRATE+NITRITE-N	0.25
12/18/2017 10:15	Grab	PHOSPHATE, TOTAL AS P	0.128
12/18/2017 10:15	Grab	TOTAL NITROGEN	1.39
12/27/2017 9:41	Grab	NITRATE+NITRITE-N	0.231
12/27/2017 9:41	Grab	PHOSPHATE, TOTAL AS P	0.122
12/27/2017 9:41	Grab	TOTAL NITROGEN	1.34
1/3/2018 9:51	Grab	NITRATE+NITRITE-N	0.215
1/3/2018 9:51	Grab	PHOSPHATE, TOTAL AS P	0.114
1/3/2018 9:51	Grab	TOTAL NITROGEN	1.26

Table C-1. S-78 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
1/8/2018 9:36	Grab	NITRATE+NITRITE-N	0.303
1/8/2018 9:36	Grab	PHOSPHATE, TOTAL AS P	0.136
1/8/2018 9:36	Grab	TOTAL NITROGEN	1.33
1/18/2018 11:00	Grab	NITRATE+NITRITE-N	0.352
1/18/2018 11:00	Grab	PHOSPHATE, TOTAL AS P	0.122
1/18/2018 11:00	Grab	TOTAL NITROGEN	1.37
1/22/2018 9:34	Grab	NITRATE+NITRITE-N	0.336
1/22/2018 9:34	Grab	PHOSPHATE, TOTAL AS P	0.138
1/22/2018 9:34	Grab	TOTAL NITROGEN	1.4
1/29/2018 9:45	Grab	NITRATE+NITRITE-N	0.249
1/29/2018 9:45	Grab	PHOSPHATE, TOTAL AS P	0.108
1/29/2018 9:45	Grab	TOTAL NITROGEN	1.19
2/5/2018 11:08	Grab	NITRATE+NITRITE-N	0.146
2/5/2018 11:08	Grab	PHOSPHATE, TOTAL AS P	0.091
2/5/2018 11:08	Grab	TOTAL NITROGEN	1.18
2/12/2018 9:59	Grab	NITRATE+NITRITE-N	0.167
2/12/2018 9:59	Grab	PHOSPHATE, TOTAL AS P	0.122
2/12/2018 9:59	Grab	TOTAL NITROGEN	1.25
2/19/2018 10:07	Grab	NITRATE+NITRITE-N	0.084
2/19/2018 10:07	Grab	PHOSPHATE, TOTAL AS P	0.103
2/19/2018 10:07	Grab	TOTAL NITROGEN	1.16
2/26/2018 10:08	Grab	NITRATE+NITRITE-N	0.106
2/26/2018 10:08	Grab	PHOSPHATE, TOTAL AS P	0.117
2/26/2018 10:08	Grab	TOTAL NITROGEN	1.17
3/5/2018 10:35	Grab	NITRATE+NITRITE-N	0.186
3/5/2018 10:35	Grab	PHOSPHATE, TOTAL AS P	0.127
3/5/2018 10:35	Grab	TOTAL NITROGEN	1.36
3/12/2018 9:32	Grab	NITRATE+NITRITE-N	0.252
3/12/2018 9:32	Grab	PHOSPHATE, TOTAL AS P	0.135
3/12/2018 9:32	Grab	TOTAL NITROGEN	1.01
3/19/2018 10:38	Grab	NITRATE+NITRITE-N	0.179
3/19/2018 10:38	Grab	PHOSPHATE, TOTAL AS P	0.118
3/19/2018 10:38	Grab	TOTAL NITROGEN	1.3
3/26/2018 10:34	Grab	NITRATE+NITRITE-N	0.19
3/26/2018 10:34	Grab	PHOSPHATE, TOTAL AS P	0.106
3/26/2018 10:34	Grab	TOTAL NITROGEN	1.2
4/2/2018 10:29	Grab	NITRATE+NITRITE-N	0.036
4/2/2018 10:29	Grab	PHOSPHATE, TOTAL AS P	0.087
4/2/2018 10:29	Grab	TOTAL NITROGEN	1.08
4/9/2018 9:35	Grab	NITRATE+NITRITE-N	0.148
4/9/2018 9:35	Grab	PHOSPHATE, TOTAL AS P	0.109
4/9/2018 9:35	Grab	TOTAL NITROGEN	1.26
4/16/2018 10:29	Grab	NITRATE+NITRITE-N	0.323
4/16/2018 10:29	Grab	PHOSPHATE, TOTAL AS P	0.135
4/16/2018 10:29	Grab	TOTAL NITROGEN	1.41
4/23/2018 10:59	Grab	NITRATE+NITRITE-N	0.292
4/23/2018 10:59	Grab	PHOSPHATE, TOTAL AS P	0.129

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
4/23/2018 10:59	Grab	TOTAL NITROGEN	1.39
4/30/2018 9:25	Grab	NITRATE+NITRITE-N	0.155
4/30/2018 9:25	Grab	PHOSPHATE, TOTAL AS P	0.108
4/30/2018 9:25	Grab	TOTAL NITROGEN	1.29
5/7/2018 9:38	Grab	NITRATE+NITRITE-N	0.07
5/7/2018 9:38	Grab	PHOSPHATE, TOTAL AS P	0.106
5/7/2018 9:38	Grab	TOTAL NITROGEN	1.24
5/14/2018 10:05	Grab	NITRATE+NITRITE-N	0.123
5/14/2018 10:05	Grab	PHOSPHATE, TOTAL AS P	0.111
5/14/2018 10:05	Grab	TOTAL NITROGEN	1.31
5/21/2018 9:49	Grab	NITRATE+NITRITE-N	0.386
5/21/2018 9:49	Grab	PHOSPHATE, TOTAL AS P	0.138
5/21/2018 9:49	Grab	TOTAL NITROGEN	1.75
5/30/2018 10:49	Grab	NITRATE+NITRITE-N	0.318
5/30/2018 10:49	Grab	PHOSPHATE, TOTAL AS P	0.18
5/30/2018 10:49	Grab	TOTAL NITROGEN	1.78
6/4/2018 12:59	Grab	NITRATE+NITRITE-N	0.395
6/4/2018 12:59	Grab	PHOSPHATE, TOTAL AS P	0.237
6/4/2018 12:59	Grab	TOTAL NITROGEN	1.94
6/11/2018 9:43	Grab	NITRATE+NITRITE-N	0.181
6/11/2018 9:43	Grab	PHOSPHATE, TOTAL AS P	0.243
6/11/2018 9:43	Grab	TOTAL NITROGEN	1.79
6/18/2018 9:41	Grab	NITRATE+NITRITE-N	0.176
6/18/2018 9:41	Grab	PHOSPHATE, TOTAL AS P	0.258
6/18/2018 9:41	Grab	TOTAL NITROGEN	2.02
7/5/2018 10:21	Grab	NITRATE+NITRITE-N	0.223
7/5/2018 10:21	Grab	PHOSPHATE, TOTAL AS P	0.22
7/5/2018 10:21	Grab	TOTAL NITROGEN	1.91
7/9/2018 10:43	Grab	NITRATE+NITRITE-N	0.182
7/9/2018 10:43	Grab	PHOSPHATE, TOTAL AS P	0.185
7/9/2018 10:43	Grab	TOTAL NITROGEN	1.87
7/16/2018 10:30	Grab	NITRATE+NITRITE-N	0.103
7/16/2018 10:30	Grab	PHOSPHATE, TOTAL AS P	0.184
7/16/2018 10:30	Grab	TOTAL NITROGEN	1.76
7/23/2018 10:22	Grab	NITRATE+NITRITE-N	0.115
7/23/2018 10:22	Grab	PHOSPHATE, TOTAL AS P	0.159
7/23/2018 10:22	Grab	TOTAL NITROGEN	1.52
7/30/2018 10:30	Grab	NITRATE+NITRITE-N	0.106
7/30/2018 10:30	Grab	PHOSPHATE, TOTAL AS P	0.18
7/30/2018 10:30	Grab	TOTAL NITROGEN	1.95
8/6/2018 10:13	Grab	NITRATE+NITRITE-N	0.196
8/6/2018 10:13	Grab	PHOSPHATE, TOTAL AS P	0.173
8/6/2018 10:13	Grab	TOTAL NITROGEN	1.58
8/13/2018 10:19	Grab	NITRATE+NITRITE-N	0.121
8/13/2018 10:19	Grab	PHOSPHATE, TOTAL AS P	0.137
8/13/2018 10:19	Grab	TOTAL NITROGEN	1.42
8/20/2018 10:15	Grab	NITRATE+NITRITE-N	0.112

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
8/20/2018 10:15	Grab	PHOSPHATE, TOTAL AS P	0.147
8/20/2018 10:15	Grab	TOTAL NITROGEN	1.44
8/27/2018 9:45	Grab	NITRATE+NITRITE-N	0.105
8/27/2018 9:45	Grab	PHOSPHATE, TOTAL AS P	0.131
8/27/2018 9:45	Grab	TOTAL NITROGEN	1.35
9/6/2018 10:10	Grab	NITRATE+NITRITE-N	0.191
9/6/2018 10:10	Grab	PHOSPHATE, TOTAL AS P	0.133
9/6/2018 10:10	Grab	TOTAL NITROGEN	1.54
9/10/2018 10:12	Grab	NITRATE+NITRITE-N	0.159
9/10/2018 10:12	Grab	PHOSPHATE, TOTAL AS P	0.143
9/10/2018 10:12	Grab	TOTAL NITROGEN	1.42
9/17/2018 13:28	Grab	NITRATE+NITRITE-N	0.122
9/17/2018 13:28	Grab	PHOSPHATE, TOTAL AS P	0.161
9/17/2018 13:28	Grab	TOTAL NITROGEN	1.49
9/24/2018 10:15	Grab	NITRATE+NITRITE-N	0.1
9/24/2018 10:15	Grab	PHOSPHATE, TOTAL AS P	0.148
9/24/2018 10:15	Grab	TOTAL NITROGEN	1.3
10/1/2018 9:36	Grab	NITRATE+NITRITE-N	0.083
10/1/2018 9:36	Grab	PHOSPHATE, TOTAL AS P	0.106
10/1/2018 9:36	Grab	TOTAL NITROGEN	1.32
10/8/2018 9:58	Grab	NITRATE+NITRITE-N	0.087
10/8/2018 9:58	Grab	PHOSPHATE, TOTAL AS P	0.087
10/8/2018 9:58	Grab	TOTAL NITROGEN	1.31
10/15/2018 10:04	Grab	NITRATE+NITRITE-N	0.098
10/15/2018 10:04	Grab	PHOSPHATE, TOTAL AS P	0.087
10/15/2018 10:04	Grab	TOTAL NITROGEN	1.3
10/22/2018 10:21	Grab	NITRATE+NITRITE-N	0.028
10/22/2018 10:21	Grab	PHOSPHATE, TOTAL AS P	0.086
10/22/2018 10:21	Grab	TOTAL NITROGEN	1.24
10/29/2018 10:04	Grab	NITRATE+NITRITE-N	0.09
10/29/2018 10:04	Grab	PHOSPHATE, TOTAL AS P	0.089
10/29/2018 10:04	Grab	TOTAL NITROGEN	1.55
11/5/2018 9:55	Grab	NITRATE+NITRITE-N	0.086
11/5/2018 9:55	Grab	PHOSPHATE, TOTAL AS P	0.108
11/5/2018 9:55	Grab	TOTAL NITROGEN	1.84
11/14/2018 11:25	Grab	NITRATE+NITRITE-N	0.223
11/14/2018 11:25	Grab	PHOSPHATE, TOTAL AS P	0.121
11/14/2018 11:25	Grab	TOTAL NITROGEN	1.69
11/19/2018 9:21	Grab	NITRATE+NITRITE-N	0.155
11/19/2018 9:21	Grab	PHOSPHATE, TOTAL AS P	0.081
11/19/2018 9:21	Grab	TOTAL NITROGEN	1.4
11/26/2018 9:45	Grab	NITRATE+NITRITE-N	0.071
11/26/2018 9:45	Grab	PHOSPHATE, TOTAL AS P	0.083
11/26/2018 9:45	Grab	TOTAL NITROGEN	1.4
12/3/2018 9:55	Grab	NITRATE+NITRITE-N	0.024
12/3/2018 9:55	Grab	PHOSPHATE, TOTAL AS P	0.092
12/3/2018 9:55	Grab	TOTAL NITROGEN	1.46

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
12/10/2018 10:06	Grab	NITRATE+NITRITE-N	0.031
12/10/2018 10:06	Grab	PHOSPHATE, TOTAL AS P	0.097
12/10/2018 10:06	Grab	TOTAL NITROGEN	1.49
12/17/2018 9:18	Grab	NITRATE+NITRITE-N	0.011
12/17/2018 9:18	Grab	PHOSPHATE, TOTAL AS P	0.086
12/17/2018 9:18	Grab	TOTAL NITROGEN	1.36
12/26/2018 9:47	Grab	NITRATE+NITRITE-N	0.021
12/26/2018 9:47	Grab	PHOSPHATE, TOTAL AS P	0.078
12/26/2018 9:47	Grab	TOTAL NITROGEN	1.27
1/3/2019 9:46	Grab	NITRATE+NITRITE-N	-0.005
1/3/2019 9:46	Grab	PHOSPHATE, TOTAL AS P	0.064
1/3/2019 9:46	Grab	TOTAL NITROGEN	1.23
1/7/2019 10:07	Grab	NITRATE+NITRITE-N	0.029
1/7/2019 10:07	Grab	PHOSPHATE, TOTAL AS P	0.067
1/7/2019 10:07	Grab	TOTAL NITROGEN	1.26
1/14/2019 10:10	Grab	NITRATE+NITRITE-N	0.037
1/14/2019 10:10	Grab	PHOSPHATE, TOTAL AS P	0.074
1/14/2019 10:10	Grab	TOTAL NITROGEN	1.24
1/23/2019 12:05	Grab	NITRATE+NITRITE-N	0.043
1/23/2019 12:05	Grab	PHOSPHATE, TOTAL AS P	0.084
1/23/2019 12:05	Grab	TOTAL NITROGEN	1.29
1/28/2019 10:49	Grab	NITRATE+NITRITE-N	0.093
1/28/2019 10:49	Grab	PHOSPHATE, TOTAL AS P	0.079
1/28/2019 10:49	Grab	TOTAL NITROGEN	1.16
2/4/2019 10:15	Grab	NITRATE+NITRITE-N	0.477
2/4/2019 10:15	Grab	PHOSPHATE, TOTAL AS P	0.092
2/4/2019 10:15	Grab	TOTAL NITROGEN	1.76
2/11/2019 9:55	Grab	NITRATE+NITRITE-N	1.222
2/11/2019 9:55	Grab	PHOSPHATE, TOTAL AS P	0.139
2/11/2019 9:55	Grab	TOTAL NITROGEN	2.76
2/18/2019 10:18	Grab	NITRATE+NITRITE-N	0.175
2/18/2019 10:18	Grab	PHOSPHATE, TOTAL AS P	0.08
2/18/2019 10:18	Grab	TOTAL NITROGEN	1.34
2/25/2019 10:15	Grab	NITRATE+NITRITE-N	0.067
2/25/2019 10:15	Grab	PHOSPHATE, TOTAL AS P	0.09
2/25/2019 10:15	Grab	TOTAL NITROGEN	1.39
3/4/2019 9:27	Grab	NITRATE+NITRITE-N	0.081
3/4/2019 9:27	Grab	PHOSPHATE, TOTAL AS P	0.092
3/4/2019 9:27	Grab	TOTAL NITROGEN	1.36
3/11/2019 10:07	Grab	NITRATE+NITRITE-N	0.189
3/11/2019 10:07	Grab	PHOSPHATE, TOTAL AS P	0.085
3/11/2019 10:07	Grab	TOTAL NITROGEN	1.28
3/18/2019 9:51	Grab	NITRATE+NITRITE-N	0.062
3/18/2019 9:51	Grab	PHOSPHATE, TOTAL AS P	0.088
3/18/2019 9:51	Grab	TOTAL NITROGEN	1.37
3/25/2019 9:59	Grab	NITRATE+NITRITE-N	0.153
3/25/2019 9:59	Grab	PHOSPHATE, TOTAL AS P	0.07

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
3/25/2019 9:59	Grab	TOTAL NITROGEN	1.33
4/1/2019 9:54	Grab	NITRATE+NITRITE-N	0.022
4/1/2019 9:54	Grab	PHOSPHATE, TOTAL AS P	0.08
4/1/2019 9:54	Grab	TOTAL NITROGEN	1.23
4/8/2019 9:50	Grab	NITRATE+NITRITE-N	0.042
4/8/2019 9:50	Grab	PHOSPHATE, TOTAL AS P	0.076
4/8/2019 9:50	Grab	TOTAL NITROGEN	1.25
4/15/2019 10:36	Grab	NITRATE+NITRITE-N	-0.005
4/15/2019 10:36	Grab	PHOSPHATE, TOTAL AS P	0.076
4/15/2019 10:36	Grab	TOTAL NITROGEN	1.33
4/22/2019 10:32	Grab	NITRATE+NITRITE-N	0.065
4/22/2019 10:32	Grab	PHOSPHATE, TOTAL AS P	0.105
4/22/2019 10:32	Grab	TOTAL NITROGEN	1.59
4/29/2019 9:59	Grab	NITRATE+NITRITE-N	0.113
4/29/2019 9:59	Grab	PHOSPHATE, TOTAL AS P	0.082
4/29/2019 9:59	Grab	TOTAL NITROGEN	1.48
5/6/2019 9:41	Grab	NITRATE+NITRITE-N	0.024
5/6/2019 9:41	Grab	PHOSPHATE, TOTAL AS P	0.108
5/6/2019 9:41	Grab	TOTAL NITROGEN	1.38
5/13/2019 9:46	Grab	NITRATE+NITRITE-N	-0.005
5/13/2019 9:46	Grab	PHOSPHATE, TOTAL AS P	0.075
5/13/2019 9:46	Grab	TOTAL NITROGEN	1.26
5/20/2019 10:48	Grab	NITRATE+NITRITE-N	0.01
5/20/2019 10:48	Grab	PHOSPHATE, TOTAL AS P	0.081
5/20/2019 10:48	Grab	TOTAL NITROGEN	1.34
5/29/2019 9:39	Grab	NITRATE+NITRITE-N	-0.005
5/29/2019 9:39	Grab	PHOSPHATE, TOTAL AS P	0.094
5/29/2019 9:39	Grab	TOTAL NITROGEN	1.73
6/3/2019 10:07	Grab	NITRATE+NITRITE-N	-0.005
6/3/2019 10:07	Grab	PHOSPHATE, TOTAL AS P	0.074
6/3/2019 10:07	Grab	TOTAL NITROGEN	1.54
6/10/2019 9:49	Grab	NITRATE+NITRITE-N	0.016
6/10/2019 9:49	Grab	PHOSPHATE, TOTAL AS P	0.09
6/10/2019 9:49	Grab	TOTAL NITROGEN	1.47
6/17/2019 9:13	Grab	NITRATE+NITRITE-N	0.01
6/17/2019 9:13	Grab	PHOSPHATE, TOTAL AS P	0.08
6/17/2019 9:13	Grab	TOTAL NITROGEN	1.4
6/24/2019 9:23	Grab	NITRATE+NITRITE-N	0.016
6/24/2019 9:23	Grab	PHOSPHATE, TOTAL AS P	0.088
6/24/2019 9:23	Grab	TOTAL NITROGEN	1.5
7/1/2019 9:24	Grab	NITRATE+NITRITE-N	-0.005
7/1/2019 9:24	Grab	PHOSPHATE, TOTAL AS P	0.127
7/1/2019 9:24	Grab	TOTAL NITROGEN	1.53
7/8/2019 10:11	Grab	NITRATE+NITRITE-N	-0.005
7/8/2019 10:11	Grab	PHOSPHATE, TOTAL AS P	0.09
7/8/2019 10:11	Grab	TOTAL NITROGEN	1.31
7/15/2019 9:28	Grab	NITRATE+NITRITE-N	0.037

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/15/2019 9:28	Grab	PHOSPHATE, TOTAL AS P	0.113
7/15/2019 9:28	Grab	TOTAL NITROGEN	1.48
7/22/2019 9:22	Grab	NITRATE+NITRITE-N	0.017
7/22/2019 9:22	Grab	PHOSPHATE, TOTAL AS P	0.122
7/22/2019 9:22	Grab	TOTAL NITROGEN	1.52
7/29/2019 10:20	Grab	NITRATE+NITRITE-N	0.011
7/29/2019 10:20	Grab	PHOSPHATE, TOTAL AS P	0.11
7/29/2019 10:20	Grab	TOTAL NITROGEN	1.41
8/5/2019 9:42	Grab	NITRATE+NITRITE-N	0.156
8/5/2019 9:42	Grab	PHOSPHATE, TOTAL AS P	0.172
8/5/2019 9:42	Grab	TOTAL NITROGEN	1.76
8/12/2019 10:02	Grab	NITRATE+NITRITE-N	0.151
8/12/2019 10:02	Grab	PHOSPHATE, TOTAL AS P	0.17
8/12/2019 10:02	Grab	TOTAL NITROGEN	1.98
8/19/2019 9:38	Grab	NITRATE+NITRITE-N	0.172
8/19/2019 9:38	Grab	PHOSPHATE, TOTAL AS P	0.155
8/19/2019 9:38	Grab	TOTAL NITROGEN	1.94
8/26/2019 10:02	Grab	NITRATE+NITRITE-N	0.238
8/26/2019 10:02	Grab	PHOSPHATE, TOTAL AS P	0.195
8/26/2019 10:02	Grab	TOTAL NITROGEN	1.84
9/4/2019 9:55	Grab	NITRATE+NITRITE-N	0.356
9/4/2019 9:55	Grab	PHOSPHATE, TOTAL AS P	0.18
9/4/2019 9:55	Grab	TOTAL NITROGEN	1.81
9/9/2019 9:41	Grab	NITRATE+NITRITE-N	0.321
9/9/2019 9:41	Grab	PHOSPHATE, TOTAL AS P	0.162
9/9/2019 9:41	Grab	TOTAL NITROGEN	1.56
9/16/2019 9:26	Grab	NITRATE+NITRITE-N	0.415
9/16/2019 9:26	Grab	PHOSPHATE, TOTAL AS P	0.173
9/16/2019 9:26	Grab	TOTAL NITROGEN	1.77
9/23/2019 10:12	Grab	NITRATE+NITRITE-N	0.471
9/23/2019 10:12	Grab	PHOSPHATE, TOTAL AS P	0.17
9/23/2019 10:12	Grab	TOTAL NITROGEN	1.76
9/30/2019 9:37	Grab	NITRATE+NITRITE-N	0.492
9/30/2019 9:37	Grab	PHOSPHATE, TOTAL AS P	0.176
9/30/2019 9:37	Grab	TOTAL NITROGEN	1.86
10/7/2019 10:09	Grab	NITRATE+NITRITE-N	0.55
10/7/2019 10:09	Grab	PHOSPHATE, TOTAL AS P	0.157
10/7/2019 10:09	Grab	TOTAL NITROGEN	1.97
10/14/2019 9:39	Grab	NITRATE+NITRITE-N	0.329
10/14/2019 9:39	Grab	PHOSPHATE, TOTAL AS P	0.148
10/14/2019 9:39	Grab	TOTAL NITROGEN	1.84
10/21/2019 10:16	Grab	NITRATE+NITRITE-N	0.34
10/21/2019 10:16	Grab	PHOSPHATE, TOTAL AS P	0.133
10/21/2019 10:16	Grab	TOTAL NITROGEN	1.72
10/28/2019 9:54	Grab	NITRATE+NITRITE-N	0.392
10/28/2019 9:54	Grab	PHOSPHATE, TOTAL AS P	0.162
10/28/2019 9:54	Grab	TOTAL NITROGEN	1.73

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
11/4/2019 9:32	Grab	NITRATE+NITRITE-N	0.449
11/4/2019 9:32	Grab	PHOSPHATE, TOTAL AS P	0.168
11/4/2019 9:32	Grab	TOTAL NITROGEN	1.76
11/13/2019 10:22	Grab	NITRATE+NITRITE-N	0.231
11/13/2019 10:22	Grab	PHOSPHATE, TOTAL AS P	0.1
11/13/2019 10:22	Grab	TOTAL NITROGEN	1.38
11/18/2019 10:13	Grab	NITRATE+NITRITE-N	0.173
11/18/2019 10:13	Grab	PHOSPHATE, TOTAL AS P	0.095
11/18/2019 10:13	Grab	TOTAL NITROGEN	1.29
11/25/2019 10:42	Grab	NITRATE+NITRITE-N	0.146
11/25/2019 10:42	Grab	PHOSPHATE, TOTAL AS P	0.082
11/25/2019 10:42	Grab	TOTAL NITROGEN	1.27
12/2/2019 9:37	Grab	NITRATE+NITRITE-N	0.047
12/2/2019 9:37	Grab	PHOSPHATE, TOTAL AS P	0.065
12/2/2019 9:37	Grab	TOTAL NITROGEN	1.22
12/9/2019 9:33	Grab	NITRATE+NITRITE-N	0.005
12/9/2019 9:33	Grab	PHOSPHATE, TOTAL AS P	0.077
12/9/2019 9:33	Grab	TOTAL NITROGEN	1.23
12/16/2019 9:27	Grab	NITRATE+NITRITE-N	-0.005
12/16/2019 9:27	Grab	PHOSPHATE, TOTAL AS P	0.093
12/16/2019 9:27	Grab	TOTAL NITROGEN	1.51
12/23/2019 9:12	Grab	NITRATE+NITRITE-N	0.105
12/23/2019 9:12	Grab	PHOSPHATE, TOTAL AS P	0.079
12/23/2019 9:12	Grab	TOTAL NITROGEN	1.44
12/30/2019 9:10	Grab	NITRATE+NITRITE-N	0.162
12/30/2019 9:10	Grab	PHOSPHATE, TOTAL AS P	0.077
12/30/2019 9:10	Grab	TOTAL NITROGEN	1.46
1/6/2020 9:05	Grab	NITRATE+NITRITE-N	0.227
1/6/2020 9:05	Grab	PHOSPHATE, TOTAL AS P	0.077
1/6/2020 9:05	Grab	TOTAL NITROGEN	1.44
1/13/2020 11:02	Grab	NITRATE+NITRITE-N	0.2
1/13/2020 11:02	Grab	PHOSPHATE, TOTAL AS P	0.07
1/13/2020 11:02	Grab	TOTAL NITROGEN	1.3
1/21/2020 9:45	Grab	NITRATE+NITRITE-N	0.121
1/21/2020 9:45	Grab	PHOSPHATE, TOTAL AS P	0.069
1/21/2020 9:45	Grab	TOTAL NITROGEN	1.28
1/27/2020 9:53	Grab	NITRATE+NITRITE-N	0.056
1/27/2020 9:53	Grab	PHOSPHATE, TOTAL AS P	0.071
1/27/2020 9:53	Grab	TOTAL NITROGEN	1.22
2/3/2020 9:56	Grab	NITRATE+NITRITE-N	0.202
2/3/2020 9:56	Grab	PHOSPHATE, TOTAL AS P	0.073
2/3/2020 9:56	Grab	TOTAL NITROGEN	1.29
2/10/2020 9:45	Grab	NITRATE+NITRITE-N	0.139
2/10/2020 9:45	Grab	PHOSPHATE, TOTAL AS P	0.07
2/10/2020 9:45	Grab	TOTAL NITROGEN	1.3
2/17/2020 9:36	Grab	NITRATE+NITRITE-N	0.082
2/17/2020 9:36	Grab	PHOSPHATE, TOTAL AS P	0.071

Table C-1. S-78 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/17/2020 9:36	Grab	TOTAL NITROGEN	1.29
2/24/2020 9:53	Grab	NITRATE+NITRITE-N	0.091
2/24/2020 9:53	Grab	PHOSPHATE, TOTAL AS P	0.066
2/24/2020 9:53	Grab	TOTAL NITROGEN	1.15
3/2/2020 9:38	Grab	NITRATE+NITRITE-N	0.099
3/2/2020 9:38	Grab	PHOSPHATE, TOTAL AS P	0.071
3/2/2020 9:38	Grab	TOTAL NITROGEN	1.21
3/9/2020 10:35	Grab	NITRATE+NITRITE-N	0.142
3/9/2020 10:35	Grab	PHOSPHATE, TOTAL AS P	0.079
3/9/2020 10:35	Grab	TOTAL NITROGEN	1.25
3/16/2020 9:40	Grab	NITRATE+NITRITE-N	0.02
3/16/2020 9:40	Grab	PHOSPHATE, TOTAL AS P	0.064
3/16/2020 9:40	Grab	TOTAL NITROGEN	1.29

Table C-2. Townsend Canal Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/29/2011 10:01	Grab	KJELDAHL NITROGEN, TOTAL	1.47
6/29/2011 10:01	Grab	NITRATE+NITRITE-N	0.301
6/29/2011 10:01	Grab	PHOSPHATE, TOTAL AS P	0.43
7/13/2011 10:04	Grab	KJELDAHL NITROGEN, TOTAL	1.39
7/13/2011 10:04	Grab	NITRATE+NITRITE-N	0.109
7/13/2011 10:04	Grab	PHOSPHATE, TOTAL AS P	0.363
7/20/2011 10:07	Grab	KJELDAHL NITROGEN, TOTAL	1.21
7/20/2011 10:07	Grab	NITRATE+NITRITE-N	0.085
7/20/2011 10:07	Grab	PHOSPHATE, TOTAL AS P	0.213
7/27/2011 9:41	Grab	KJELDAHL NITROGEN, TOTAL	1.37
7/27/2011 9:41	Grab	NITRATE+NITRITE-N	0.113
7/27/2011 9:41	Grab	PHOSPHATE, TOTAL AS P	0.223
8/3/2011 10:07	Grab	KJELDAHL NITROGEN, TOTAL	1.27
8/3/2011 10:07	Grab	NITRATE+NITRITE-N	0.068
8/3/2011 10:07	Grab	PHOSPHATE, TOTAL AS P	0.234
8/10/2011 9:53	Grab	KJELDAHL NITROGEN, TOTAL	1.34
8/10/2011 9:53	Grab	NITRATE+NITRITE-N	0.117
8/10/2011 9:53	Grab	PHOSPHATE, TOTAL AS P	0.308
8/17/2011 9:38	Grab	KJELDAHL NITROGEN, TOTAL	1.35
8/17/2011 9:38	Grab	NITRATE+NITRITE-N	0.136
8/17/2011 9:38	Grab	PHOSPHATE, TOTAL AS P	0.321
8/24/2011 9:32	Grab	KJELDAHL NITROGEN, TOTAL	1.15
8/24/2011 9:32	Grab	NITRATE+NITRITE-N	0.142
8/24/2011 9:32	Grab	PHOSPHATE, TOTAL AS P	0.341
8/31/2011 10:14	Grab	KJELDAHL NITROGEN, TOTAL	1.14
8/31/2011 10:14	Grab	NITRATE+NITRITE-N	0.162
8/31/2011 10:14	Grab	PHOSPHATE, TOTAL AS P	0.251
9/7/2011 9:04	Grab	KJELDAHL NITROGEN, TOTAL	1.33
9/7/2011 9:04	Grab	NITRATE+NITRITE-N	0.102
9/7/2011 9:04	Grab	PHOSPHATE, TOTAL AS P	0.311
9/14/2011 9:59	Grab	KJELDAHL NITROGEN, TOTAL	1.19
9/14/2011 9:59	Grab	NITRATE+NITRITE-N	0.157
9/14/2011 9:59	Grab	PHOSPHATE, TOTAL AS P	0.224
9/28/2011 9:44	Grab	KJELDAHL NITROGEN, TOTAL	1.07
9/28/2011 9:44	Grab	NITRATE+NITRITE-N	0.187
9/28/2011 9:44	Grab	PHOSPHATE, TOTAL AS P	0.193
10/12/2011 9:54	Grab	KJELDAHL NITROGEN, TOTAL	1.14
10/12/2011 9:54	Grab	NITRATE+NITRITE-N	0.129
10/12/2011 9:54	Grab	PHOSPHATE, TOTAL AS P	0.251
10/19/2011 9:34	Grab	KJELDAHL NITROGEN, TOTAL	1.19
10/19/2011 9:34	Grab	NITRATE+NITRITE-N	0.098
10/19/2011 9:34	Grab	PHOSPHATE, TOTAL AS P	0.213
10/26/2011 9:07	Grab	KJELDAHL NITROGEN, TOTAL	0.95
10/26/2011 9:07	Grab	NITRATE+NITRITE-N	0.146
10/26/2011 9:07	Grab	PHOSPHATE, TOTAL AS P	0.149
11/2/2011 10:18	Grab	KJELDAHL NITROGEN, TOTAL	1.14

Table C-2. Townsend Canal Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
11/2/2011 10:18	Grab	NITRATE+NITRITE-N	0.198
11/2/2011 10:18	Grab	PHOSPHATE, TOTAL AS P	0.214
11/2/2011 10:30	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/2/2011 10:30	Grab	NITRATE+NITRITE-N	-0.005
11/2/2011 10:30	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/9/2011 10:07	Grab	KJELDAHL NITROGEN, TOTAL	1.01
11/9/2011 10:07	Grab	NITRATE+NITRITE-N	0.135
11/9/2011 10:07	Grab	PHOSPHATE, TOTAL AS P	0.122
11/16/2011 10:04	Grab	KJELDAHL NITROGEN, TOTAL	1.08
11/16/2011 10:04	Grab	NITRATE+NITRITE-N	0.388
11/16/2011 10:04	Grab	PHOSPHATE, TOTAL AS P	0.1
12/8/2011 10:13	Grab	KJELDAHL NITROGEN, TOTAL	0.97
12/8/2011 10:13	Grab	NITRATE+NITRITE-N	0.474
12/8/2011 10:13	Grab	PHOSPHATE, TOTAL AS P	0.1
12/8/2011 10:22	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/8/2011 10:22	Grab	NITRATE+NITRITE-N	-0.005
12/8/2011 10:22	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/1/2014 11:23	Grab	KJELDAHL NITROGEN, TOTAL	1.04
5/1/2014 11:23	Grab	NITRATE+NITRITE-N	0.012
5/1/2014 11:23	Grab	PHOSPHATE, TOTAL AS P	0.102
5/15/2014 10:51	Grab	KJELDAHL NITROGEN, TOTAL	0.99
5/15/2014 10:51	Grab	NITRATE+NITRITE-N	0.049
5/15/2014 10:51	Grab	PHOSPHATE, TOTAL AS P	0.123
5/29/2014 12:03	Grab	KJELDAHL NITROGEN, TOTAL	1.01
5/29/2014 12:03	Grab	NITRATE+NITRITE-N	-0.005
5/29/2014 12:03	Grab	PHOSPHATE, TOTAL AS P	0.069
6/12/2014 11:02	Grab	NITRATE+NITRITE-N	0.029
6/12/2014 11:02	Grab	TOTAL NITROGEN	0.93
6/12/2014 11:02	Grab	PHOSPHATE, TOTAL AS P	0.127
6/26/2014 10:41	Grab	NITRATE+NITRITE-N	-0.005
6/26/2014 10:41	Grab	TOTAL NITROGEN	1.27
6/26/2014 10:41	Grab	PHOSPHATE, TOTAL AS P	0.143
7/14/2014 10:28	Grab	NITRATE+NITRITE-N	0.156
7/14/2014 10:28	Grab	TOTAL NITROGEN	1.22
7/14/2014 10:28	Grab	PHOSPHATE, TOTAL AS P	0.148
7/28/2014 10:34	Grab	NITRATE+NITRITE-N	0.178
7/28/2014 10:34	Grab	TOTAL NITROGEN	1.36
7/28/2014 10:34	Grab	PHOSPHATE, TOTAL AS P	0.137
8/11/2014 10:30	Grab	NITRATE+NITRITE-N	0.193
8/11/2014 10:30	Grab	TOTAL NITROGEN	1.44
8/11/2014 10:30	Grab	PHOSPHATE, TOTAL AS P	0.323
8/25/2014 10:34	Grab	NITRATE+NITRITE-N	0.109
8/25/2014 10:34	Grab	TOTAL NITROGEN	1.45
8/25/2014 10:34	Grab	PHOSPHATE, TOTAL AS P	0.383
9/8/2014 10:09	Grab	NITRATE+NITRITE-N	0.22
9/8/2014 10:09	Grab	TOTAL NITROGEN	1.34
9/8/2014 10:09	Grab	PHOSPHATE, TOTAL AS P	0.207

Table C-2. Townsend Canal Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/22/2014 10:10	Grab	NITRATE+NITRITE-N	0.219
9/22/2014 10:10	Grab	TOTAL NITROGEN	1.39
9/22/2014 10:10	Grab	PHOSPHATE, TOTAL AS P	0.193
10/6/2014 10:45	Grab	NITRATE+NITRITE-N	0.241
10/6/2014 10:45	Grab	TOTAL NITROGEN	1.35
10/6/2014 10:45	Grab	PHOSPHATE, TOTAL AS P	0.247
10/20/2014 10:27	Grab	NITRATE+NITRITE-N	0.332
10/20/2014 10:27	Grab	TOTAL NITROGEN	1.38
10/20/2014 10:27	Grab	PHOSPHATE, TOTAL AS P	0.153
5/11/2015 11:05	Grab	NITRATE+NITRITE-N	0.03
5/11/2015 11:05	Grab	TOTAL NITROGEN	1.2
5/11/2015 11:05	Grab	PHOSPHATE, TOTAL AS P	0.104
5/26/2015 10:51	Grab	NITRATE+NITRITE-N	0.154
5/26/2015 10:51	Grab	TOTAL NITROGEN	1.35
5/26/2015 10:51	Grab	PHOSPHATE, TOTAL AS P	0.133
6/8/2015 10:21	Grab	NITRATE+NITRITE-N	-0.005
6/8/2015 10:21	Grab	TOTAL NITROGEN	1.2
6/8/2015 10:21	Grab	PHOSPHATE, TOTAL AS P	0.119
6/22/2015 10:19	Grab	NITRATE+NITRITE-N	-0.005
6/22/2015 10:19	Grab	TOTAL NITROGEN	1.1
6/22/2015 10:19	Grab	PHOSPHATE, TOTAL AS P	0.114
7/6/2015 10:01	Grab	NITRATE+NITRITE-N	0.005
7/6/2015 10:01	Grab	TOTAL NITROGEN	1.11
7/6/2015 10:01	Grab	PHOSPHATE, TOTAL AS P	0.17
7/20/2015 10:10	Grab	NITRATE+NITRITE-N	0.421
7/20/2015 10:10	Grab	TOTAL NITROGEN	1.73
7/20/2015 10:10	Grab	PHOSPHATE, TOTAL AS P	0.296
8/3/2015 10:37	Grab	NITRATE+NITRITE-N	0.164
8/3/2015 10:37	Grab	TOTAL NITROGEN	1.22
8/3/2015 10:37	Grab	PHOSPHATE, TOTAL AS P	0.155
8/17/2015 10:06	Grab	NITRATE+NITRITE-N	0.337
8/17/2015 10:06	Grab	TOTAL NITROGEN	1.52
8/17/2015 10:06	Grab	PHOSPHATE, TOTAL AS P	0.375
9/1/2015 9:54	Grab	NITRATE+NITRITE-N	0.243
9/1/2015 9:54	Grab	TOTAL NITROGEN	1.51
9/1/2015 9:54	Grab	PHOSPHATE, TOTAL AS P	0.246
9/14/2015 9:51	Grab	NITRATE+NITRITE-N	0.191
9/14/2015 9:51	Grab	TOTAL NITROGEN	1.36
9/14/2015 9:51	Grab	PHOSPHATE, TOTAL AS P	0.227
9/28/2015 10:07	Grab	NITRATE+NITRITE-N	0.187
9/28/2015 10:07	Grab	TOTAL NITROGEN	1.3
9/28/2015 10:07	Grab	PHOSPHATE, TOTAL AS P	0.27

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/8/2000 13:40	Grab	KJELDAHL NITROGEN, TOTAL	0.924
2/8/2000 13:40	Grab	NITRATE+NITRITE-N	0.543
2/8/2000 13:40	Grab	PHOSPHATE, TOTAL AS P	0.11
4/5/2000 13:40	Grab	KJELDAHL NITROGEN, TOTAL	0.855
4/5/2000 13:40	Grab	NITRATE+NITRITE-N	0.37
4/5/2000 13:40	Grab	PHOSPHATE, TOTAL AS P	0.121
6/1/2000 13:25	Grab	KJELDAHL NITROGEN, TOTAL	1.303
6/1/2000 13:25	Grab	NITRATE+NITRITE-N	0.264
6/1/2000 13:25	Grab	PHOSPHATE, TOTAL AS P	0.178
9/7/2000 13:35	Grab	KJELDAHL NITROGEN, TOTAL	1.027
9/7/2000 13:35	Grab	NITRATE+NITRITE-N	0.241
9/7/2000 13:35	Grab	PHOSPHATE, TOTAL AS P	0.173
10/19/2000 14:15	Grab	KJELDAHL NITROGEN, TOTAL	1.051
10/19/2000 14:15	Grab	NITRATE+NITRITE-N	0.429
10/19/2000 14:15	Grab	PHOSPHATE, TOTAL AS P	0.151
12/14/2000 14:00	Grab	KJELDAHL NITROGEN, TOTAL	1.421
12/14/2000 14:00	Grab	NITRATE+NITRITE-N	0.726
12/14/2000 14:00	Grab	PHOSPHATE, TOTAL AS P	0.174
1/5/2001 12:35	Grab	KJELDAHL NITROGEN, TOTAL	1.163
1/5/2001 12:35	Grab	NITRATE+NITRITE-N	0.843
1/5/2001 12:35	Grab	PHOSPHATE, TOTAL AS P	0.123
2/12/2001 15:00	Grab	KJELDAHL NITROGEN, TOTAL	1.273
2/12/2001 15:00	Grab	NITRATE+NITRITE-N	0.454
2/12/2001 15:00	Grab	PHOSPHATE, TOTAL AS P	0.098
6/11/2001 14:30	Grab	KJELDAHL NITROGEN, TOTAL	1.707
6/11/2001 14:30	Grab	NITRATE+NITRITE-N	0.008
6/11/2001 14:30	Grab	PHOSPHATE, TOTAL AS P	0.213
8/1/2001 10:50	Grab	KJELDAHL NITROGEN, TOTAL	1.456
8/1/2001 10:50	Grab	NITRATE+NITRITE-N	0.278
8/1/2001 10:50	Grab	PHOSPHATE, TOTAL AS P	0.287
10/31/2001 14:00	Grab	KJELDAHL NITROGEN, TOTAL	1.068
10/31/2001 14:00	Grab	NITRATE+NITRITE-N	0.415
10/31/2001 14:00	Grab	PHOSPHATE, TOTAL AS P	0.144
10/31/2001 14:15	Grab	KJELDAHL NITROGEN, TOTAL	-0.5
10/31/2001 14:15	Grab	NITRATE+NITRITE-N	0.004
10/31/2001 14:15	Grab	PHOSPHATE, TOTAL AS P	-0.004
12/27/2001 13:10	Grab	KJELDAHL NITROGEN, TOTAL	0.84
12/27/2001 13:10	Grab	NITRATE+NITRITE-N	0.556
12/27/2001 13:10	Grab	PHOSPHATE, TOTAL AS P	0.099
12/27/2001 13:15	Grab	KJELDAHL NITROGEN, TOTAL	-0.1
12/27/2001 13:15	Grab	NITRATE+NITRITE-N	0.004
12/27/2001 13:15	Grab	PHOSPHATE, TOTAL AS P	-0.004
2/27/2002 13:50	Grab	KJELDAHL NITROGEN, TOTAL	1.05
2/27/2002 13:50	Grab	NITRATE+NITRITE-N	0.276
2/27/2002 13:50	Grab	PHOSPHATE, TOTAL AS P	0.091
4/22/2002 12:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.1

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
4/22/2002 12:20	Grab	NITRATE+NITRITE-N	0.008
4/22/2002 12:20	Grab	PHOSPHATE, TOTAL AS P	-0.004
4/22/2002 12:35	Grab	KJELDAHL NITROGEN, TOTAL	1.19
4/22/2002 12:35	Grab	NITRATE+NITRITE-N	0.269
4/22/2002 12:35	Grab	PHOSPHATE, TOTAL AS P	0.147
4/22/2002 12:50	Grab	KJELDAHL NITROGEN, TOTAL	-0.1
4/22/2002 12:50	Grab	NITRATE+NITRITE-N	0.007
4/22/2002 12:50	Grab	PHOSPHATE, TOTAL AS P	-0.004
6/13/2002 12:30	Grab	KJELDAHL NITROGEN, TOTAL	1.61
6/13/2002 12:30	Grab	NITRATE+NITRITE-N	-0.004
6/13/2002 12:30	Grab	PHOSPHATE, TOTAL AS P	0.142
7/17/2002 13:30	Grab	KJELDAHL NITROGEN, TOTAL	1.87
7/17/2002 13:30	Grab	NITRATE+NITRITE-N	0.28
7/17/2002 13:30	Grab	PHOSPHATE, TOTAL AS P	0.263
8/1/2002 13:55	Grab	KJELDAHL NITROGEN, TOTAL	1.5
8/1/2002 13:55	Grab	NITRATE+NITRITE-N	0.232
8/1/2002 13:55	Grab	PHOSPHATE, TOTAL AS P	0.23
10/15/2002 12:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/15/2002 12:20	Grab	NITRATE+NITRITE-N	-0.004
10/15/2002 12:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/18/2002 11:25	Grab	KJELDAHL NITROGEN, TOTAL	1.25
12/18/2002 11:25	Grab	NITRATE+NITRITE-N	0.309
12/18/2002 11:25	Grab	PHOSPHATE, TOTAL AS P	0.073
4/28/2003 13:32	Grab	KJELDAHL NITROGEN, TOTAL	1.22
4/28/2003 13:32	Grab	NITRATE+NITRITE-N	0.303
4/28/2003 13:32	Grab	PHOSPHATE, TOTAL AS P	0.125
6/25/2003 13:32	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/25/2003 13:32	Grab	NITRATE+NITRITE-N	-0.004
6/25/2003 13:32	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/25/2003 14:16	Grab	KJELDAHL NITROGEN, TOTAL	1.21
8/25/2003 14:16	Grab	NITRATE+NITRITE-N	0.202
8/25/2003 14:16	Grab	PHOSPHATE, TOTAL AS P	0.121
10/28/2003 14:30	Grab	KJELDAHL NITROGEN, TOTAL	1.14
10/28/2003 14:30	Grab	NITRATE+NITRITE-N	0.12
10/28/2003 14:30	Grab	PHOSPHATE, TOTAL AS P	0.068
12/22/2003 15:20	Grab	KJELDAHL NITROGEN, TOTAL	1.08
12/22/2003 15:20	Grab	NITRATE+NITRITE-N	0.196
12/22/2003 15:20	Grab	PHOSPHATE, TOTAL AS P	0.065
2/23/2004 12:55	Grab	KJELDAHL NITROGEN, TOTAL	1.12
2/23/2004 12:55	Grab	NITRATE+NITRITE-N	0.118
2/23/2004 12:55	Grab	PHOSPHATE, TOTAL AS P	0.086
4/12/2004 12:46	Grab	KJELDAHL NITROGEN, TOTAL	1.01
4/12/2004 12:46	Grab	NITRATE+NITRITE-N	0.121
4/12/2004 12:46	Grab	PHOSPHATE, TOTAL AS P	0.079
4/12/2004 13:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/12/2004 13:00	Grab	NITRATE+NITRITE-N	-0.004
4/12/2004 13:00	Grab	PHOSPHATE, TOTAL AS P	-0.002

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/14/2004 12:30	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/14/2004 12:30	Grab	NITRATE+NITRITE-N	-0.004
6/14/2004 12:30	Grab	PHOSPHATE, TOTAL AS P	0.002
6/14/2004 12:40	Grab	KJELDAHL NITROGEN, TOTAL	1.2
6/14/2004 12:40	Grab	NITRATE+NITRITE-N	0.117
6/14/2004 12:40	Grab	PHOSPHATE, TOTAL AS P	0.16
8/30/2004 12:08	Grab	KJELDAHL NITROGEN, TOTAL	1.75
8/30/2004 12:08	Grab	NITRATE+NITRITE-N	0.153
8/30/2004 12:08	Grab	PHOSPHATE, TOTAL AS P	0.214
11/1/2004 11:38	Grab	KJELDAHL NITROGEN, TOTAL	0.99
11/1/2004 11:38	Grab	NITRATE+NITRITE-N	0.206
11/1/2004 11:38	Grab	PHOSPHATE, TOTAL AS P	0.086
1/10/2005 11:52	Grab	KJELDAHL NITROGEN, TOTAL	0.98
1/10/2005 11:52	Grab	NITRATE+NITRITE-N	0.367
1/10/2005 11:52	Grab	PHOSPHATE, TOTAL AS P	0.095
3/30/2005 12:02	Grab	KJELDAHL NITROGEN, TOTAL	1.22
3/30/2005 12:02	Grab	NITRATE+NITRITE-N	0.457
3/30/2005 12:02	Grab	PHOSPHATE, TOTAL AS P	0.148
3/30/2005 12:13	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/30/2005 12:13	Grab	NITRATE+NITRITE-N	-0.006
3/30/2005 12:13	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/18/2005 13:45	Grab	KJELDAHL NITROGEN, TOTAL	1.33
5/18/2005 13:45	Grab	NITRATE+NITRITE-N	0.527
5/18/2005 13:45	Grab	PHOSPHATE, TOTAL AS P	0.149
7/13/2005 11:47	Grab	KJELDAHL NITROGEN, TOTAL	1.14
7/13/2005 11:47	Grab	NITRATE+NITRITE-N	0.139
7/13/2005 11:47	Grab	PHOSPHATE, TOTAL AS P	0.121
11/28/2005 9:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/28/2005 9:25	Grab	NITRATE+NITRITE-N	-0.006
11/28/2005 9:25	Grab	PHOSPHATE, TOTAL AS P	0.002
11/28/2005 9:34	Grab	KJELDAHL NITROGEN, TOTAL	1.15
11/28/2005 9:34	Grab	NITRATE+NITRITE-N	0.339
11/28/2005 9:34	Grab	PHOSPHATE, TOTAL AS P	0.118
1/10/2006 10:02	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/10/2006 10:02	Grab	NITRATE+NITRITE-N	-0.006
1/10/2006 10:02	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/10/2006 10:15	Grab	KJELDAHL NITROGEN, TOTAL	1.01
1/10/2006 10:15	Grab	NITRATE+NITRITE-N	0.509
1/10/2006 10:15	Grab	PHOSPHATE, TOTAL AS P	0.13
3/13/2006 11:32	Grab	KJELDAHL NITROGEN, TOTAL	1.03
3/13/2006 11:32	Grab	NITRATE+NITRITE-N	0.397
3/13/2006 11:32	Grab	PHOSPHATE, TOTAL AS P	0.131
5/1/2006 9:14	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/1/2006 9:14	Grab	NITRATE+NITRITE-N	-0.006
5/1/2006 9:14	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/1/2006 9:22	Grab	KJELDAHL NITROGEN, TOTAL	0.99
5/1/2006 9:22	Grab	NITRATE+NITRITE-N	0.391

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/1/2006 9:22	Grab	PHOSPHATE, TOTAL AS P	0.127
7/17/2006 11:15	Grab	KJELDAHL NITROGEN, TOTAL	1.71
7/17/2006 11:15	Grab	NITRATE+NITRITE-N	-0.006
7/17/2006 11:15	Grab	PHOSPHATE, TOTAL AS P	0.154
9/19/2006 9:42	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/19/2006 9:42	Grab	NITRATE+NITRITE-N	-0.006
9/19/2006 9:42	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/19/2006 9:50	Grab	KJELDAHL NITROGEN, TOTAL	1.14
9/19/2006 9:50	Grab	NITRATE+NITRITE-N	0.276
9/19/2006 9:50	Grab	PHOSPHATE, TOTAL AS P	0.213
11/29/2006 10:24	Grab	KJELDAHL NITROGEN, TOTAL	0.97
11/29/2006 10:24	Grab	NITRATE+NITRITE-N	0.666
11/29/2006 10:24	Grab	PHOSPHATE, TOTAL AS P	0.13
11/29/2006 10:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/29/2006 10:45	Grab	NITRATE+NITRITE-N	-0.006
11/29/2006 10:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/29/2007 13:42	Grab	KJELDAHL NITROGEN, TOTAL	0.91
1/29/2007 13:42	Grab	NITRATE+NITRITE-N	0.334
1/29/2007 13:42	Grab	PHOSPHATE, TOTAL AS P	0.107
3/12/2007 13:27	Grab	KJELDAHL NITROGEN, TOTAL	1.19
3/12/2007 13:27	Grab	NITRATE+NITRITE-N	-0.006
3/12/2007 13:27	Grab	PHOSPHATE, TOTAL AS P	0.09
5/29/2007 13:40	Grab	KJELDAHL NITROGEN, TOTAL	1.3
5/29/2007 13:40	Grab	NITRATE+NITRITE-N	-0.006
5/29/2007 13:40	Grab	PHOSPHATE, TOTAL AS P	0.201
7/10/2007 11:04	Grab	KJELDAHL NITROGEN, TOTAL	1.4
7/10/2007 11:04	Grab	NITRATE+NITRITE-N	-0.005
7/10/2007 11:04	Grab	PHOSPHATE, TOTAL AS P	0.27
7/10/2007 11:20	Grab	KJELDAHL NITROGEN, TOTAL	0.06
7/10/2007 11:20	Grab	NITRATE+NITRITE-N	-0.005
7/10/2007 11:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/5/2007 13:46	Grab	KJELDAHL NITROGEN, TOTAL	1.13
9/5/2007 13:46	Grab	NITRATE+NITRITE-N	0.299
9/5/2007 13:46	Grab	PHOSPHATE, TOTAL AS P	0.263
11/27/2007 12:52	Grab	KJELDAHL NITROGEN, TOTAL	0.89
11/27/2007 12:52	Grab	NITRATE+NITRITE-N	0.589
11/27/2007 12:52	Grab	PHOSPHATE, TOTAL AS P	0.154
1/7/2008 11:30	Grab	KJELDAHL NITROGEN, TOTAL	1.14
1/7/2008 11:30	Grab	NITRATE+NITRITE-N	0.598
1/7/2008 11:30	Grab	PHOSPHATE, TOTAL AS P	0.158
3/13/2008 13:11	Grab	KJELDAHL NITROGEN, TOTAL	0.91
3/13/2008 13:11	Grab	NITRATE+NITRITE-N	0.316
3/13/2008 13:11	Grab	PHOSPHATE, TOTAL AS P	0.178
5/12/2008 12:27	Grab	KJELDAHL NITROGEN, TOTAL	0.96
5/12/2008 12:27	Grab	NITRATE+NITRITE-N	0.005
5/12/2008 12:27	Grab	PHOSPHATE, TOTAL AS P	0.261
7/14/2008 1:46	Grab	KJELDAHL NITROGEN, TOTAL	1.53

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/14/2008 1:46	Grab	NITRATE+NITRITE-N	0.132
7/14/2008 1:46	Grab	PHOSPHATE, TOTAL AS P	0.226
9/8/2008 13:57	Grab	KJELDAHL NITROGEN, TOTAL	2
9/8/2008 13:57	Grab	NITRATE+NITRITE-N	0.143
9/8/2008 13:57	Grab	PHOSPHATE, TOTAL AS P	0.272
11/12/2008 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.08
11/12/2008 11:54	Grab	NITRATE+NITRITE-N	0.467
11/12/2008 11:54	Grab	PHOSPHATE, TOTAL AS P	0.15
1/5/2009 11:18	Grab	KJELDAHL NITROGEN, TOTAL	1.3
1/5/2009 11:18	Grab	NITRATE+NITRITE-N	0.204
1/5/2009 11:18	Grab	PHOSPHATE, TOTAL AS P	0.101
3/16/2009 10:47	Grab	KJELDAHL NITROGEN, TOTAL	1.37
3/16/2009 10:47	Grab	NITRATE+NITRITE-N	0.043
3/16/2009 10:47	Grab	PHOSPHATE, TOTAL AS P	0.099
5/5/2009 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.31
5/5/2009 11:20	Grab	NITRATE+NITRITE-N	0.016
5/5/2009 11:20	Grab	PHOSPHATE, TOTAL AS P	0.118
5/18/2009 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/18/2009 10:00	Grab	NITRATE+NITRITE-N	-0.005
5/18/2009 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/18/2009 10:20	Grab	KJELDAHL NITROGEN, TOTAL	1.29
5/18/2009 10:20	Grab	NITRATE+NITRITE-N	0.073
5/18/2009 10:20	Grab	PHOSPHATE, TOTAL AS P	0.125
5/18/2009 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.32
5/18/2009 10:40	Grab	NITRATE+NITRITE-N	0.071
5/18/2009 10:40	Grab	PHOSPHATE, TOTAL AS P	0.126
5/18/2009 10:55	Grab	KJELDAHL NITROGEN, TOTAL	1.25
5/18/2009 10:55	Grab	NITRATE+NITRITE-N	0.07
5/18/2009 10:55	Grab	PHOSPHATE, TOTAL AS P	0.125
6/1/2009 13:35	Grab	KJELDAHL NITROGEN, TOTAL	1.29
6/1/2009 13:35	Grab	NITRATE+NITRITE-N	0.028
6/1/2009 13:35	Grab	PHOSPHATE, TOTAL AS P	0.141
6/15/2009 14:21	Grab	KJELDAHL NITROGEN, TOTAL	1.72
6/15/2009 14:21	Grab	NITRATE+NITRITE-N	-0.005
6/15/2009 14:21	Grab	PHOSPHATE, TOTAL AS P	0.244
7/6/2009 13:12	Grab	KJELDAHL NITROGEN, TOTAL	1.31
7/6/2009 13:12	Grab	NITRATE+NITRITE-N	0.13
7/6/2009 13:12	Grab	PHOSPHATE, TOTAL AS P	0.178
7/20/2009 13:22	Grab	KJELDAHL NITROGEN, TOTAL	1.27
7/20/2009 13:22	Grab	NITRATE+NITRITE-N	0.19
7/20/2009 13:22	Grab	PHOSPHATE, TOTAL AS P	0.172
7/20/2009 13:29	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/20/2009 13:29	Grab	NITRATE+NITRITE-N	-0.005
7/20/2009 13:29	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/3/2009 13:26	Grab	KJELDAHL NITROGEN, TOTAL	1.67
8/3/2009 13:26	Grab	NITRATE+NITRITE-N	0.161
8/3/2009 13:26	Grab	PHOSPHATE, TOTAL AS P	0.221

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
8/3/2009 13:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/3/2009 13:35	Grab	NITRATE+NITRITE-N	-0.005
8/3/2009 13:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/17/2009 13:25	Grab	KJELDAHL NITROGEN, TOTAL	1.29
8/17/2009 13:25	Grab	NITRATE+NITRITE-N	0.194
8/17/2009 13:25	Grab	PHOSPHATE, TOTAL AS P	0.152
9/8/2009 13:35	Grab	KJELDAHL NITROGEN, TOTAL	1.2
9/8/2009 13:35	Grab	NITRATE+NITRITE-N	0.156
9/8/2009 13:35	Grab	PHOSPHATE, TOTAL AS P	0.149
9/21/2009 13:12	Grab	KJELDAHL NITROGEN, TOTAL	1.14
9/21/2009 13:12	Grab	NITRATE+NITRITE-N	0.201
9/21/2009 13:12	Grab	PHOSPHATE, TOTAL AS P	0.151
10/26/2009 10:40	Grab	KJELDAHL NITROGEN, TOTAL	0.93
10/26/2009 10:40	Grab	NITRATE+NITRITE-N	0.455
10/26/2009 10:40	Grab	PHOSPHATE, TOTAL AS P	0.137
10/26/2009 10:55	Grab	KJELDAHL NITROGEN, TOTAL	0.91
10/26/2009 10:55	Grab	NITRATE+NITRITE-N	0.455
10/26/2009 10:55	Grab	PHOSPHATE, TOTAL AS P	0.139
10/26/2009 11:05	Grab	KJELDAHL NITROGEN, TOTAL	0.92
10/26/2009 11:05	Grab	NITRATE+NITRITE-N	0.455
10/26/2009 11:05	Grab	PHOSPHATE, TOTAL AS P	0.136
10/26/2009 11:15	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/26/2009 11:15	Grab	NITRATE+NITRITE-N	-0.005
10/26/2009 11:15	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/23/2009 9:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/23/2009 9:40	Grab	NITRATE+NITRITE-N	0.007
11/23/2009 9:57	Grab	KJELDAHL NITROGEN, TOTAL	1
11/23/2009 9:57	Grab	NITRATE+NITRITE-N	0.502
11/23/2009 9:57	Grab	PHOSPHATE, TOTAL AS P	0.118
11/23/2009 10:13	Grab	KJELDAHL NITROGEN, TOTAL	1
11/23/2009 10:13	Grab	NITRATE+NITRITE-N	0.501
11/23/2009 10:27	Grab	KJELDAHL NITROGEN, TOTAL	0.96
11/23/2009 10:27	Grab	NITRATE+NITRITE-N	0.5
11/23/2009 10:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/23/2009 10:35	Grab	NITRATE+NITRITE-N	-0.005
11/23/2009 10:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/22/2009 11:10	Grab	KJELDAHL NITROGEN, TOTAL	0.96
12/22/2009 11:10	Grab	NITRATE+NITRITE-N	0.328
12/22/2009 11:10	Grab	PHOSPHATE, TOTAL AS P	0.118
12/22/2009 11:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/22/2009 11:25	Grab	NITRATE+NITRITE-N	-0.005
12/22/2009 11:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/26/2010 10:22	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/26/2010 10:22	Grab	NITRATE+NITRITE-N	-0.005
1/26/2010 10:22	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/26/2010 10:37	Grab	KJELDAHL NITROGEN, TOTAL	0.98
1/26/2010 10:37	Grab	NITRATE+NITRITE-N	0.281

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
1/26/2010 10:37	Grab	PHOSPHATE, TOTAL AS P	0.088
1/26/2010 10:58	Grab	KJELDAHL NITROGEN, TOTAL	0.99
1/26/2010 10:58	Grab	NITRATE+NITRITE-N	0.281
1/26/2010 10:58	Grab	PHOSPHATE, TOTAL AS P	0.086
1/26/2010 11:11	Grab	KJELDAHL NITROGEN, TOTAL	0.99
1/26/2010 11:11	Grab	NITRATE+NITRITE-N	0.278
1/26/2010 11:11	Grab	PHOSPHATE, TOTAL AS P	0.086
1/26/2010 11:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/26/2010 11:25	Grab	NITRATE+NITRITE-N	-0.005
1/26/2010 11:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/23/2010 11:11	Grab	KJELDAHL NITROGEN, TOTAL	1.12
2/23/2010 11:11	Grab	NITRATE+NITRITE-N	0.147
2/23/2010 11:11	Grab	PHOSPHATE, TOTAL AS P	0.073
2/23/2010 11:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/23/2010 11:20	Grab	NITRATE+NITRITE-N	-0.005
2/23/2010 11:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/23/2010 9:24	Grab	KJELDAHL NITROGEN, TOTAL	1.03
3/23/2010 9:24	Grab	NITRATE+NITRITE-N	0.429
3/23/2010 9:24	Grab	PHOSPHATE, TOTAL AS P	0.129
3/23/2010 9:46	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/23/2010 9:46	Grab	NITRATE+NITRITE-N	-0.005
3/23/2010 9:46	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/27/2010 9:30	Grab	KJELDAHL NITROGEN, TOTAL	1.14
4/27/2010 9:30	Grab	NITRATE+NITRITE-N	0.146
4/27/2010 9:30	Grab	PHOSPHATE, TOTAL AS P	0.121
4/27/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/27/2010 10:00	Grab	NITRATE+NITRITE-N	-0.005
4/27/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/4/2010 10:14	Grab	KJELDAHL NITROGEN, TOTAL	1.3
5/4/2010 10:14	Grab	NITRATE+NITRITE-N	0.144
5/4/2010 10:14	Grab	PHOSPHATE, TOTAL AS P	0.125
5/11/2010 9:52	Grab	KJELDAHL NITROGEN, TOTAL	1.29
5/11/2010 9:52	Grab	NITRATE+NITRITE-N	0.152
5/11/2010 9:52	Grab	PHOSPHATE, TOTAL AS P	0.121
5/11/2010 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/11/2010 10:05	Grab	NITRATE+NITRITE-N	-0.005
5/11/2010 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/18/2010 10:12	Grab	KJELDAHL NITROGEN, TOTAL	1.19
5/18/2010 10:12	Grab	NITRATE+NITRITE-N	0.093
5/18/2010 10:12	Grab	PHOSPHATE, TOTAL AS P	0.099
5/25/2010 9:41	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/25/2010 9:41	Grab	NITRATE+NITRITE-N	-0.005
5/25/2010 9:41	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/25/2010 9:50	Grab	KJELDAHL NITROGEN, TOTAL	1.2
5/25/2010 9:50	Grab	NITRATE+NITRITE-N	0.09
5/25/2010 9:50	Grab	PHOSPHATE, TOTAL AS P	0.099
5/25/2010 9:55	Grab	KJELDAHL NITROGEN, TOTAL	1.23

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/25/2010 9:55	Grab	NITRATE+NITRITE-N	0.1
5/25/2010 9:55	Grab	PHOSPHATE, TOTAL AS P	0.1
5/25/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	1.23
5/25/2010 10:00	Grab	NITRATE+NITRITE-N	0.097
5/25/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	0.102
5/25/2010 10:10	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/25/2010 10:10	Grab	NITRATE+NITRITE-N	-0.005
5/25/2010 10:10	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/1/2010 10:06	Grab	KJELDAHL NITROGEN, TOTAL	1.06
6/1/2010 10:06	Grab	NITRATE+NITRITE-N	0.05
6/1/2010 10:06	Grab	PHOSPHATE, TOTAL AS P	0.102
6/8/2010 9:27	Grab	KJELDAHL NITROGEN, TOTAL	1.12
6/8/2010 9:27	Grab	NITRATE+NITRITE-N	0.074
6/8/2010 9:27	Grab	PHOSPHATE, TOTAL AS P	0.109
6/8/2010 10:12	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/8/2010 10:12	Grab	NITRATE+NITRITE-N	-0.005
6/8/2010 10:12	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/15/2010 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.22
6/15/2010 9:45	Grab	NITRATE+NITRITE-N	0.111
6/15/2010 9:45	Grab	PHOSPHATE, TOTAL AS P	0.109
6/15/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/15/2010 10:00	Grab	NITRATE+NITRITE-N	-0.005
6/15/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/22/2010 10:37	Grab	KJELDAHL NITROGEN, TOTAL	1.23
6/22/2010 10:37	Grab	NITRATE+NITRITE-N	0.043
6/22/2010 10:37	Grab	PHOSPHATE, TOTAL AS P	0.104
6/29/2010 9:30	Grab	KJELDAHL NITROGEN, TOTAL	1.44
6/29/2010 9:30	Grab	NITRATE+NITRITE-N	0.009
6/29/2010 9:30	Grab	PHOSPHATE, TOTAL AS P	0.112
6/29/2010 9:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/29/2010 9:45	Grab	NITRATE+NITRITE-N	-0.005
6/29/2010 9:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/6/2010 9:55	Grab	KJELDAHL NITROGEN, TOTAL	1.24
7/6/2010 9:55	Grab	NITRATE+NITRITE-N	0.141
7/6/2010 9:55	Grab	PHOSPHATE, TOTAL AS P	0.18
7/6/2010 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/6/2010 10:05	Grab	NITRATE+NITRITE-N	-0.005
7/6/2010 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/13/2010 9:26	Grab	KJELDAHL NITROGEN, TOTAL	1.26
7/13/2010 9:26	Grab	NITRATE+NITRITE-N	0.12
7/13/2010 9:26	Grab	PHOSPHATE, TOTAL AS P	0.155
7/13/2010 9:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/13/2010 9:45	Grab	NITRATE+NITRITE-N	-0.005
7/13/2010 9:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/20/2010 9:30	Grab	KJELDAHL NITROGEN, TOTAL	1.4
7/20/2010 9:30	Grab	NITRATE+NITRITE-N	0.071
7/20/2010 9:30	Grab	PHOSPHATE, TOTAL AS P	0.102

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/20/2010 9:50	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/20/2010 9:50	Grab	NITRATE+NITRITE-N	-0.005
7/20/2010 9:50	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/27/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/27/2010 10:00	Grab	NITRATE+NITRITE-N	-0.005
7/27/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/27/2010 10:15	Grab	KJELDAHL NITROGEN, TOTAL	1.37
7/27/2010 10:15	Grab	NITRATE+NITRITE-N	-0.005
7/27/2010 10:15	Grab	PHOSPHATE, TOTAL AS P	0.083
7/27/2010 10:34	Grab	KJELDAHL NITROGEN, TOTAL	1.28
7/27/2010 10:34	Grab	NITRATE+NITRITE-N	-0.005
7/27/2010 10:34	Grab	PHOSPHATE, TOTAL AS P	0.087
7/27/2010 10:46	Grab	KJELDAHL NITROGEN, TOTAL	1.37
7/27/2010 10:46	Grab	NITRATE+NITRITE-N	-0.005
7/27/2010 10:46	Grab	PHOSPHATE, TOTAL AS P	0.085
7/27/2010 10:58	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/27/2010 10:58	Grab	NITRATE+NITRITE-N	-0.005
7/27/2010 10:58	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/3/2010 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.24
8/3/2010 9:45	Grab	NITRATE+NITRITE-N	0.005
8/3/2010 9:45	Grab	PHOSPHATE, TOTAL AS P	0.116
8/3/2010 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/3/2010 10:05	Grab	NITRATE+NITRITE-N	-0.005
8/3/2010 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/10/2010 9:20	Grab	KJELDAHL NITROGEN, TOTAL	1.13
8/10/2010 9:20	Grab	NITRATE+NITRITE-N	0.059
8/10/2010 9:20	Grab	PHOSPHATE, TOTAL AS P	0.135
8/10/2010 9:30	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/10/2010 9:30	Grab	NITRATE+NITRITE-N	-0.005
8/10/2010 9:30	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/17/2010 9:40	Grab	KJELDAHL NITROGEN, TOTAL	1.15
8/17/2010 9:40	Grab	NITRATE+NITRITE-N	0.019
8/17/2010 9:40	Grab	PHOSPHATE, TOTAL AS P	0.12
8/17/2010 9:52	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/17/2010 9:52	Grab	NITRATE+NITRITE-N	-0.005
8/17/2010 9:52	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/24/2010 9:55	Grab	KJELDAHL NITROGEN, TOTAL	1.2
8/24/2010 9:55	Grab	NITRATE+NITRITE-N	0.097
8/24/2010 9:55	Grab	PHOSPHATE, TOTAL AS P	0.149
8/24/2010 10:10	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/24/2010 10:10	Grab	NITRATE+NITRITE-N	-0.005
8/24/2010 10:10	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/31/2010 9:50	Grab	KJELDAHL NITROGEN, TOTAL	1.19
8/31/2010 9:50	Grab	NITRATE+NITRITE-N	0.175
8/31/2010 9:50	Grab	PHOSPHATE, TOTAL AS P	0.124
8/31/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/31/2010 10:00	Grab	NITRATE+NITRITE-N	-0.005

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
8/31/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/7/2010 10:05	Grab	KJELDAHL NITROGEN, TOTAL	1.23
9/7/2010 10:05	Grab	NITRATE+NITRITE-N	0.247
9/7/2010 10:05	Grab	PHOSPHATE, TOTAL AS P	0.122
9/7/2010 10:36	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/7/2010 10:36	Grab	NITRATE+NITRITE-N	-0.005
9/7/2010 10:36	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/13/2010 9:28	Grab	KJELDAHL NITROGEN, TOTAL	1.2
9/13/2010 9:28	Grab	NITRATE+NITRITE-N	0.187
9/13/2010 9:28	Grab	PHOSPHATE, TOTAL AS P	0.127
9/13/2010 10:21	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/13/2010 10:21	Grab	NITRATE+NITRITE-N	-0.005
9/13/2010 10:21	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/21/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	0.99
9/21/2010 10:00	Grab	NITRATE+NITRITE-N	0.218
9/21/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	0.108
9/21/2010 10:15	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/21/2010 10:15	Grab	NITRATE+NITRITE-N	-0.005
9/21/2010 10:15	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/28/2010 9:45	Grab	KJELDAHL NITROGEN, TOTAL	0.95
9/28/2010 9:45	Grab	NITRATE+NITRITE-N	0.389
9/28/2010 9:45	Grab	PHOSPHATE, TOTAL AS P	0.119
9/28/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/28/2010 10:00	Grab	NITRATE+NITRITE-N	-0.005
9/28/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/5/2010 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.07
10/5/2010 9:45	Grab	NITRATE+NITRITE-N	0.33
10/5/2010 9:45	Grab	PHOSPHATE, TOTAL AS P	0.108
10/5/2010 10:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/5/2010 10:00	Grab	NITRATE+NITRITE-N	-0.005
10/5/2010 10:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/12/2010 9:50	Grab	KJELDAHL NITROGEN, TOTAL	1.05
10/12/2010 9:50	Grab	NITRATE+NITRITE-N	0.159
10/12/2010 9:50	Grab	PHOSPHATE, TOTAL AS P	0.091
10/12/2010 10:10	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/12/2010 10:10	Grab	NITRATE+NITRITE-N	-0.005
10/12/2010 10:10	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/19/2010 10:03	Grab	KJELDAHL NITROGEN, TOTAL	0.95
10/19/2010 10:03	Grab	NITRATE+NITRITE-N	0.345
10/19/2010 10:03	Grab	PHOSPHATE, TOTAL AS P	0.096
10/19/2010 10:18	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/19/2010 10:18	Grab	NITRATE+NITRITE-N	-0.005
10/19/2010 10:18	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/26/2010 10:05	Grab	KJELDAHL NITROGEN, TOTAL	1
10/26/2010 10:05	Grab	NITRATE+NITRITE-N	0.272
10/26/2010 10:05	Grab	PHOSPHATE, TOTAL AS P	0.093
10/26/2010 10:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.05

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
10/26/2010 10:20	Grab	NITRATE+NITRITE-N	-0.005
10/26/2010 10:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/2/2010 9:53	Grab	KJELDAHL NITROGEN, TOTAL	1.06
11/2/2010 9:53	Grab	NITRATE+NITRITE-N	0.307
11/2/2010 9:53	Grab	PHOSPHATE, TOTAL AS P	0.09
11/2/2010 10:03	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/2/2010 10:03	Grab	NITRATE+NITRITE-N	-0.005
11/2/2010 10:03	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/9/2010 10:25	Grab	KJELDAHL NITROGEN, TOTAL	1.04
11/9/2010 10:25	Grab	NITRATE+NITRITE-N	0.423
11/9/2010 10:25	Grab	PHOSPHATE, TOTAL AS P	0.113
11/9/2010 10:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/9/2010 10:40	Grab	NITRATE+NITRITE-N	-0.005
11/9/2010 10:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/16/2010 9:26	Grab	KJELDAHL NITROGEN, TOTAL	1.01
11/16/2010 9:26	Grab	NITRATE+NITRITE-N	0.315
11/16/2010 9:26	Grab	PHOSPHATE, TOTAL AS P	0.103
11/16/2010 9:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/16/2010 9:40	Grab	NITRATE+NITRITE-N	-0.005
11/16/2010 9:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/22/2010 10:20	Grab	KJELDAHL NITROGEN, TOTAL	1.03
11/22/2010 10:20	Grab	NITRATE+NITRITE-N	0.287
11/22/2010 10:20	Grab	PHOSPHATE, TOTAL AS P	0.095
11/22/2010 10:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/22/2010 10:40	Grab	NITRATE+NITRITE-N	-0.005
11/22/2010 10:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/30/2010 10:30	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/30/2010 10:30	Grab	NITRATE+NITRITE-N	-0.005
11/30/2010 10:30	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/30/2010 10:45	Grab	KJELDAHL NITROGEN, TOTAL	1.07
11/30/2010 10:45	Grab	NITRATE+NITRITE-N	0.282
11/30/2010 10:45	Grab	PHOSPHATE, TOTAL AS P	0.098
11/30/2010 10:58	Grab	KJELDAHL NITROGEN, TOTAL	1.07
11/30/2010 10:58	Grab	NITRATE+NITRITE-N	0.285
11/30/2010 10:58	Grab	PHOSPHATE, TOTAL AS P	0.098
11/30/2010 11:10	Grab	KJELDAHL NITROGEN, TOTAL	1.07
11/30/2010 11:10	Grab	NITRATE+NITRITE-N	0.281
11/30/2010 11:10	Grab	PHOSPHATE, TOTAL AS P	0.099
11/30/2010 11:22	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/30/2010 11:22	Grab	NITRATE+NITRITE-N	-0.005
11/30/2010 11:22	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/7/2010 9:58	Grab	KJELDAHL NITROGEN, TOTAL	0.97
12/7/2010 9:58	Grab	NITRATE+NITRITE-N	0.316
12/7/2010 9:58	Grab	PHOSPHATE, TOTAL AS P	0.091
12/7/2010 10:10	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/7/2010 10:10	Grab	NITRATE+NITRITE-N	-0.005
12/7/2010 10:10	Grab	PHOSPHATE, TOTAL AS P	-0.002

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
12/14/2010 9:56	Grab	KJELDAHL NITROGEN, TOTAL	0.98
12/14/2010 9:56	Grab	NITRATE+NITRITE-N	0.281
12/14/2010 9:56	Grab	PHOSPHATE, TOTAL AS P	0.088
12/21/2010 10:22	Grab	KJELDAHL NITROGEN, TOTAL	1.01
12/21/2010 10:22	Grab	NITRATE+NITRITE-N	0.266
12/21/2010 10:22	Grab	PHOSPHATE, TOTAL AS P	0.089
12/21/2010 10:52	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/21/2010 10:52	Grab	NITRATE+NITRITE-N	-0.005
12/21/2010 10:52	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/28/2010 10:05	Grab	KJELDAHL NITROGEN, TOTAL	0.95
12/28/2010 10:05	Grab	NITRATE+NITRITE-N	0.199
12/28/2010 10:05	Grab	PHOSPHATE, TOTAL AS P	0.073
12/28/2010 10:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/28/2010 10:25	Grab	NITRATE+NITRITE-N	-0.005
12/28/2010 10:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/5/2011 9:56	Grab	KJELDAHL NITROGEN, TOTAL	1.05
1/5/2011 9:56	Grab	NITRATE+NITRITE-N	0.238
1/5/2011 9:56	Grab	PHOSPHATE, TOTAL AS P	0.082
1/12/2011 9:47	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/12/2011 9:47	Grab	NITRATE+NITRITE-N	-0.005
1/12/2011 9:47	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/12/2011 10:04	Grab	KJELDAHL NITROGEN, TOTAL	0.97
1/12/2011 10:04	Grab	NITRATE+NITRITE-N	0.247
1/12/2011 10:04	Grab	PHOSPHATE, TOTAL AS P	0.079
1/12/2011 10:15	Grab	KJELDAHL NITROGEN, TOTAL	0.96
1/12/2011 10:15	Grab	NITRATE+NITRITE-N	0.245
1/12/2011 10:15	Grab	PHOSPHATE, TOTAL AS P	0.08
1/12/2011 10:24	Grab	KJELDAHL NITROGEN, TOTAL	0.97
1/12/2011 10:24	Grab	NITRATE+NITRITE-N	0.249
1/12/2011 10:24	Grab	PHOSPHATE, TOTAL AS P	0.078
1/12/2011 10:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/12/2011 10:35	Grab	NITRATE+NITRITE-N	-0.005
1/12/2011 10:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/19/2011 10:25	Grab	KJELDAHL NITROGEN, TOTAL	0.93
1/19/2011 10:25	Grab	NITRATE+NITRITE-N	0.183
1/19/2011 10:25	Grab	PHOSPHATE, TOTAL AS P	0.07
1/26/2011 10:15	Grab	KJELDAHL NITROGEN, TOTAL	0.95
1/26/2011 10:15	Grab	NITRATE+NITRITE-N	0.142
1/26/2011 10:15	Grab	PHOSPHATE, TOTAL AS P	0.069
2/2/2011 9:37	Grab	KJELDAHL NITROGEN, TOTAL	1.12
2/2/2011 9:37	Grab	NITRATE+NITRITE-N	0.005
2/2/2011 9:37	Grab	PHOSPHATE, TOTAL AS P	0.075
2/2/2011 10:03	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/2/2011 10:03	Grab	NITRATE+NITRITE-N	-0.005
2/2/2011 10:03	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/9/2011 10:21	Grab	KJELDAHL NITROGEN, TOTAL	0.94
2/9/2011 10:21	Grab	NITRATE+NITRITE-N	0.017

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/9/2011 10:21	Grab	PHOSPHATE, TOTAL AS P	0.066
2/9/2011 10:50	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/9/2011 10:50	Grab	NITRATE+NITRITE-N	-0.005
2/9/2011 10:50	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/16/2011 10:05	Grab	KJELDAHL NITROGEN, TOTAL	1.12
2/16/2011 10:05	Grab	NITRATE+NITRITE-N	-0.005
2/16/2011 10:05	Grab	PHOSPHATE, TOTAL AS P	0.074
2/23/2011 10:07	Grab	KJELDAHL NITROGEN, TOTAL	0.97
2/23/2011 10:07	Grab	NITRATE+NITRITE-N	0.007
2/23/2011 10:07	Grab	PHOSPHATE, TOTAL AS P	0.063
3/2/2011 10:05	Grab	KJELDAHL NITROGEN, TOTAL	0.98
3/2/2011 10:05	Grab	NITRATE+NITRITE-N	0.005
3/2/2011 10:05	Grab	PHOSPHATE, TOTAL AS P	0.06
3/9/2011 9:40	Grab	KJELDAHL NITROGEN, TOTAL	1.03
3/9/2011 9:40	Grab	NITRATE+NITRITE-N	0.011
3/9/2011 9:40	Grab	PHOSPHATE, TOTAL AS P	0.085
3/16/2011 10:09	Grab	KJELDAHL NITROGEN, TOTAL	1.17
3/16/2011 10:09	Grab	NITRATE+NITRITE-N	0.019
3/16/2011 10:09	Grab	PHOSPHATE, TOTAL AS P	0.087
3/23/2011 10:06	Grab	KJELDAHL NITROGEN, TOTAL	1.14
3/23/2011 10:06	Grab	NITRATE+NITRITE-N	-0.005
3/23/2011 10:06	Grab	PHOSPHATE, TOTAL AS P	0.085
3/23/2011 10:22	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/23/2011 10:22	Grab	NITRATE+NITRITE-N	-0.005
3/23/2011 10:22	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/30/2011 9:51	Grab	KJELDAHL NITROGEN, TOTAL	1.13
3/30/2011 9:51	Grab	NITRATE+NITRITE-N	0.039
3/30/2011 9:51	Grab	PHOSPHATE, TOTAL AS P	0.082
3/30/2011 10:04	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/30/2011 10:04	Grab	NITRATE+NITRITE-N	-0.005
3/30/2011 10:04	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/6/2011 10:02	Grab	KJELDAHL NITROGEN, TOTAL	1.12
4/6/2011 10:02	Grab	NITRATE+NITRITE-N	0.022
4/6/2011 10:02	Grab	PHOSPHATE, TOTAL AS P	0.097
4/6/2011 10:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/6/2011 10:25	Grab	NITRATE+NITRITE-N	-0.005
4/6/2011 10:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/13/2011 10:29	Grab	KJELDAHL NITROGEN, TOTAL	1.08
4/13/2011 10:29	Grab	NITRATE+NITRITE-N	0.009
4/13/2011 10:29	Grab	PHOSPHATE, TOTAL AS P	0.096
4/13/2011 10:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/13/2011 10:45	Grab	NITRATE+NITRITE-N	-0.005
4/13/2011 10:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/20/2011 10:44	Grab	KJELDAHL NITROGEN, TOTAL	1.17
4/20/2011 10:44	Grab	NITRATE+NITRITE-N	-0.005
4/20/2011 10:44	Grab	PHOSPHATE, TOTAL AS P	0.121
4/20/2011 11:29	Grab	KJELDAHL NITROGEN, TOTAL	-0.05

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
4/20/2011 11:29	Grab	NITRATE+NITRITE-N	-0.005
4/20/2011 11:29	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/27/2011 11:10	Grab	KJELDAHL NITROGEN, TOTAL	1.16
4/27/2011 11:10	Grab	NITRATE+NITRITE-N	-0.005
4/27/2011 11:10	Grab	PHOSPHATE, TOTAL AS P	0.107
5/4/2011 9:49	Grab	KJELDAHL NITROGEN, TOTAL	1.4
5/4/2011 9:49	Grab	NITRATE+NITRITE-N	-0.005
5/4/2011 9:49	Grab	PHOSPHATE, TOTAL AS P	0.135
5/4/2011 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/4/2011 10:05	Grab	NITRATE+NITRITE-N	-0.005
5/4/2011 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/11/2011 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.46
5/11/2011 9:45	Grab	NITRATE+NITRITE-N	-0.005
5/11/2011 9:45	Grab	PHOSPHATE, TOTAL AS P	0.165
5/11/2011 10:06	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/11/2011 10:06	Grab	NITRATE+NITRITE-N	-0.005
5/11/2011 10:06	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/18/2011 10:01	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/18/2011 10:01	Grab	NITRATE+NITRITE-N	-0.005
5/18/2011 10:01	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/18/2011 10:15	Grab	KJELDAHL NITROGEN, TOTAL	1.27
5/18/2011 10:15	Grab	NITRATE+NITRITE-N	0.023
5/18/2011 10:15	Grab	PHOSPHATE, TOTAL AS P	0.184
5/18/2011 10:41	Grab	KJELDAHL NITROGEN, TOTAL	1.28
5/18/2011 10:41	Grab	NITRATE+NITRITE-N	0.025
5/18/2011 10:41	Grab	PHOSPHATE, TOTAL AS P	0.192
5/18/2011 10:54	Grab	KJELDAHL NITROGEN, TOTAL	1.28
5/18/2011 10:54	Grab	NITRATE+NITRITE-N	0.02
5/18/2011 10:54	Grab	PHOSPHATE, TOTAL AS P	0.187
5/18/2011 11:11	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/18/2011 11:11	Grab	NITRATE+NITRITE-N	-0.005
5/18/2011 11:11	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/25/2011 9:58	Grab	KJELDAHL NITROGEN, TOTAL	1.75
5/25/2011 9:58	Grab	NITRATE+NITRITE-N	-0.005
5/25/2011 9:58	Grab	PHOSPHATE, TOTAL AS P	0.2
5/25/2011 10:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/25/2011 10:25	Grab	NITRATE+NITRITE-N	-0.005
5/25/2011 10:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/1/2011 10:46	Grab	KJELDAHL NITROGEN, TOTAL	2.24
6/1/2011 10:46	Grab	NITRATE+NITRITE-N	-0.005
6/1/2011 10:46	Grab	PHOSPHATE, TOTAL AS P	0.186
6/1/2011 11:00	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/1/2011 11:00	Grab	NITRATE+NITRITE-N	-0.005
6/1/2011 11:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/8/2011 9:47	Grab	KJELDAHL NITROGEN, TOTAL	4.67
6/8/2011 9:47	Grab	NITRATE+NITRITE-N	0.015
6/8/2011 9:47	Grab	PHOSPHATE, TOTAL AS P	0.311

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/8/2011 10:17	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/8/2011 10:17	Grab	NITRATE+NITRITE-N	-0.005
6/8/2011 10:17	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/15/2011 10:21	Grab	KJELDAHL NITROGEN, TOTAL	2.37
6/15/2011 10:21	Grab	NITRATE+NITRITE-N	0.008
6/15/2011 10:21	Grab	PHOSPHATE, TOTAL AS P	0.264
6/22/2011 10:18	Grab	KJELDAHL NITROGEN, TOTAL	1.83
6/22/2011 10:18	Grab	NITRATE+NITRITE-N	0.11
6/22/2011 10:18	Grab	PHOSPHATE, TOTAL AS P	0.233
6/22/2011 10:37	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/22/2011 10:37	Grab	NITRATE+NITRITE-N	-0.005
6/22/2011 10:37	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/29/2011 10:35	Grab	KJELDAHL NITROGEN, TOTAL	1.58
6/29/2011 10:35	Grab	NITRATE+NITRITE-N	0.164
6/29/2011 10:35	Grab	PHOSPHATE, TOTAL AS P	0.198
6/29/2011 10:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/29/2011 10:45	Grab	NITRATE+NITRITE-N	-0.005
6/29/2011 10:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/6/2011 10:17	Grab	KJELDAHL NITROGEN, TOTAL	1.43
7/6/2011 10:17	Grab	NITRATE+NITRITE-N	-0.005
7/6/2011 10:17	Grab	PHOSPHATE, TOTAL AS P	0.197
7/6/2011 10:32	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/6/2011 10:32	Grab	NITRATE+NITRITE-N	-0.005
7/6/2011 10:32	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/13/2011 10:36	Grab	KJELDAHL NITROGEN, TOTAL	1.31
7/13/2011 10:36	Grab	NITRATE+NITRITE-N	0.016
7/13/2011 10:36	Grab	PHOSPHATE, TOTAL AS P	0.196
7/13/2011 10:53	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/13/2011 10:53	Grab	NITRATE+NITRITE-N	-0.005
7/13/2011 10:53	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/20/2011 10:38	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/20/2011 10:38	Grab	NITRATE+NITRITE-N	-0.005
7/20/2011 10:38	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/20/2011 11:04	Grab	KJELDAHL NITROGEN, TOTAL	1.29
7/20/2011 11:04	Grab	NITRATE+NITRITE-N	-0.005
7/20/2011 11:04	Grab	PHOSPHATE, TOTAL AS P	0.218
7/20/2011 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.29
7/20/2011 11:20	Grab	NITRATE+NITRITE-N	-0.005
7/20/2011 11:20	Grab	PHOSPHATE, TOTAL AS P	0.218
7/20/2011 11:48	Grab	KJELDAHL NITROGEN, TOTAL	1.38
7/20/2011 11:48	Grab	NITRATE+NITRITE-N	-0.005
7/20/2011 11:48	Grab	PHOSPHATE, TOTAL AS P	0.231
7/20/2011 12:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/20/2011 12:05	Grab	NITRATE+NITRITE-N	-0.005
7/20/2011 12:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/27/2011 10:16	Grab	KJELDAHL NITROGEN, TOTAL	1.45
7/27/2011 10:16	Grab	NITRATE+NITRITE-N	0.024

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
7/27/2011 10:16	Grab	PHOSPHATE, TOTAL AS P	0.268
7/27/2011 10:33	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/27/2011 10:33	Grab	NITRATE+NITRITE-N	-0.005
7/27/2011 10:33	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/3/2011 10:37	Grab	KJELDAHL NITROGEN, TOTAL	1.41
8/3/2011 10:37	Grab	NITRATE+NITRITE-N	0.16
8/3/2011 10:37	Grab	PHOSPHATE, TOTAL AS P	0.278
8/3/2011 10:53	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/3/2011 10:53	Grab	NITRATE+NITRITE-N	-0.005
8/3/2011 10:53	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/10/2011 10:22	Grab	KJELDAHL NITROGEN, TOTAL	1.04
8/10/2011 10:22	Grab	NITRATE+NITRITE-N	0.251
8/10/2011 10:22	Grab	PHOSPHATE, TOTAL AS P	0.24
8/10/2011 10:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/10/2011 10:35	Grab	NITRATE+NITRITE-N	-0.005
8/10/2011 10:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/17/2011 10:13	Grab	KJELDAHL NITROGEN, TOTAL	1.12
8/17/2011 10:13	Grab	NITRATE+NITRITE-N	0.242
8/17/2011 10:13	Grab	PHOSPHATE, TOTAL AS P	0.204
8/17/2011 10:29	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/17/2011 10:29	Grab	NITRATE+NITRITE-N	-0.005
8/17/2011 10:29	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/24/2011 10:04	Grab	KJELDAHL NITROGEN, TOTAL	1.13
8/24/2011 10:04	Grab	NITRATE+NITRITE-N	0.153
8/24/2011 10:04	Grab	PHOSPHATE, TOTAL AS P	0.171
8/24/2011 10:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/24/2011 10:20	Grab	NITRATE+NITRITE-N	-0.005
8/24/2011 10:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/31/2011 10:41	Grab	KJELDAHL NITROGEN, TOTAL	1.19
8/31/2011 10:41	Grab	NITRATE+NITRITE-N	0.239
8/31/2011 10:41	Grab	PHOSPHATE, TOTAL AS P	0.187
8/31/2011 11:07	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/31/2011 11:07	Grab	NITRATE+NITRITE-N	-0.005
8/31/2011 11:07	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/7/2011 9:48	Grab	KJELDAHL NITROGEN, TOTAL	1.1
9/7/2011 9:48	Grab	NITRATE+NITRITE-N	0.25
9/7/2011 9:48	Grab	PHOSPHATE, TOTAL AS P	0.172
9/7/2011 10:03	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/7/2011 10:03	Grab	NITRATE+NITRITE-N	-0.005
9/7/2011 10:03	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/14/2011 10:23	Grab	KJELDAHL NITROGEN, TOTAL	1.12
9/14/2011 10:23	Grab	NITRATE+NITRITE-N	0.219
9/14/2011 10:23	Grab	PHOSPHATE, TOTAL AS P	0.141
9/14/2011 10:46	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/14/2011 10:46	Grab	NITRATE+NITRITE-N	-0.005
9/14/2011 10:46	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/21/2011 9:38	Grab	KJELDAHL NITROGEN, TOTAL	1.14

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/21/2011 9:38	Grab	NITRATE+NITRITE-N	0.24
9/21/2011 9:38	Grab	PHOSPHATE, TOTAL AS P	0.148
9/21/2011 10:08	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/21/2011 10:08	Grab	NITRATE+NITRITE-N	-0.005
9/21/2011 10:08	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/28/2011 10:14	Grab	KJELDAHL NITROGEN, TOTAL	1.12
9/28/2011 10:14	Grab	NITRATE+NITRITE-N	0.352
9/28/2011 10:14	Grab	PHOSPHATE, TOTAL AS P	0.174
9/28/2011 10:37	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/28/2011 10:37	Grab	NITRATE+NITRITE-N	-0.005
9/28/2011 10:37	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/5/2011 9:47	Grab	KJELDAHL NITROGEN, TOTAL	0.97
10/5/2011 9:47	Grab	NITRATE+NITRITE-N	0.334
10/5/2011 9:47	Grab	PHOSPHATE, TOTAL AS P	0.147
10/5/2011 10:04	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/5/2011 10:04	Grab	NITRATE+NITRITE-N	-0.005
10/5/2011 10:04	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/12/2011 10:27	Grab	KJELDAHL NITROGEN, TOTAL	0.82
10/12/2011 10:27	Grab	NITRATE+NITRITE-N	0.3
10/12/2011 10:27	Grab	PHOSPHATE, TOTAL AS P	0.115
10/12/2011 10:48	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/12/2011 10:48	Grab	NITRATE+NITRITE-N	-0.005
10/12/2011 10:48	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/19/2011 10:06	Grab	KJELDAHL NITROGEN, TOTAL	0.97
10/19/2011 10:06	Grab	NITRATE+NITRITE-N	0.37
10/19/2011 10:06	Grab	PHOSPHATE, TOTAL AS P	0.164
10/19/2011 10:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/19/2011 10:35	Grab	NITRATE+NITRITE-N	-0.005
10/19/2011 10:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/26/2011 9:37	Grab	KJELDAHL NITROGEN, TOTAL	0.95
10/26/2011 9:37	Grab	NITRATE+NITRITE-N	0.189
10/26/2011 9:37	Grab	PHOSPHATE, TOTAL AS P	0.1
10/26/2011 9:50	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/26/2011 9:50	Grab	NITRATE+NITRITE-N	-0.005
10/26/2011 9:50	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/2/2011 10:43	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/2/2011 10:43	Grab	NITRATE+NITRITE-N	0.007
11/2/2011 10:43	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/2/2011 10:58	Grab	KJELDAHL NITROGEN, TOTAL	1.07
11/2/2011 10:58	Grab	NITRATE+NITRITE-N	0.232
11/2/2011 10:58	Grab	PHOSPHATE, TOTAL AS P	0.098
11/2/2011 11:11	Grab	KJELDAHL NITROGEN, TOTAL	1.05
11/2/2011 11:11	Grab	NITRATE+NITRITE-N	0.234
11/2/2011 11:11	Grab	PHOSPHATE, TOTAL AS P	0.097
11/2/2011 11:30	Grab	KJELDAHL NITROGEN, TOTAL	1.06
11/2/2011 11:30	Grab	NITRATE+NITRITE-N	0.228
11/2/2011 11:30	Grab	PHOSPHATE, TOTAL AS P	0.101

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
11/2/2011 11:51	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/2/2011 11:51	Grab	NITRATE+NITRITE-N	0.007
11/2/2011 11:51	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/9/2011 10:34	Grab	KJELDAHL NITROGEN, TOTAL	1.02
11/9/2011 10:34	Grab	NITRATE+NITRITE-N	0.272
11/9/2011 10:34	Grab	PHOSPHATE, TOTAL AS P	0.085
11/9/2011 10:53	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/9/2011 10:53	Grab	NITRATE+NITRITE-N	-0.005
11/9/2011 10:53	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/16/2011 10:34	Grab	KJELDAHL NITROGEN, TOTAL	0.99
11/16/2011 10:34	Grab	NITRATE+NITRITE-N	0.331
11/16/2011 10:34	Grab	PHOSPHATE, TOTAL AS P	0.082
11/16/2011 10:49	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/16/2011 10:49	Grab	NITRATE+NITRITE-N	0.007
11/16/2011 10:49	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/22/2011 9:45	Grab	KJELDAHL NITROGEN, TOTAL	0.96
11/22/2011 9:45	Grab	NITRATE+NITRITE-N	0.349
11/22/2011 9:45	Grab	PHOSPHATE, TOTAL AS P	0.082
11/22/2011 10:09	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/22/2011 10:09	Grab	NITRATE+NITRITE-N	-0.005
11/22/2011 10:09	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/30/2011 10:32	Grab	KJELDAHL NITROGEN, TOTAL	0.88
11/30/2011 10:32	Grab	NITRATE+NITRITE-N	0.413
11/30/2011 10:32	Grab	PHOSPHATE, TOTAL AS P	0.085
11/30/2011 10:52	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/30/2011 10:52	Grab	NITRATE+NITRITE-N	-0.005
11/30/2011 10:52	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/7/2011 11:03	Grab	KJELDAHL NITROGEN, TOTAL	0.92
12/7/2011 11:03	Grab	NITRATE+NITRITE-N	0.443
12/7/2011 11:03	Grab	PHOSPHATE, TOTAL AS P	0.09
12/7/2011 11:17	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/7/2011 11:17	Grab	NITRATE+NITRITE-N	-0.005
12/7/2011 11:17	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/14/2011 10:37	Grab	KJELDAHL NITROGEN, TOTAL	0.81
12/14/2011 10:37	Grab	NITRATE+NITRITE-N	0.53
12/14/2011 10:37	Grab	PHOSPHATE, TOTAL AS P	0.09
12/14/2011 11:04	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/14/2011 11:04	Grab	NITRATE+NITRITE-N	-0.005
12/14/2011 11:04	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/21/2011 9:22	Grab	KJELDAHL NITROGEN, TOTAL	0.9
12/21/2011 9:22	Grab	NITRATE+NITRITE-N	0.525
12/21/2011 9:22	Grab	PHOSPHATE, TOTAL AS P	0.092
12/21/2011 9:55	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/21/2011 9:55	Grab	NITRATE+NITRITE-N	-0.005
12/21/2011 9:55	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/28/2011 9:58	Grab	KJELDAHL NITROGEN, TOTAL	0.9
12/28/2011 9:58	Grab	NITRATE+NITRITE-N	0.493

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
12/28/2011 9:58	Grab	PHOSPHATE, TOTAL AS P	0.096
12/28/2011 10:14	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/28/2011 10:14	Grab	NITRATE+NITRITE-N	-0.005
12/28/2011 10:14	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/4/2012 10:36	Grab	KJELDAHL NITROGEN, TOTAL	0.96
1/4/2012 10:36	Grab	NITRATE+NITRITE-N	0.542
1/4/2012 10:36	Grab	PHOSPHATE, TOTAL AS P	0.099
1/4/2012 10:49	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/4/2012 10:49	Grab	NITRATE+NITRITE-N	-0.005
1/4/2012 10:49	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/11/2012 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/11/2012 10:05	Grab	NITRATE+NITRITE-N	-0.005
1/11/2012 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/11/2012 10:27	Grab	KJELDAHL NITROGEN, TOTAL	1.02
1/11/2012 10:27	Grab	NITRATE+NITRITE-N	0.573
1/11/2012 10:27	Grab	PHOSPHATE, TOTAL AS P	0.106
1/11/2012 10:36	Grab	KJELDAHL NITROGEN, TOTAL	1.01
1/11/2012 10:36	Grab	NITRATE+NITRITE-N	0.573
1/11/2012 10:36	Grab	PHOSPHATE, TOTAL AS P	0.108
1/11/2012 10:53	Grab	KJELDAHL NITROGEN, TOTAL	1.01
1/11/2012 10:53	Grab	NITRATE+NITRITE-N	0.569
1/11/2012 10:53	Grab	PHOSPHATE, TOTAL AS P	0.109
1/11/2012 11:13	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/11/2012 11:13	Grab	NITRATE+NITRITE-N	-0.005
1/11/2012 11:13	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/18/2012 10:04	Grab	KJELDAHL NITROGEN, TOTAL	0.99
1/18/2012 10:04	Grab	NITRATE+NITRITE-N	0.493
1/18/2012 10:04	Grab	PHOSPHATE, TOTAL AS P	0.1
1/25/2012 10:26	Grab	KJELDAHL NITROGEN, TOTAL	1.27
1/25/2012 10:26	Grab	NITRATE+NITRITE-N	0.301
1/25/2012 10:26	Grab	PHOSPHATE, TOTAL AS P	0.114
1/25/2012 10:55	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/25/2012 10:55	Grab	NITRATE+NITRITE-N	-0.005
1/25/2012 10:55	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/1/2012 9:12	Grab	KJELDAHL NITROGEN, TOTAL	1.12
2/1/2012 9:12	Grab	NITRATE+NITRITE-N	0.347
2/1/2012 9:12	Grab	PHOSPHATE, TOTAL AS P	0.098
2/1/2012 9:25	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/1/2012 9:25	Grab	NITRATE+NITRITE-N	-0.005
2/1/2012 9:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/8/2012 10:00	Grab	KJELDAHL NITROGEN, TOTAL	1.04
2/8/2012 10:00	Grab	NITRATE+NITRITE-N	0.299
2/8/2012 10:00	Grab	PHOSPHATE, TOTAL AS P	0.089
2/15/2012 10:24	Grab	KJELDAHL NITROGEN, TOTAL	1.09
2/15/2012 10:24	Grab	NITRATE+NITRITE-N	0.277
2/15/2012 10:24	Grab	PHOSPHATE, TOTAL AS P	0.081
2/15/2012 10:48	Grab	KJELDAHL NITROGEN, TOTAL	-0.05

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/15/2012 10:48	Grab	NITRATE+NITRITE-N	0.017
2/15/2012 10:48	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/22/2012 10:25	Grab	KJELDAHL NITROGEN, TOTAL	1.12
2/22/2012 10:25	Grab	NITRATE+NITRITE-N	0.261
2/22/2012 10:25	Grab	PHOSPHATE, TOTAL AS P	0.09
2/22/2012 10:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/22/2012 10:40	Grab	NITRATE+NITRITE-N	-0.005
2/22/2012 10:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/29/2012 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.04
2/29/2012 9:45	Grab	NITRATE+NITRITE-N	0.251
2/29/2012 9:45	Grab	PHOSPHATE, TOTAL AS P	0.093
3/7/2012 9:50	Grab	KJELDAHL NITROGEN, TOTAL	1.04
3/7/2012 9:50	Grab	NITRATE+NITRITE-N	0.214
3/7/2012 9:50	Grab	PHOSPHATE, TOTAL AS P	0.089
3/7/2012 10:12	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/7/2012 10:12	Grab	NITRATE+NITRITE-N	-0.005
3/7/2012 10:12	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/14/2012 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.05
3/14/2012 9:45	Grab	NITRATE+NITRITE-N	0.201
3/14/2012 9:45	Grab	PHOSPHATE, TOTAL AS P	0.09
3/14/2012 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/14/2012 10:05	Grab	NITRATE+NITRITE-N	-0.005
3/14/2012 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/21/2012 9:23	Grab	KJELDAHL NITROGEN, TOTAL	1.02
3/21/2012 9:23	Grab	NITRATE+NITRITE-N	0.212
3/21/2012 9:23	Grab	PHOSPHATE, TOTAL AS P	0.093
3/21/2012 9:39	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/21/2012 9:39	Grab	NITRATE+NITRITE-N	-0.005
3/21/2012 9:39	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/28/2012 9:32	Grab	KJELDAHL NITROGEN, TOTAL	1.13
3/28/2012 9:32	Grab	NITRATE+NITRITE-N	-0.005
3/28/2012 9:32	Grab	PHOSPHATE, TOTAL AS P	0.075
3/28/2012 9:46	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/28/2012 9:46	Grab	NITRATE+NITRITE-N	-0.005
3/28/2012 9:46	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/4/2012 9:37	Grab	KJELDAHL NITROGEN, TOTAL	1.25
4/4/2012 9:37	Grab	NITRATE+NITRITE-N	-0.005
4/4/2012 9:37	Grab	PHOSPHATE, TOTAL AS P	0.08
4/4/2012 9:59	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/4/2012 9:59	Grab	NITRATE+NITRITE-N	-0.005
4/4/2012 9:59	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/11/2012 10:01	Grab	KJELDAHL NITROGEN, TOTAL	1.31
4/11/2012 10:01	Grab	NITRATE+NITRITE-N	-0.005
4/11/2012 10:01	Grab	PHOSPHATE, TOTAL AS P	0.109
4/11/2012 10:34	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/11/2012 10:34	Grab	NITRATE+NITRITE-N	0.012
4/11/2012 10:34	Grab	PHOSPHATE, TOTAL AS P	-0.002

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
4/18/2012 10:33	Grab	KJELDAHL NITROGEN, TOTAL	1.32
4/18/2012 10:33	Grab	NITRATE+NITRITE-N	-0.005
4/18/2012 10:33	Grab	PHOSPHATE, TOTAL AS P	0.123
4/18/2012 10:58	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/18/2012 10:58	Grab	NITRATE+NITRITE-N	-0.005
4/18/2012 10:58	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/25/2012 10:23	Grab	KJELDAHL NITROGEN, TOTAL	1.33
4/25/2012 10:23	Grab	NITRATE+NITRITE-N	-0.005
4/25/2012 10:23	Grab	PHOSPHATE, TOTAL AS P	0.154
4/25/2012 10:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/25/2012 10:40	Grab	NITRATE+NITRITE-N	-0.005
4/25/2012 10:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/2/2012 9:41	Grab	KJELDAHL NITROGEN, TOTAL	1.34
5/2/2012 9:41	Grab	NITRATE+NITRITE-N	-0.005
5/2/2012 9:41	Grab	PHOSPHATE, TOTAL AS P	0.118
5/2/2012 9:56	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/2/2012 9:56	Grab	NITRATE+NITRITE-N	-0.005
5/2/2012 9:56	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/9/2012 10:23	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/9/2012 10:23	Grab	NITRATE+NITRITE-N	-0.005
5/9/2012 10:23	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/9/2012 10:35	Grab	KJELDAHL NITROGEN, TOTAL	1.24
5/9/2012 10:35	Grab	NITRATE+NITRITE-N	-0.005
5/9/2012 10:35	Grab	PHOSPHATE, TOTAL AS P	0.106
5/9/2012 10:48	Grab	KJELDAHL NITROGEN, TOTAL	1.27
5/9/2012 10:48	Grab	NITRATE+NITRITE-N	-0.005
5/9/2012 10:48	Grab	PHOSPHATE, TOTAL AS P	0.104
5/9/2012 10:59	Grab	KJELDAHL NITROGEN, TOTAL	1.28
5/9/2012 10:59	Grab	NITRATE+NITRITE-N	-0.005
5/9/2012 10:59	Grab	PHOSPHATE, TOTAL AS P	0.106
5/9/2012 11:09	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/9/2012 11:09	Grab	NITRATE+NITRITE-N	-0.005
5/9/2012 11:09	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/15/2012 10:17	Grab	KJELDAHL NITROGEN, TOTAL	1.24
5/15/2012 10:17	Grab	NITRATE+NITRITE-N	-0.005
5/15/2012 10:17	Grab	PHOSPHATE, TOTAL AS P	0.116
5/15/2012 10:31	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/15/2012 10:31	Grab	NITRATE+NITRITE-N	-0.005
5/15/2012 10:31	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/23/2012 9:29	Grab	KJELDAHL NITROGEN, TOTAL	1.27
5/23/2012 9:29	Grab	NITRATE+NITRITE-N	-0.005
5/23/2012 9:29	Grab	PHOSPHATE, TOTAL AS P	0.096
5/23/2012 9:43	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/23/2012 9:43	Grab	NITRATE+NITRITE-N	-0.005
5/23/2012 9:43	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/30/2012 10:16	Grab	KJELDAHL NITROGEN, TOTAL	1.24
5/30/2012 10:16	Grab	NITRATE+NITRITE-N	-0.005

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/30/2012 10:16	Grab	PHOSPHATE, TOTAL AS P	0.108
5/30/2012 10:38	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/30/2012 10:38	Grab	NITRATE+NITRITE-N	-0.005
5/30/2012 10:38	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/6/2012 10:59	Grab	KJELDAHL NITROGEN, TOTAL	1.25
6/6/2012 10:59	Grab	NITRATE+NITRITE-N	0.01
6/6/2012 10:59	Grab	PHOSPHATE, TOTAL AS P	0.17
6/6/2012 11:21	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/6/2012 11:21	Grab	NITRATE+NITRITE-N	-0.005
6/6/2012 11:21	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/13/2012 10:47	Grab	KJELDAHL NITROGEN, TOTAL	1.29
6/13/2012 10:47	Grab	NITRATE+NITRITE-N	-0.005
6/13/2012 10:47	Grab	PHOSPHATE, TOTAL AS P	0.145
6/13/2012 11:03	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/13/2012 11:03	Grab	NITRATE+NITRITE-N	-0.005
6/13/2012 11:03	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/21/2012 9:45	Grab	KJELDAHL NITROGEN, TOTAL	1.24
6/21/2012 9:45	Grab	NITRATE+NITRITE-N	0.055
6/21/2012 9:45	Grab	PHOSPHATE, TOTAL AS P	0.132
6/21/2012 9:59	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/21/2012 9:59	Grab	NITRATE+NITRITE-N	-0.005
6/21/2012 9:59	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/27/2012 9:20	Grab	KJELDAHL NITROGEN, TOTAL	1.02
6/27/2012 9:20	Grab	NITRATE+NITRITE-N	0.242
6/27/2012 9:20	Grab	PHOSPHATE, TOTAL AS P	0.146
7/3/2012 9:59	Grab	KJELDAHL NITROGEN, TOTAL	1.2
7/3/2012 9:59	Grab	NITRATE+NITRITE-N	-0.005
7/3/2012 9:59	Grab	PHOSPHATE, TOTAL AS P	0.106
7/3/2012 10:12	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/3/2012 10:12	Grab	NITRATE+NITRITE-N	-0.005
7/3/2012 10:12	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/10/2012 9:57	Grab	KJELDAHL NITROGEN, TOTAL	1.41
7/10/2012 9:57	Grab	NITRATE+NITRITE-N	-0.005
7/10/2012 9:57	Grab	PHOSPHATE, TOTAL AS P	0.114
7/10/2012 10:19	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/10/2012 10:19	Grab	NITRATE+NITRITE-N	-0.005
7/10/2012 10:19	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/18/2012 9:59	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/18/2012 9:59	Grab	NITRATE+NITRITE-N	-0.005
7/18/2012 9:59	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/18/2012 10:18	Grab	KJELDAHL NITROGEN, TOTAL	1.21
7/18/2012 10:18	Grab	NITRATE+NITRITE-N	0.104
7/18/2012 10:18	Grab	PHOSPHATE, TOTAL AS P	0.153
7/18/2012 10:30	Grab	KJELDAHL NITROGEN, TOTAL	1.19
7/18/2012 10:30	Grab	NITRATE+NITRITE-N	0.103
7/18/2012 10:30	Grab	PHOSPHATE, TOTAL AS P	0.154
7/18/2012 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.2

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/18/2012 10:40	Grab	NITRATE+NITRITE-N	0.102
7/18/2012 10:40	Grab	PHOSPHATE, TOTAL AS P	0.156
7/18/2012 10:52	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/18/2012 10:52	Grab	NITRATE+NITRITE-N	-0.005
7/18/2012 10:52	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/25/2012 9:25	Grab	KJELDAHL NITROGEN, TOTAL	1.02
7/25/2012 9:25	Grab	NITRATE+NITRITE-N	0.061
7/25/2012 9:25	Grab	PHOSPHATE, TOTAL AS P	0.116
8/1/2012 10:30	Grab	KJELDAHL NITROGEN, TOTAL	1.21
8/1/2012 10:30	Grab	NITRATE+NITRITE-N	-0.005
8/1/2012 10:30	Grab	PHOSPHATE, TOTAL AS P	0.143
8/1/2012 10:56	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/1/2012 10:56	Grab	NITRATE+NITRITE-N	-0.005
8/1/2012 10:56	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/8/2012 10:48	Grab	KJELDAHL NITROGEN, TOTAL	1.26
8/8/2012 10:48	Grab	NITRATE+NITRITE-N	-0.005
8/8/2012 10:48	Grab	PHOSPHATE, TOTAL AS P	0.143
8/15/2012 10:19	Grab	KJELDAHL NITROGEN, TOTAL	1.1
8/15/2012 10:19	Grab	NITRATE+NITRITE-N	0.018
8/15/2012 10:19	Grab	PHOSPHATE, TOTAL AS P	0.121
8/15/2012 10:31	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/15/2012 10:31	Grab	NITRATE+NITRITE-N	-0.005
8/15/2012 10:31	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/22/2012 12:01	Grab	KJELDAHL NITROGEN, TOTAL	1.3
8/22/2012 12:01	Grab	NITRATE+NITRITE-N	0.007
8/22/2012 12:01	Grab	PHOSPHATE, TOTAL AS P	0.159
8/29/2012 10:03	Grab	KJELDAHL NITROGEN, TOTAL	1.38
8/29/2012 10:03	Grab	NITRATE+NITRITE-N	0.189
8/29/2012 10:03	Grab	PHOSPHATE, TOTAL AS P	0.124
8/29/2012 10:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/29/2012 10:20	Grab	NITRATE+NITRITE-N	-0.005
8/29/2012 10:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/5/2012 11:44	Grab	KJELDAHL NITROGEN, TOTAL	1.37
9/5/2012 11:44	Grab	NITRATE+NITRITE-N	0.197
9/5/2012 11:44	Grab	PHOSPHATE, TOTAL AS P	0.188
9/12/2012 11:54	Grab	KJELDAHL NITROGEN, TOTAL	1.25
9/12/2012 11:54	Grab	NITRATE+NITRITE-N	0.121
9/12/2012 11:54	Grab	PHOSPHATE, TOTAL AS P	0.138
9/19/2012 11:20	Grab	KJELDAHL NITROGEN, TOTAL	1.28
9/19/2012 11:20	Grab	NITRATE+NITRITE-N	0.261
9/19/2012 11:20	Grab	PHOSPHATE, TOTAL AS P	0.149
9/19/2012 11:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/19/2012 11:35	Grab	NITRATE+NITRITE-N	-0.005
9/19/2012 11:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/26/2012 12:15	Grab	KJELDAHL NITROGEN, TOTAL	1.4
9/26/2012 12:15	Grab	NITRATE+NITRITE-N	0.2
9/26/2012 12:15	Grab	PHOSPHATE, TOTAL AS P	0.165

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
10/3/2012 12:15	Grab	KJELDAHL NITROGEN, TOTAL	1.56
10/3/2012 12:15	Grab	NITRATE+NITRITE-N	0.095
10/3/2012 12:15	Grab	PHOSPHATE, TOTAL AS P	0.219
10/10/2012 12:04	Grab	KJELDAHL NITROGEN, TOTAL	1.62
10/10/2012 12:04	Grab	NITRATE+NITRITE-N	0.069
10/10/2012 12:04	Grab	PHOSPHATE, TOTAL AS P	0.13
10/17/2012 12:04	Grab	KJELDAHL NITROGEN, TOTAL	1.57
10/17/2012 12:04	Grab	NITRATE+NITRITE-N	0.082
10/17/2012 12:04	Grab	PHOSPHATE, TOTAL AS P	0.106
10/17/2012 12:39	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/17/2012 12:39	Grab	NITRATE+NITRITE-N	-0.005
10/17/2012 12:39	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/24/2012 12:34	Grab	KJELDAHL NITROGEN, TOTAL	1.56
10/24/2012 12:34	Grab	NITRATE+NITRITE-N	0.073
10/24/2012 12:34	Grab	PHOSPHATE, TOTAL AS P	0.124
11/1/2012 9:10	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/1/2012 9:10	Grab	NITRATE+NITRITE-N	-0.005
11/1/2012 9:10	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/1/2012 9:20	Grab	KJELDAHL NITROGEN, TOTAL	1.39
11/1/2012 9:20	Grab	NITRATE+NITRITE-N	0.12
11/1/2012 9:20	Grab	PHOSPHATE, TOTAL AS P	0.1
11/1/2012 9:36	Grab	KJELDAHL NITROGEN, TOTAL	1.4
11/1/2012 9:36	Grab	NITRATE+NITRITE-N	0.12
11/1/2012 9:36	Grab	PHOSPHATE, TOTAL AS P	0.098
11/1/2012 9:47	Grab	KJELDAHL NITROGEN, TOTAL	1.4
11/1/2012 9:47	Grab	NITRATE+NITRITE-N	0.12
11/1/2012 9:47	Grab	PHOSPHATE, TOTAL AS P	0.094
11/1/2012 10:16	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/1/2012 10:16	Grab	NITRATE+NITRITE-N	-0.005
11/1/2012 10:16	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/7/2012 11:31	Grab	KJELDAHL NITROGEN, TOTAL	1.32
11/7/2012 11:31	Grab	NITRATE+NITRITE-N	0.124
11/7/2012 11:31	Grab	PHOSPHATE, TOTAL AS P	0.07
11/14/2012 11:47	Grab	KJELDAHL NITROGEN, TOTAL	1.33
11/14/2012 11:47	Grab	NITRATE+NITRITE-N	0.176
11/14/2012 11:47	Grab	PHOSPHATE, TOTAL AS P	0.086
11/20/2012 11:33	Grab	KJELDAHL NITROGEN, TOTAL	1.16
11/20/2012 11:33	Grab	NITRATE+NITRITE-N	0.292
11/20/2012 11:33	Grab	PHOSPHATE, TOTAL AS P	0.091
11/28/2012 12:45	Grab	KJELDAHL NITROGEN, TOTAL	1.13
11/28/2012 12:45	Grab	NITRATE+NITRITE-N	0.302
11/28/2012 12:45	Grab	PHOSPHATE, TOTAL AS P	0.093
12/5/2012 11:55	Grab	KJELDAHL NITROGEN, TOTAL	1.21
12/5/2012 11:55	Grab	NITRATE+NITRITE-N	0.292
12/5/2012 11:55	Grab	PHOSPHATE, TOTAL AS P	0.092
12/12/2012 12:29	Grab	KJELDAHL NITROGEN, TOTAL	1.12
12/12/2012 12:29	Grab	NITRATE+NITRITE-N	0.252

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
12/12/2012 12:29	Grab	PHOSPHATE, TOTAL AS P	0.076
12/19/2012 12:17	Grab	KJELDAHL NITROGEN, TOTAL	1.05
12/19/2012 12:17	Grab	NITRATE+NITRITE-N	0.26
12/19/2012 12:17	Grab	PHOSPHATE, TOTAL AS P	0.076
12/19/2012 12:32	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/19/2012 12:32	Grab	NITRATE+NITRITE-N	-0.005
12/19/2012 12:32	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/27/2012 11:31	Grab	KJELDAHL NITROGEN, TOTAL	1.14
12/27/2012 11:31	Grab	NITRATE+NITRITE-N	0.314
12/27/2012 11:31	Grab	PHOSPHATE, TOTAL AS P	0.102
1/3/2013 11:12	Grab	KJELDAHL NITROGEN, TOTAL	1.19
1/3/2013 11:12	Grab	NITRATE+NITRITE-N	0.316
1/3/2013 11:12	Grab	PHOSPHATE, TOTAL AS P	0.103
1/9/2013 11:42	Grab	KJELDAHL NITROGEN, TOTAL	1.23
1/9/2013 11:42	Grab	NITRATE+NITRITE-N	0.255
1/9/2013 11:42	Grab	PHOSPHATE, TOTAL AS P	0.09
1/16/2013 11:33	Grab	KJELDAHL NITROGEN, TOTAL	1.09
1/16/2013 11:33	Grab	NITRATE+NITRITE-N	0.232
1/16/2013 11:33	Grab	PHOSPHATE, TOTAL AS P	0.07
1/23/2013 12:32	Grab	KJELDAHL NITROGEN, TOTAL	1.06
1/23/2013 12:32	Grab	NITRATE+NITRITE-N	0.251
1/23/2013 12:32	Grab	PHOSPHATE, TOTAL AS P	0.073
1/30/2013 9:48	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/30/2013 9:48	Grab	NITRATE+NITRITE-N	-0.005
1/30/2013 9:48	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/30/2013 10:18	Grab	KJELDAHL NITROGEN, TOTAL	1.14
1/30/2013 10:18	Grab	NITRATE+NITRITE-N	0.221
1/30/2013 10:18	Grab	PHOSPHATE, TOTAL AS P	0.082
1/30/2013 10:39	Grab	KJELDAHL NITROGEN, TOTAL	1.13
1/30/2013 10:39	Grab	NITRATE+NITRITE-N	0.211
1/30/2013 10:39	Grab	PHOSPHATE, TOTAL AS P	0.079
1/30/2013 10:50	Grab	KJELDAHL NITROGEN, TOTAL	1.13
1/30/2013 10:50	Grab	NITRATE+NITRITE-N	0.211
1/30/2013 10:50	Grab	PHOSPHATE, TOTAL AS P	0.08
1/30/2013 11:03	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/30/2013 11:03	Grab	NITRATE+NITRITE-N	-0.005
1/30/2013 11:03	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/6/2013 11:42	Grab	KJELDAHL NITROGEN, TOTAL	1.22
2/6/2013 11:42	Grab	NITRATE+NITRITE-N	0.28
2/6/2013 11:42	Grab	PHOSPHATE, TOTAL AS P	0.092
2/13/2013 11:42	Grab	KJELDAHL NITROGEN, TOTAL	1.1
2/13/2013 11:42	Grab	NITRATE+NITRITE-N	0.03
2/13/2013 11:42	Grab	PHOSPHATE, TOTAL AS P	0.056
2/21/2013 9:39	Grab	KJELDAHL NITROGEN, TOTAL	1.09
2/21/2013 9:39	Grab	NITRATE+NITRITE-N	0.085
2/21/2013 9:39	Grab	PHOSPHATE, TOTAL AS P	0.068
2/21/2013 10:03	Grab	KJELDAHL NITROGEN, TOTAL	-0.05

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/21/2013 10:03	Grab	NITRATE+NITRITE-N	-0.005
2/21/2013 10:03	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/27/2013 11:46	Grab	KJELDAHL NITROGEN, TOTAL	1.41
2/27/2013 11:46	Grab	NITRATE+NITRITE-N	0.146
2/27/2013 11:46	Grab	PHOSPHATE, TOTAL AS P	0.079
3/6/2013 12:02	Grab	KJELDAHL NITROGEN, TOTAL	1.19
3/6/2013 12:02	Grab	NITRATE+NITRITE-N	0.255
3/6/2013 12:02	Grab	PHOSPHATE, TOTAL AS P	0.071
3/13/2013 12:33	Grab	KJELDAHL NITROGEN, TOTAL	1.22
3/13/2013 12:33	Grab	NITRATE+NITRITE-N	0.135
3/13/2013 12:33	Grab	PHOSPHATE, TOTAL AS P	0.067
3/13/2013 12:55	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/13/2013 12:55	Grab	NITRATE+NITRITE-N	-0.005
3/13/2013 12:55	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/20/2013 11:55	Grab	KJELDAHL NITROGEN, TOTAL	1.2
3/20/2013 11:55	Grab	NITRATE+NITRITE-N	0.069
3/20/2013 11:55	Grab	PHOSPHATE, TOTAL AS P	0.075
3/27/2013 12:30	Grab	KJELDAHL NITROGEN, TOTAL	1.05
3/27/2013 12:30	Grab	NITRATE+NITRITE-N	0.037
3/27/2013 12:30	Grab	PHOSPHATE, TOTAL AS P	0.066
4/3/2013 12:41	Grab	KJELDAHL NITROGEN, TOTAL	1.15
4/3/2013 12:41	Grab	NITRATE+NITRITE-N	-0.005
4/3/2013 12:41	Grab	PHOSPHATE, TOTAL AS P	0.069
4/10/2013 12:25	Grab	KJELDAHL NITROGEN, TOTAL	1.17
4/10/2013 12:25	Grab	NITRATE+NITRITE-N	0.034
4/10/2013 12:25	Grab	PHOSPHATE, TOTAL AS P	0.08
4/17/2013 10:43	Grab	KJELDAHL NITROGEN, TOTAL	1.17
4/17/2013 10:43	Grab	NITRATE+NITRITE-N	-0.005
4/17/2013 10:43	Grab	PHOSPHATE, TOTAL AS P	0.079
4/24/2013 11:56	Grab	KJELDAHL NITROGEN, TOTAL	1.17
4/24/2013 11:56	Grab	NITRATE+NITRITE-N	0.039
4/24/2013 11:56	Grab	PHOSPHATE, TOTAL AS P	0.103
5/1/2013 11:53	Grab	KJELDAHL NITROGEN, TOTAL	1.13
5/1/2013 11:53	Grab	NITRATE+NITRITE-N	0.081
5/1/2013 11:53	Grab	PHOSPHATE, TOTAL AS P	0.129
5/8/2013 12:49	Grab	KJELDAHL NITROGEN, TOTAL	1.09
5/8/2013 12:49	Grab	NITRATE+NITRITE-N	0.049
5/8/2013 12:49	Grab	PHOSPHATE, TOTAL AS P	0.112
5/15/2013 11:48	Grab	KJELDAHL NITROGEN, TOTAL	1.15
5/15/2013 11:48	Grab	NITRATE+NITRITE-N	-0.005
5/15/2013 11:48	Grab	PHOSPHATE, TOTAL AS P	0.088
5/22/2013 10:06	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/22/2013 10:06	Grab	NITRATE+NITRITE-N	-0.005
5/22/2013 10:06	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/22/2013 10:20	Grab	KJELDAHL NITROGEN, TOTAL	1.15
5/22/2013 10:20	Grab	NITRATE+NITRITE-N	0.012
5/22/2013 10:20	Grab	PHOSPHATE, TOTAL AS P	0.075

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/22/2013 10:30	Grab	KJELDAHL NITROGEN, TOTAL	1.18
5/22/2013 10:30	Grab	NITRATE+NITRITE-N	0.012
5/22/2013 10:30	Grab	PHOSPHATE, TOTAL AS P	0.076
5/22/2013 10:40	Grab	KJELDAHL NITROGEN, TOTAL	1.2
5/22/2013 10:40	Grab	NITRATE+NITRITE-N	0.012
5/22/2013 10:40	Grab	PHOSPHATE, TOTAL AS P	0.081
5/22/2013 11:15	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/22/2013 11:15	Grab	NITRATE+NITRITE-N	-0.005
5/22/2013 11:15	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/29/2013 12:14	Grab	KJELDAHL NITROGEN, TOTAL	1.29
5/29/2013 12:14	Grab	NITRATE+NITRITE-N	-0.005
5/29/2013 12:14	Grab	PHOSPHATE, TOTAL AS P	0.119
6/5/2013 11:44	Grab	KJELDAHL NITROGEN, TOTAL	1.23
6/5/2013 11:44	Grab	NITRATE+NITRITE-N	0.06
6/5/2013 11:44	Grab	PHOSPHATE, TOTAL AS P	0.103
6/12/2013 11:17	Grab	KJELDAHL NITROGEN, TOTAL	1.16
6/12/2013 11:17	Grab	NITRATE+NITRITE-N	0.107
6/12/2013 11:17	Grab	PHOSPHATE, TOTAL AS P	0.095
6/19/2013 12:09	Grab	KJELDAHL NITROGEN, TOTAL	1.26
6/19/2013 12:09	Grab	NITRATE+NITRITE-N	0.049
6/19/2013 12:09	Grab	PHOSPHATE, TOTAL AS P	0.14
6/19/2013 12:34	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
6/19/2013 12:34	Grab	NITRATE+NITRITE-N	-0.005
6/19/2013 12:34	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/26/2013 11:49	Grab	KJELDAHL NITROGEN, TOTAL	1.28
6/26/2013 11:49	Grab	NITRATE+NITRITE-N	0.159
6/26/2013 11:49	Grab	PHOSPHATE, TOTAL AS P	0.172
7/3/2013 12:10	Grab	KJELDAHL NITROGEN, TOTAL	1.27
7/3/2013 12:10	Grab	NITRATE+NITRITE-N	0.238
7/3/2013 12:10	Grab	PHOSPHATE, TOTAL AS P	0.22
7/3/2013 12:33	Grab	KJELDAHL NITROGEN, TOTAL	1.3
7/3/2013 12:33	Grab	NITRATE+NITRITE-N	0.239
7/3/2013 12:33	Grab	PHOSPHATE, TOTAL AS P	0.216
7/3/2013 12:51	Grab	KJELDAHL NITROGEN, TOTAL	1.3
7/3/2013 12:51	Grab	NITRATE+NITRITE-N	0.238
7/3/2013 12:51	Grab	PHOSPHATE, TOTAL AS P	0.217
7/3/2013 13:12	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/3/2013 13:12	Grab	NITRATE+NITRITE-N	-0.005
7/3/2013 13:12	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/10/2013 12:11	Grab	KJELDAHL NITROGEN, TOTAL	1.46
7/10/2013 12:11	Grab	NITRATE+NITRITE-N	0.16
7/10/2013 12:11	Grab	PHOSPHATE, TOTAL AS P	0.149
7/17/2013 11:33	Grab	KJELDAHL NITROGEN, TOTAL	1.32
7/17/2013 11:33	Grab	NITRATE+NITRITE-N	0.124
7/17/2013 11:33	Grab	PHOSPHATE, TOTAL AS P	0.126
7/24/2013 12:30	Grab	KJELDAHL NITROGEN, TOTAL	1.34
7/24/2013 12:30	Grab	NITRATE+NITRITE-N	0.177

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
7/24/2013 12:30	Grab	PHOSPHATE, TOTAL AS P	0.112
7/31/2013 11:39	Grab	KJELDAHL NITROGEN, TOTAL	1.24
7/31/2013 11:39	Grab	NITRATE+NITRITE-N	0.112
7/31/2013 11:39	Grab	PHOSPHATE, TOTAL AS P	0.1
8/7/2013 10:13	Grab	KJELDAHL NITROGEN, TOTAL	1.39
8/7/2013 10:13	Grab	NITRATE+NITRITE-N	0.116
8/7/2013 10:13	Grab	PHOSPHATE, TOTAL AS P	0.119
8/14/2013 12:57	Grab	KJELDAHL NITROGEN, TOTAL	1.3
8/14/2013 12:57	Grab	NITRATE+NITRITE-N	0.108
8/14/2013 12:57	Grab	PHOSPHATE, TOTAL AS P	0.094
8/14/2013 13:28	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/14/2013 13:28	Grab	NITRATE+NITRITE-N	-0.005
8/14/2013 13:28	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/21/2013 12:14	Grab	KJELDAHL NITROGEN, TOTAL	1.36
8/21/2013 12:14	Grab	NITRATE+NITRITE-N	0.115
8/21/2013 12:14	Grab	PHOSPHATE, TOTAL AS P	0.115
8/28/2013 12:47	Grab	KJELDAHL NITROGEN, TOTAL	1.18
8/28/2013 12:47	Grab	NITRATE+NITRITE-N	0.119
8/28/2013 12:47	Grab	PHOSPHATE, TOTAL AS P	0.129
9/4/2013 11:43	Grab	KJELDAHL NITROGEN, TOTAL	1.27
9/4/2013 11:43	Grab	NITRATE+NITRITE-N	0.113
9/4/2013 11:43	Grab	PHOSPHATE, TOTAL AS P	0.126
9/11/2013 11:21	Grab	KJELDAHL NITROGEN, TOTAL	1.22
9/11/2013 11:21	Grab	NITRATE+NITRITE-N	0.125
9/11/2013 11:21	Grab	PHOSPHATE, TOTAL AS P	0.098
9/11/2013 11:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/11/2013 11:40	Grab	NITRATE+NITRITE-N	-0.005
9/11/2013 11:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/18/2013 12:06	Grab	KJELDAHL NITROGEN, TOTAL	1.08
9/18/2013 12:06	Grab	NITRATE+NITRITE-N	0.137
9/18/2013 12:06	Grab	PHOSPHATE, TOTAL AS P	0.12
9/25/2013 11:41	Grab	KJELDAHL NITROGEN, TOTAL	1.09
9/25/2013 11:41	Grab	NITRATE+NITRITE-N	0.136
9/25/2013 11:41	Grab	PHOSPHATE, TOTAL AS P	0.123
10/2/2013 11:52	Grab	KJELDAHL NITROGEN, TOTAL	1.16
10/2/2013 11:52	Grab	NITRATE+NITRITE-N	0.121
10/2/2013 11:52	Grab	PHOSPHATE, TOTAL AS P	0.101
10/9/2013 12:24	Grab	KJELDAHL NITROGEN, TOTAL	1.2
10/9/2013 12:24	Grab	NITRATE+NITRITE-N	0.121
10/9/2013 12:24	Grab	PHOSPHATE, TOTAL AS P	0.083
10/9/2013 12:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/9/2013 12:45	Grab	NITRATE+NITRITE-N	-0.005
10/9/2013 12:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/23/2013 11:08	Grab	KJELDAHL NITROGEN, TOTAL	1.01
10/23/2013 11:08	Grab	NITRATE+NITRITE-N	0.219
10/23/2013 11:08	Grab	PHOSPHATE, TOTAL AS P	0.094
10/30/2013 11:16	Grab	KJELDAHL NITROGEN, TOTAL	0.95

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
10/30/2013 11:16	Grab	NITRATE+NITRITE-N	0.344
10/30/2013 11:16	Grab	PHOSPHATE, TOTAL AS P	0.111
11/6/2013 11:29	Grab	KJELDAHL NITROGEN, TOTAL	0.95
11/6/2013 11:29	Grab	NITRATE+NITRITE-N	0.401
11/6/2013 11:29	Grab	PHOSPHATE, TOTAL AS P	0.108
11/14/2013 11:34	Grab	KJELDAHL NITROGEN, TOTAL	1.01
11/14/2013 11:34	Grab	NITRATE+NITRITE-N	0.437
11/14/2013 11:34	Grab	PHOSPHATE, TOTAL AS P	0.116
11/20/2013 12:11	Grab	KJELDAHL NITROGEN, TOTAL	0.9
11/20/2013 12:11	Grab	NITRATE+NITRITE-N	0.369
11/20/2013 12:11	Grab	PHOSPHATE, TOTAL AS P	0.094
11/20/2013 12:15	Grab	KJELDAHL NITROGEN, TOTAL	0.94
11/20/2013 12:15	Grab	NITRATE+NITRITE-N	0.369
11/20/2013 12:15	Grab	PHOSPHATE, TOTAL AS P	0.092
11/20/2013 12:22	Grab	KJELDAHL NITROGEN, TOTAL	0.97
11/20/2013 12:22	Grab	NITRATE+NITRITE-N	0.353
11/20/2013 12:22	Grab	PHOSPHATE, TOTAL AS P	0.093
11/20/2013 12:27	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/20/2013 12:27	Grab	NITRATE+NITRITE-N	-0.005
11/20/2013 12:27	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/26/2013 12:34	Grab	KJELDAHL NITROGEN, TOTAL	0.9
11/26/2013 12:34	Grab	NITRATE+NITRITE-N	0.32
11/26/2013 12:34	Grab	PHOSPHATE, TOTAL AS P	0.079
12/4/2013 11:33	Grab	KJELDAHL NITROGEN, TOTAL	0.92
12/4/2013 11:33	Grab	NITRATE+NITRITE-N	0.358
12/4/2013 11:33	Grab	PHOSPHATE, TOTAL AS P	0.085
12/11/2013 11:30	Grab	KJELDAHL NITROGEN, TOTAL	0.94
12/11/2013 11:30	Grab	NITRATE+NITRITE-N	0.286
12/11/2013 11:30	Grab	PHOSPHATE, TOTAL AS P	0.076
12/11/2013 11:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/11/2013 11:40	Grab	NITRATE+NITRITE-N	-0.005
12/11/2013 11:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/18/2013 9:54	Grab	KJELDAHL NITROGEN, TOTAL	0.93
12/18/2013 9:54	Grab	NITRATE+NITRITE-N	0.257
12/18/2013 9:54	Grab	PHOSPHATE, TOTAL AS P	0.075
12/23/2013 11:48	Grab	KJELDAHL NITROGEN, TOTAL	0.97
12/23/2013 11:48	Grab	NITRATE+NITRITE-N	0.219
12/23/2013 11:48	Grab	PHOSPHATE, TOTAL AS P	0.071
12/31/2013 11:45	Grab	KJELDAHL NITROGEN, TOTAL	0.92
12/31/2013 11:45	Grab	NITRATE+NITRITE-N	0.286
12/31/2013 11:45	Grab	PHOSPHATE, TOTAL AS P	0.074
1/8/2014 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/8/2014 10:05	Grab	NITRATE+NITRITE-N	-0.005
1/8/2014 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/8/2014 10:18	Grab	KJELDAHL NITROGEN, TOTAL	0.89
1/8/2014 10:18	Grab	NITRATE+NITRITE-N	0.311
1/8/2014 10:18	Grab	PHOSPHATE, TOTAL AS P	0.08

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
1/8/2014 10:49	Grab	KJELDAHL NITROGEN, TOTAL	0.87
1/8/2014 10:49	Grab	NITRATE+NITRITE-N	0.312
1/8/2014 10:49	Grab	PHOSPHATE, TOTAL AS P	0.08
1/8/2014 11:01	Grab	KJELDAHL NITROGEN, TOTAL	0.87
1/8/2014 11:01	Grab	NITRATE+NITRITE-N	0.313
1/8/2014 11:01	Grab	PHOSPHATE, TOTAL AS P	0.081
1/8/2014 11:14	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/8/2014 11:14	Grab	NITRATE+NITRITE-N	-0.005
1/8/2014 11:14	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/15/2014 10:54	Grab	KJELDAHL NITROGEN, TOTAL	0.94
1/15/2014 10:54	Grab	NITRATE+NITRITE-N	0.284
1/15/2014 10:54	Grab	PHOSPHATE, TOTAL AS P	0.067
1/22/2014 11:17	Grab	KJELDAHL NITROGEN, TOTAL	0.95
1/22/2014 11:17	Grab	NITRATE+NITRITE-N	0.305
1/22/2014 11:17	Grab	PHOSPHATE, TOTAL AS P	0.074
1/29/2014 12:11	Grab	KJELDAHL NITROGEN, TOTAL	0.95
1/29/2014 12:11	Grab	NITRATE+NITRITE-N	0.298
1/29/2014 12:11	Grab	PHOSPHATE, TOTAL AS P	0.069
2/5/2014 12:08	Grab	KJELDAHL NITROGEN, TOTAL	1.15
2/5/2014 12:08	Grab	NITRATE+NITRITE-N	0.122
2/5/2014 12:08	Grab	PHOSPHATE, TOTAL AS P	0.081
2/12/2014 11:25	Grab	KJELDAHL NITROGEN, TOTAL	0.95
2/12/2014 11:25	Grab	NITRATE+NITRITE-N	0.083
2/12/2014 11:25	Grab	PHOSPHATE, TOTAL AS P	0.057
2/12/2014 11:43	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/12/2014 11:43	Grab	NITRATE+NITRITE-N	-0.005
2/12/2014 11:43	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/19/2014 11:13	Grab	KJELDAHL NITROGEN, TOTAL	1.02
2/19/2014 11:13	Grab	NITRATE+NITRITE-N	0.172
2/19/2014 11:13	Grab	PHOSPHATE, TOTAL AS P	0.074
2/26/2014 11:14	Grab	KJELDAHL NITROGEN, TOTAL	1.09
2/26/2014 11:14	Grab	NITRATE+NITRITE-N	0.121
2/26/2014 11:14	Grab	PHOSPHATE, TOTAL AS P	0.077
3/5/2014 12:20	Grab	KJELDAHL NITROGEN, TOTAL	1.18
3/5/2014 12:20	Grab	NITRATE+NITRITE-N	0.101
3/5/2014 12:20	Grab	PHOSPHATE, TOTAL AS P	0.086
3/5/2014 12:42	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/5/2014 12:42	Grab	NITRATE+NITRITE-N	-0.005
3/5/2014 12:42	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/12/2014 11:31	Grab	KJELDAHL NITROGEN, TOTAL	1.12
3/12/2014 11:31	Grab	NITRATE+NITRITE-N	0.064
3/12/2014 11:31	Grab	PHOSPHATE, TOTAL AS P	0.089
3/19/2014 11:30	Grab	KJELDAHL NITROGEN, TOTAL	0.97
3/19/2014 11:30	Grab	NITRATE+NITRITE-N	0.12
3/19/2014 11:30	Grab	PHOSPHATE, TOTAL AS P	0.098
3/26/2014 10:58	Grab	KJELDAHL NITROGEN, TOTAL	1.14
3/26/2014 10:58	Grab	NITRATE+NITRITE-N	0.166

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
3/26/2014 10:58	Grab	PHOSPHATE, TOTAL AS P	0.105
3/26/2014 11:27	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/26/2014 11:27	Grab	NITRATE+NITRITE-N	-0.005
3/26/2014 11:27	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/2/2014 12:00	Grab	KJELDAHL NITROGEN, TOTAL	0.98
4/2/2014 12:00	Grab	NITRATE+NITRITE-N	0.058
4/2/2014 12:00	Grab	PHOSPHATE, TOTAL AS P	0.081
4/9/2014 10:22	Grab	KJELDAHL NITROGEN, TOTAL	0.96
4/9/2014 10:22	Grab	NITRATE+NITRITE-N	0.03
4/9/2014 10:22	Grab	PHOSPHATE, TOTAL AS P	0.082
4/9/2014 10:35	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/9/2014 10:35	Grab	NITRATE+NITRITE-N	-0.005
4/9/2014 10:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/16/2014 11:45	Grab	KJELDAHL NITROGEN, TOTAL	1.04
4/16/2014 11:45	Grab	NITRATE+NITRITE-N	0.018
4/16/2014 11:45	Grab	PHOSPHATE, TOTAL AS P	0.086
4/23/2014 11:08	Grab	KJELDAHL NITROGEN, TOTAL	1.04
4/23/2014 11:08	Grab	NITRATE+NITRITE-N	-0.005
4/23/2014 11:08	Grab	PHOSPHATE, TOTAL AS P	0.088
4/30/2014 12:35	Grab	KJELDAHL NITROGEN, TOTAL	1.2
4/30/2014 12:35	Grab	NITRATE+NITRITE-N	-0.005
4/30/2014 12:35	Grab	PHOSPHATE, TOTAL AS P	0.096
5/7/2014 11:43	Grab	KJELDAHL NITROGEN, TOTAL	1.14
5/7/2014 11:43	Grab	NITRATE+NITRITE-N	-0.005
5/7/2014 11:43	Grab	PHOSPHATE, TOTAL AS P	0.121
5/7/2014 12:02	Grab	KJELDAHL NITROGEN, TOTAL	1.12
5/7/2014 12:02	Grab	NITRATE+NITRITE-N	-0.005
5/7/2014 12:02	Grab	PHOSPHATE, TOTAL AS P	0.121
5/7/2014 12:15	Grab	KJELDAHL NITROGEN, TOTAL	1.13
5/7/2014 12:15	Grab	NITRATE+NITRITE-N	-0.005
5/7/2014 12:15	Grab	PHOSPHATE, TOTAL AS P	0.123
5/7/2014 12:34	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/7/2014 12:34	Grab	NITRATE+NITRITE-N	-0.005
5/7/2014 12:34	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/14/2014 10:54	Grab	KJELDAHL NITROGEN, TOTAL	1.09
5/14/2014 10:54	Grab	NITRATE+NITRITE-N	0.047
5/14/2014 10:54	Grab	PHOSPHATE, TOTAL AS P	0.136
5/21/2014 11:57	Grab	KJELDAHL NITROGEN, TOTAL	1.04
5/21/2014 11:57	Grab	NITRATE+NITRITE-N	0.111
5/21/2014 11:57	Grab	PHOSPHATE, TOTAL AS P	0.144
5/28/2014 11:45	Grab	KJELDAHL NITROGEN, TOTAL	0.99
5/28/2014 11:45	Grab	NITRATE+NITRITE-N	-0.005
5/28/2014 11:45	Grab	PHOSPHATE, TOTAL AS P	0.093
6/4/2014 12:32	Grab	NITRATE+NITRITE-N	0.125
6/4/2014 12:32	Grab	TOTAL NITROGEN	1.14
6/4/2014 12:32	Grab	PHOSPHATE, TOTAL AS P	0.126
6/11/2014 12:14	Grab	NITRATE+NITRITE-N	-0.005

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
6/11/2014 12:14	Grab	TOTAL NITROGEN	1.12
6/11/2014 12:14	Grab	PHOSPHATE, TOTAL AS P	0.125
6/18/2014 12:47	Grab	NITRATE+NITRITE-N	0.091
6/18/2014 12:47	Grab	TOTAL NITROGEN	1.02
6/18/2014 12:47	Grab	PHOSPHATE, TOTAL AS P	0.16
6/25/2014 11:58	Grab	NITRATE+NITRITE-N	0.045
6/25/2014 11:58	Grab	TOTAL NITROGEN	1.07
6/25/2014 11:58	Grab	PHOSPHATE, TOTAL AS P	0.125
7/2/2014 11:28	Grab	NITRATE+NITRITE-N	0.086
7/2/2014 11:28	Grab	TOTAL NITROGEN	1.19
7/2/2014 11:28	Grab	PHOSPHATE, TOTAL AS P	0.147
7/9/2014 11:34	Grab	NITRATE+NITRITE-N	0.118
7/9/2014 11:34	Grab	TOTAL NITROGEN	1.07
7/9/2014 11:34	Grab	PHOSPHATE, TOTAL AS P	0.159
7/9/2014 11:45	Grab	NITRATE+NITRITE-N	0.117
7/9/2014 11:45	Grab	TOTAL NITROGEN	1.1
7/9/2014 11:45	Grab	PHOSPHATE, TOTAL AS P	0.164
7/9/2014 11:52	Grab	NITRATE+NITRITE-N	0.118
7/9/2014 11:52	Grab	TOTAL NITROGEN	1.08
7/9/2014 11:52	Grab	PHOSPHATE, TOTAL AS P	0.163
7/16/2014 11:14	Grab	NITRATE+NITRITE-N	0.052
7/16/2014 11:14	Grab	TOTAL NITROGEN	1.23
7/16/2014 11:14	Grab	PHOSPHATE, TOTAL AS P	0.114
7/23/2014 13:04	Grab	NITRATE+NITRITE-N	0.052
7/23/2014 13:04	Grab	TOTAL NITROGEN	1.33
7/23/2014 13:04	Grab	PHOSPHATE, TOTAL AS P	0.08
7/30/2014 11:59	Grab	NITRATE+NITRITE-N	0.103
7/30/2014 11:59	Grab	TOTAL NITROGEN	1.36
7/30/2014 11:59	Grab	PHOSPHATE, TOTAL AS P	0.093
8/6/2014 11:58	Grab	NITRATE+NITRITE-N	0.275
8/6/2014 11:58	Grab	TOTAL NITROGEN	1.42
8/6/2014 11:58	Grab	PHOSPHATE, TOTAL AS P	0.147
8/13/2014 11:22	Grab	NITRATE+NITRITE-N	0.237
8/13/2014 11:22	Grab	TOTAL NITROGEN	1.44
8/13/2014 11:22	Grab	PHOSPHATE, TOTAL AS P	0.186
8/13/2014 11:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/13/2014 11:45	Grab	NITRATE+NITRITE-N	-0.005
8/13/2014 11:45	Grab	TOTAL NITROGEN	-0.02
8/13/2014 11:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/20/2014 12:29	Grab	NITRATE+NITRITE-N	0.262
8/20/2014 12:29	Grab	TOTAL NITROGEN	1.4
8/20/2014 12:29	Grab	PHOSPHATE, TOTAL AS P	0.184
8/27/2014 10:40	Grab	NITRATE+NITRITE-N	0.167
8/27/2014 10:40	Grab	TOTAL NITROGEN	1.35
8/27/2014 10:40	Grab	PHOSPHATE, TOTAL AS P	0.166
9/3/2014 11:59	Grab	NITRATE+NITRITE-N	0.311
9/3/2014 11:59	Grab	TOTAL NITROGEN	1.39

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/3/2014 11:59	Grab	PHOSPHATE, TOTAL AS P	0.172
9/10/2014 12:01	Grab	NITRATE+NITRITE-N	0.349
9/10/2014 12:01	Grab	TOTAL NITROGEN	1.51
9/10/2014 12:01	Grab	PHOSPHATE, TOTAL AS P	0.168
9/10/2014 12:16	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
9/10/2014 12:16	Grab	NITRATE+NITRITE-N	-0.005
9/10/2014 12:16	Grab	TOTAL NITROGEN	-0.02
9/10/2014 12:16	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/17/2014 11:48	Grab	NITRATE+NITRITE-N	0.335
9/17/2014 11:48	Grab	TOTAL NITROGEN	1.45
9/17/2014 11:48	Grab	PHOSPHATE, TOTAL AS P	0.132
9/24/2014 11:49	Grab	NITRATE+NITRITE-N	0.327
9/24/2014 11:49	Grab	TOTAL NITROGEN	1.42
9/24/2014 11:49	Grab	PHOSPHATE, TOTAL AS P	0.121
10/1/2014 11:46	Grab	NITRATE+NITRITE-N	0.256
10/1/2014 11:46	Grab	TOTAL NITROGEN	1.42
10/1/2014 11:46	Grab	PHOSPHATE, TOTAL AS P	0.158
10/8/2014 12:00	Grab	NITRATE+NITRITE-N	0.267
10/8/2014 12:00	Grab	TOTAL NITROGEN	1.38
10/8/2014 12:00	Grab	PHOSPHATE, TOTAL AS P	0.152
10/15/2014 9:51	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/15/2014 9:51	Grab	NITRATE+NITRITE-N	-0.005
10/15/2014 9:51	Grab	TOTAL NITROGEN	-0.02
10/15/2014 9:51	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/15/2014 10:04	Grab	NITRATE+NITRITE-N	0.316
10/15/2014 10:04	Grab	TOTAL NITROGEN	1.48
10/15/2014 10:04	Grab	PHOSPHATE, TOTAL AS P	0.144
10/15/2014 10:15	Grab	NITRATE+NITRITE-N	0.319
10/15/2014 10:15	Grab	TOTAL NITROGEN	1.47
10/15/2014 10:15	Grab	PHOSPHATE, TOTAL AS P	0.143
10/15/2014 10:26	Grab	NITRATE+NITRITE-N	0.318
10/15/2014 10:26	Grab	TOTAL NITROGEN	1.54
10/15/2014 10:26	Grab	PHOSPHATE, TOTAL AS P	0.146
10/15/2014 10:37	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/15/2014 10:37	Grab	NITRATE+NITRITE-N	-0.005
10/15/2014 10:37	Grab	TOTAL NITROGEN	-0.02
10/15/2014 10:37	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/22/2014 12:06	Grab	NITRATE+NITRITE-N	0.375
10/22/2014 12:06	Grab	TOTAL NITROGEN	1.38
10/22/2014 12:06	Grab	PHOSPHATE, TOTAL AS P	0.138
10/29/2014 11:49	Grab	NITRATE+NITRITE-N	0.411
10/29/2014 11:49	Grab	TOTAL NITROGEN	1.49
10/29/2014 11:49	Grab	PHOSPHATE, TOTAL AS P	0.134
11/5/2014 12:00	Grab	NITRATE+NITRITE-N	0.513
11/5/2014 12:00	Grab	TOTAL NITROGEN	1.58
11/5/2014 12:00	Grab	PHOSPHATE, TOTAL AS P	0.131
11/12/2014 11:09	Grab	NITRATE+NITRITE-N	0.445

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
11/12/2014 11:09	Grab	TOTAL NITROGEN	1.42
11/12/2014 11:09	Grab	PHOSPHATE, TOTAL AS P	0.118
11/19/2014 11:57	Grab	NITRATE+NITRITE-N	0.225
11/19/2014 11:57	Grab	TOTAL NITROGEN	1.26
11/19/2014 11:57	Grab	PHOSPHATE, TOTAL AS P	0.099
11/26/2014 11:53	Grab	NITRATE+NITRITE-N	0.25
11/26/2014 11:53	Grab	TOTAL NITROGEN	1.28
11/26/2014 11:53	Grab	PHOSPHATE, TOTAL AS P	0.087
12/3/2014 11:45	Grab	NITRATE+NITRITE-N	0.247
12/3/2014 11:45	Grab	TOTAL NITROGEN	1.25
12/3/2014 11:45	Grab	PHOSPHATE, TOTAL AS P	0.08
12/10/2014 11:40	Grab	NITRATE+NITRITE-N	0.24
12/10/2014 11:40	Grab	TOTAL NITROGEN	1.18
12/10/2014 11:40	Grab	PHOSPHATE, TOTAL AS P	0.071
12/10/2014 11:48	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/10/2014 11:48	Grab	NITRATE+NITRITE-N	-0.005
12/10/2014 11:48	Grab	TOTAL NITROGEN	-0.02
12/10/2014 11:48	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/17/2014 12:33	Grab	NITRATE+NITRITE-N	0.252
12/17/2014 12:33	Grab	TOTAL NITROGEN	1.3
12/17/2014 12:33	Grab	PHOSPHATE, TOTAL AS P	0.069
12/23/2014 14:01	Grab	NITRATE+NITRITE-N	0.188
12/23/2014 14:01	Grab	TOTAL NITROGEN	1.28
12/23/2014 14:01	Grab	PHOSPHATE, TOTAL AS P	0.063
12/30/2014 11:02	Grab	NITRATE+NITRITE-N	0.139
12/30/2014 11:02	Grab	TOTAL NITROGEN	1.28
12/30/2014 11:02	Grab	PHOSPHATE, TOTAL AS P	0.074
1/7/2015 12:38	Grab	NITRATE+NITRITE-N	0.212
1/7/2015 12:38	Grab	TOTAL NITROGEN	1.17
1/7/2015 12:38	Grab	PHOSPHATE, TOTAL AS P	0.074
1/14/2015 12:21	Grab	NITRATE+NITRITE-N	0.283
1/14/2015 12:21	Grab	TOTAL NITROGEN	1.21
1/14/2015 12:21	Grab	PHOSPHATE, TOTAL AS P	0.086
1/14/2015 12:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/14/2015 12:40	Grab	NITRATE+NITRITE-N	-0.005
1/14/2015 12:40	Grab	TOTAL NITROGEN	-0.02
1/14/2015 12:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/21/2015 12:08	Grab	NITRATE+NITRITE-N	0.226
1/21/2015 12:08	Grab	TOTAL NITROGEN	1.06
1/21/2015 12:08	Grab	PHOSPHATE, TOTAL AS P	0.077
1/28/2015 12:17	Grab	NITRATE+NITRITE-N	0.237
1/28/2015 12:17	Grab	TOTAL NITROGEN	1.21
1/28/2015 12:17	Grab	PHOSPHATE, TOTAL AS P	0.07
1/28/2015 12:34	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/28/2015 12:34	Grab	NITRATE+NITRITE-N	-0.005
1/28/2015 12:34	Grab	TOTAL NITROGEN	-0.02
1/28/2015 12:34	Grab	PHOSPHATE, TOTAL AS P	-0.002

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/4/2015 12:47	Grab	NITRATE+NITRITE-N	0.211
2/4/2015 12:47	Grab	TOTAL NITROGEN	1.21
2/4/2015 12:47	Grab	PHOSPHATE, TOTAL AS P	0.074
2/11/2015 12:30	Grab	NITRATE+NITRITE-N	0.15
2/11/2015 12:30	Grab	TOTAL NITROGEN	1.1
2/11/2015 12:30	Grab	PHOSPHATE, TOTAL AS P	0.06
2/11/2015 12:48	Grab	NITRATE+NITRITE-N	0.152
2/11/2015 12:48	Grab	TOTAL NITROGEN	1.11
2/11/2015 12:48	Grab	PHOSPHATE, TOTAL AS P	0.062
2/11/2015 12:57	Grab	NITRATE+NITRITE-N	0.15
2/11/2015 12:57	Grab	TOTAL NITROGEN	1.07
2/11/2015 12:57	Grab	PHOSPHATE, TOTAL AS P	0.06
2/11/2015 13:10	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
2/11/2015 13:10	Grab	NITRATE+NITRITE-N	-0.005
2/11/2015 13:10	Grab	TOTAL NITROGEN	-0.02
2/11/2015 13:10	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/18/2015 12:54	Grab	NITRATE+NITRITE-N	0.059
2/18/2015 12:54	Grab	TOTAL NITROGEN	0.984
2/18/2015 12:54	Grab	PHOSPHATE, TOTAL AS P	0.05
2/25/2015 11:39	Grab	NITRATE+NITRITE-N	-0.005
2/25/2015 11:39	Grab	TOTAL NITROGEN	0.975
2/25/2015 11:39	Grab	PHOSPHATE, TOTAL AS P	0.057
3/4/2015 12:26	Grab	NITRATE+NITRITE-N	0.043
3/4/2015 12:26	Grab	TOTAL NITROGEN	1.02
3/4/2015 12:26	Grab	PHOSPHATE, TOTAL AS P	0.064
3/11/2015 11:49	Grab	NITRATE+NITRITE-N	0.08
3/11/2015 11:49	Grab	TOTAL NITROGEN	1.01
3/11/2015 11:49	Grab	PHOSPHATE, TOTAL AS P	0.076
3/11/2015 12:08	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/11/2015 12:08	Grab	NITRATE+NITRITE-N	-0.005
3/11/2015 12:08	Grab	TOTAL NITROGEN	-0.02
3/11/2015 12:08	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/18/2015 11:45	Grab	NITRATE+NITRITE-N	0.133
3/18/2015 11:45	Grab	TOTAL NITROGEN	1.09
3/18/2015 11:45	Grab	PHOSPHATE, TOTAL AS P	0.093
3/25/2015 11:32	Grab	NITRATE+NITRITE-N	0.172
3/25/2015 11:32	Grab	TOTAL NITROGEN	1.09
3/25/2015 11:32	Grab	PHOSPHATE, TOTAL AS P	0.102
3/25/2015 11:51	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
3/25/2015 11:51	Grab	NITRATE+NITRITE-N	-0.005
3/25/2015 11:51	Grab	TOTAL NITROGEN	-0.02
3/25/2015 11:51	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/1/2015 11:38	Grab	NITRATE+NITRITE-N	0.148
4/1/2015 11:38	Grab	TOTAL NITROGEN	1.14
4/1/2015 11:38	Grab	PHOSPHATE, TOTAL AS P	0.107
4/8/2015 11:44	Grab	NITRATE+NITRITE-N	0.087
4/8/2015 11:44	Grab	TOTAL NITROGEN	1.04

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
4/8/2015 11:44	Grab	PHOSPHATE, TOTAL AS P	0.078
4/15/2015 9:36	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/15/2015 9:36	Grab	NITRATE+NITRITE-N	-0.005
4/15/2015 9:36	Grab	TOTAL NITROGEN	-0.02
4/15/2015 9:36	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/15/2015 9:51	Grab	NITRATE+NITRITE-N	0.026
4/15/2015 9:51	Grab	TOTAL NITROGEN	0.908
4/15/2015 9:51	Grab	PHOSPHATE, TOTAL AS P	0.071
4/15/2015 10:03	Grab	NITRATE+NITRITE-N	0.024
4/15/2015 10:03	Grab	TOTAL NITROGEN	0.926
4/15/2015 10:03	Grab	PHOSPHATE, TOTAL AS P	0.076
4/15/2015 10:14	Grab	NITRATE+NITRITE-N	0.023
4/15/2015 10:14	Grab	TOTAL NITROGEN	0.882
4/15/2015 10:14	Grab	PHOSPHATE, TOTAL AS P	0.074
4/15/2015 10:24	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
4/15/2015 10:24	Grab	NITRATE+NITRITE-N	-0.005
4/15/2015 10:24	Grab	TOTAL NITROGEN	-0.02
4/15/2015 10:24	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/22/2015 11:38	Grab	NITRATE+NITRITE-N	0.082
4/22/2015 11:38	Grab	TOTAL NITROGEN	1.05
4/22/2015 11:38	Grab	PHOSPHATE, TOTAL AS P	0.12
4/29/2015 11:47	Grab	NITRATE+NITRITE-N	0.345
4/29/2015 11:47	Grab	TOTAL NITROGEN	1.4
4/29/2015 11:47	Grab	PHOSPHATE, TOTAL AS P	0.131
5/6/2015 11:46	Grab	NITRATE+NITRITE-N	0.3
5/6/2015 11:46	Grab	TOTAL NITROGEN	1.33
5/6/2015 11:46	Grab	PHOSPHATE, TOTAL AS P	0.133
5/13/2015 12:23	Grab	NITRATE+NITRITE-N	0.062
5/13/2015 12:23	Grab	TOTAL NITROGEN	1.26
5/13/2015 12:23	Grab	PHOSPHATE, TOTAL AS P	0.101
5/20/2015 12:11	Grab	NITRATE+NITRITE-N	-0.005
5/20/2015 12:11	Grab	TOTAL NITROGEN	1.12
5/20/2015 12:11	Grab	PHOSPHATE, TOTAL AS P	0.117
5/20/2015 12:20	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/20/2015 12:20	Grab	NITRATE+NITRITE-N	-0.005
5/20/2015 12:20	Grab	TOTAL NITROGEN	-0.02
5/20/2015 12:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/27/2015 13:07	Grab	NITRATE+NITRITE-N	0.13
5/27/2015 13:07	Grab	TOTAL NITROGEN	1.3
5/27/2015 13:07	Grab	PHOSPHATE, TOTAL AS P	0.131
6/3/2015 11:46	Grab	NITRATE+NITRITE-N	0.148
6/3/2015 11:46	Grab	TOTAL NITROGEN	1.31
6/3/2015 11:46	Grab	PHOSPHATE, TOTAL AS P	0.123
6/10/2015 11:32	Grab	NITRATE+NITRITE-N	-0.005
6/10/2015 11:32	Grab	TOTAL NITROGEN	1.34
6/10/2015 11:32	Grab	PHOSPHATE, TOTAL AS P	0.128
6/17/2015 11:32	Grab	NITRATE+NITRITE-N	-0.005

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/17/2015 11:32	Grab	TOTAL NITROGEN	1.26
6/17/2015 11:32	Grab	PHOSPHATE, TOTAL AS P	0.118
6/24/2015 10:39	Grab	NITRATE+NITRITE-N	-0.005
6/24/2015 10:39	Grab	TOTAL NITROGEN	1.11
6/24/2015 10:39	Grab	PHOSPHATE, TOTAL AS P	0.099
7/1/2015 11:33	Grab	NITRATE+NITRITE-N	-0.005
7/1/2015 11:33	Grab	TOTAL NITROGEN	1.12
7/1/2015 11:33	Grab	PHOSPHATE, TOTAL AS P	0.137
7/1/2015 11:45	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/1/2015 11:45	Grab	NITRATE+NITRITE-N	-0.005
7/1/2015 11:45	Grab	TOTAL NITROGEN	-0.02
7/1/2015 11:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/8/2015 13:02	Grab	NITRATE+NITRITE-N	0.014
7/8/2015 13:02	Grab	TOTAL NITROGEN	1.03
7/8/2015 13:02	Grab	PHOSPHATE, TOTAL AS P	0.175
7/15/2015 10:59	Grab	NITRATE+NITRITE-N	0.051
7/15/2015 10:59	Grab	TOTAL NITROGEN	0.971
7/15/2015 10:59	Grab	PHOSPHATE, TOTAL AS P	0.169
7/15/2015 11:18	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/15/2015 11:18	Grab	NITRATE+NITRITE-N	-0.005
7/15/2015 11:18	Grab	TOTAL NITROGEN	-0.02
7/15/2015 11:18	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/29/2015 10:33	Grab	NITRATE+NITRITE-N	0.227
7/29/2015 10:33	Grab	TOTAL NITROGEN	1.38
7/29/2015 10:33	Grab	PHOSPHATE, TOTAL AS P	0.218
7/29/2015 10:40	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
7/29/2015 10:40	Grab	NITRATE+NITRITE-N	-0.005
7/29/2015 10:40	Grab	TOTAL NITROGEN	-0.02
7/29/2015 10:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/5/2015 13:05	Grab	NITRATE+NITRITE-N	0.063
8/5/2015 13:05	Grab	TOTAL NITROGEN	1.33
8/5/2015 13:05	Grab	PHOSPHATE, TOTAL AS P	0.173
8/5/2015 13:24	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/5/2015 13:24	Grab	NITRATE+NITRITE-N	-0.005
8/5/2015 13:24	Grab	TOTAL NITROGEN	-0.02
8/5/2015 13:24	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/12/2015 10:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/12/2015 10:05	Grab	NITRATE+NITRITE-N	-0.005
8/12/2015 10:05	Grab	TOTAL NITROGEN	-0.02
8/12/2015 10:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/12/2015 10:18	Grab	NITRATE+NITRITE-N	0.037
8/12/2015 10:18	Grab	TOTAL NITROGEN	1.17
8/12/2015 10:18	Grab	PHOSPHATE, TOTAL AS P	0.129
8/12/2015 10:30	Grab	NITRATE+NITRITE-N	0.034
8/12/2015 10:30	Grab	TOTAL NITROGEN	1.24
8/12/2015 10:30	Grab	PHOSPHATE, TOTAL AS P	0.139
8/12/2015 10:48	Grab	NITRATE+NITRITE-N	0.045

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
8/12/2015 10:48	Grab	TOTAL NITROGEN	1.16
8/12/2015 10:48	Grab	PHOSPHATE, TOTAL AS P	0.131
8/12/2015 11:05	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
8/12/2015 11:05	Grab	NITRATE+NITRITE-N	-0.005
8/12/2015 11:05	Grab	TOTAL NITROGEN	-0.02
8/12/2015 11:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/19/2015 12:08	Grab	NITRATE+NITRITE-N	0.116
8/19/2015 12:08	Grab	TOTAL NITROGEN	1.24
8/19/2015 12:08	Grab	PHOSPHATE, TOTAL AS P	0.176
8/26/2015 11:22	Grab	NITRATE+NITRITE-N	0.154
8/26/2015 11:22	Grab	TOTAL NITROGEN	1.43
8/26/2015 11:22	Grab	PHOSPHATE, TOTAL AS P	0.194
9/2/2015 11:47	Grab	NITRATE+NITRITE-N	0.16
9/2/2015 11:47	Grab	TOTAL NITROGEN	1.48
9/2/2015 11:47	Grab	PHOSPHATE, TOTAL AS P	0.164
9/9/2015 11:05	Grab	NITRATE+NITRITE-N	0.178
9/9/2015 11:05	Grab	TOTAL NITROGEN	1.49
9/9/2015 11:05	Grab	PHOSPHATE, TOTAL AS P	0.132
9/16/2015 11:48	Grab	NITRATE+NITRITE-N	0.171
9/16/2015 11:48	Grab	TOTAL NITROGEN	1.27
9/16/2015 11:48	Grab	PHOSPHATE, TOTAL AS P	0.139
9/23/2015 11:23	Grab	NITRATE+NITRITE-N	0.17
9/23/2015 11:23	Grab	TOTAL NITROGEN	1.37
9/23/2015 11:23	Grab	PHOSPHATE, TOTAL AS P	0.122
9/30/2015 10:45	Grab	NITRATE+NITRITE-N	0.291
9/30/2015 10:45	Grab	TOTAL NITROGEN	1.38
9/30/2015 10:45	Grab	PHOSPHATE, TOTAL AS P	0.13
10/7/2015 11:32	Grab	NITRATE+NITRITE-N	0.352
10/7/2015 11:32	Grab	TOTAL NITROGEN	1.46
10/7/2015 11:32	Grab	PHOSPHATE, TOTAL AS P	0.136
10/14/2015 11:56	Grab	NITRATE+NITRITE-N	0.361
10/14/2015 11:56	Grab	TOTAL NITROGEN	1.26
10/14/2015 11:56	Grab	PHOSPHATE, TOTAL AS P	0.107
10/14/2015 12:06	Grab	NITRATE+NITRITE-N	0.371
10/14/2015 12:06	Grab	TOTAL NITROGEN	1.26
10/14/2015 12:06	Grab	PHOSPHATE, TOTAL AS P	0.107
10/14/2015 12:12	Grab	NITRATE+NITRITE-N	0.361
10/14/2015 12:12	Grab	TOTAL NITROGEN	1.26
10/14/2015 12:12	Grab	PHOSPHATE, TOTAL AS P	0.107
10/14/2015 12:19	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/14/2015 12:19	Grab	NITRATE+NITRITE-N	-0.005
10/14/2015 12:19	Grab	TOTAL NITROGEN	-0.02
10/14/2015 12:19	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/21/2015 10:23	Grab	NITRATE+NITRITE-N	0.373
10/21/2015 10:23	Grab	TOTAL NITROGEN	1.28
10/21/2015 10:23	Grab	PHOSPHATE, TOTAL AS P	0.113
10/28/2015 12:33	Grab	NITRATE+NITRITE-N	0.456

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
10/28/2015 12:33	Grab	TOTAL NITROGEN	1.43
10/28/2015 12:33	Grab	PHOSPHATE, TOTAL AS P	0.12
11/4/2015 11:22	Grab	NITRATE+NITRITE-N	0.458
11/4/2015 11:22	Grab	TOTAL NITROGEN	1.58
11/4/2015 11:22	Grab	PHOSPHATE, TOTAL AS P	0.125
11/4/2015 11:31	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/4/2015 11:31	Grab	NITRATE+NITRITE-N	-0.005
11/4/2015 11:31	Grab	TOTAL NITROGEN	-0.02
11/4/2015 11:31	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/10/2015 10:49	Grab	NITRATE+NITRITE-N	0.496
11/10/2015 10:49	Grab	TOTAL NITROGEN	1.6
11/10/2015 10:49	Grab	PHOSPHATE, TOTAL AS P	0.112
11/18/2015 11:17	Grab	NITRATE+NITRITE-N	0.418
11/18/2015 11:17	Grab	TOTAL NITROGEN	1.45
11/18/2015 11:17	Grab	PHOSPHATE, TOTAL AS P	0.107
11/18/2015 11:38	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
11/18/2015 11:38	Grab	NITRATE+NITRITE-N	-0.005
11/18/2015 11:38	Grab	TOTAL NITROGEN	-0.02
11/18/2015 11:38	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/24/2015 11:58	Grab	NITRATE+NITRITE-N	0.415
11/24/2015 11:58	Grab	TOTAL NITROGEN	1.45
11/24/2015 11:58	Grab	PHOSPHATE, TOTAL AS P	0.134
12/2/2015 10:34	Grab	NITRATE+NITRITE-N	0.403
12/2/2015 10:34	Grab	TOTAL NITROGEN	1.5
12/2/2015 10:34	Grab	PHOSPHATE, TOTAL AS P	0.136
12/2/2015 10:46	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/2/2015 10:46	Grab	NITRATE+NITRITE-N	0.021
12/2/2015 10:46	Grab	TOTAL NITROGEN	-0.02
12/2/2015 10:46	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/9/2015 11:17	Grab	NITRATE+NITRITE-N	0.304
12/9/2015 11:17	Grab	TOTAL NITROGEN	1.27
12/9/2015 11:17	Grab	PHOSPHATE, TOTAL AS P	0.102
12/21/2015 9:25	Grab	NITRATE+NITRITE-N	0.315
12/21/2015 9:25	Grab	TOTAL NITROGEN	1.24
12/21/2015 9:25	Grab	PHOSPHATE, TOTAL AS P	0.081
12/21/2015 9:32	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
12/21/2015 9:32	Grab	NITRATE+NITRITE-N	-0.005
12/21/2015 9:32	Grab	TOTAL NITROGEN	-0.02
12/21/2015 9:32	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/4/2016 10:17	Grab	NITRATE+NITRITE-N	0.281
1/4/2016 10:17	Grab	TOTAL NITROGEN	1.31
1/4/2016 10:17	Grab	PHOSPHATE, TOTAL AS P	0.102
1/19/2016 9:14	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/19/2016 9:14	Grab	NITRATE+NITRITE-N	-0.005
1/19/2016 9:14	Grab	TOTAL NITROGEN	-0.02
1/19/2016 9:14	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/19/2016 9:20	Grab	NITRATE+NITRITE-N	0.225

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
1/19/2016 9:20	Grab	TOTAL NITROGEN	1.18
1/19/2016 9:20	Grab	PHOSPHATE, TOTAL AS P	0.087
1/19/2016 9:37	Grab	NITRATE+NITRITE-N	0.222
1/19/2016 9:37	Grab	TOTAL NITROGEN	1.17
1/19/2016 9:37	Grab	PHOSPHATE, TOTAL AS P	0.086
1/19/2016 9:49	Grab	NITRATE+NITRITE-N	0.224
1/19/2016 9:49	Grab	TOTAL NITROGEN	1.18
1/19/2016 9:49	Grab	PHOSPHATE, TOTAL AS P	0.089
1/19/2016 9:59	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
1/19/2016 9:59	Grab	NITRATE+NITRITE-N	-0.005
1/19/2016 9:59	Grab	TOTAL NITROGEN	-0.02
1/19/2016 9:59	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/1/2016 9:27	Grab	NITRATE+NITRITE-N	0.47
2/1/2016 9:27	Grab	TOTAL NITROGEN	1.54
2/1/2016 9:27	Grab	PHOSPHATE, TOTAL AS P	0.128
2/15/2016 8:29	Grab	NITRATE+NITRITE-N	0.244
2/15/2016 8:29	Grab	TOTAL NITROGEN	1.45
2/15/2016 8:29	Grab	PHOSPHATE, TOTAL AS P	0.094
2/29/2016 9:37	Grab	NITRATE+NITRITE-N	0.111
2/29/2016 9:37	Grab	TOTAL NITROGEN	1.22
2/29/2016 9:37	Grab	PHOSPHATE, TOTAL AS P	0.074
3/14/2016 10:10	Grab	NITRATE+NITRITE-N	0.064
3/14/2016 10:10	Grab	TOTAL NITROGEN	1.1
3/14/2016 10:10	Grab	PHOSPHATE, TOTAL AS P	0.069
3/28/2016 8:23	Grab	NITRATE+NITRITE-N	0.142
3/28/2016 8:23	Grab	TOTAL NITROGEN	1.17
3/28/2016 8:23	Grab	PHOSPHATE, TOTAL AS P	0.092
4/11/2016 8:45	Grab	NITRATE+NITRITE-N	0.282
4/11/2016 8:45	Grab	TOTAL NITROGEN	1.28
4/11/2016 8:45	Grab	PHOSPHATE, TOTAL AS P	0.102
4/25/2016 9:44	Grab	NITRATE+NITRITE-N	0.104
4/25/2016 9:44	Grab	TOTAL NITROGEN	1.05
4/25/2016 9:44	Grab	PHOSPHATE, TOTAL AS P	0.096
5/9/2016 9:27	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
5/9/2016 9:27	Grab	NITRATE+NITRITE-N	-0.005
5/9/2016 9:27	Grab	TOTAL NITROGEN	-0.02
5/9/2016 9:27	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/9/2016 9:32	Grab	NITRATE+NITRITE-N	0.096
5/9/2016 9:32	Grab	TOTAL NITROGEN	1.1
5/9/2016 9:32	Grab	PHOSPHATE, TOTAL AS P	0.106
5/9/2016 9:41	Grab	NITRATE+NITRITE-N	0.096
5/9/2016 9:41	Grab	TOTAL NITROGEN	1.07
5/9/2016 9:41	Grab	PHOSPHATE, TOTAL AS P	0.108
5/9/2016 9:54	Grab	NITRATE+NITRITE-N	0.096
5/9/2016 9:54	Grab	TOTAL NITROGEN	1.1
5/9/2016 9:54	Grab	PHOSPHATE, TOTAL AS P	0.111
5/9/2016 10:07	Grab	KJELDAHL NITROGEN, TOTAL	-0.05

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
5/9/2016 10:07	Grab	NITRATE+NITRITE-N	-0.005
5/9/2016 10:07	Grab	TOTAL NITROGEN	-0.02
5/9/2016 10:07	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/23/2016 10:35	Grab	NITRATE+NITRITE-N	0.136
5/23/2016 10:35	Grab	TOTAL NITROGEN	1.18
5/23/2016 10:35	Grab	PHOSPHATE, TOTAL AS P	0.13
6/7/2016 11:17	Grab	NITRATE+NITRITE-N	0.167
6/7/2016 11:17	Grab	TOTAL NITROGEN	1.29
6/7/2016 11:17	Grab	PHOSPHATE, TOTAL AS P	0.128
6/20/2016 9:05	Grab	NITRATE+NITRITE-N	0.18
6/20/2016 9:05	Grab	TOTAL NITROGEN	1.4
6/20/2016 9:05	Grab	PHOSPHATE, TOTAL AS P	0.162
7/5/2016 10:05	Grab	KJELDAHL NITROGEN, TOTAL	1.19
7/5/2016 10:05	Grab	NITRATE+NITRITE-N	0.178
7/5/2016 10:05	Grab	TOTAL NITROGEN	1.33
7/5/2016 10:05	Grab	PHOSPHATE, TOTAL AS P	0.131
7/18/2016 8:26	Grab	NITRATE+NITRITE-N	0.254
7/18/2016 8:26	Grab	TOTAL NITROGEN	1.3
7/18/2016 8:26	Grab	PHOSPHATE, TOTAL AS P	0.15
8/1/2016 9:29	Grab	NITRATE+NITRITE-N	0.306
8/1/2016 9:29	Grab	TOTAL NITROGEN	1.3
8/1/2016 9:29	Grab	PHOSPHATE, TOTAL AS P	0.141
8/15/2016 11:32	Grab	NITRATE+NITRITE-N	0.181
8/15/2016 11:32	Grab	TOTAL NITROGEN	1.37
8/15/2016 11:32	Grab	PHOSPHATE, TOTAL AS P	0.126
8/29/2016 10:02	Grab	NITRATE+NITRITE-N	0.343
8/29/2016 10:02	Grab	TOTAL NITROGEN	1.36
8/29/2016 10:02	Grab	PHOSPHATE, TOTAL AS P	0.121
9/12/2016 8:20	Grab	KJELDAHL NITROGEN, TOTAL	1.08
9/12/2016 8:20	Grab	NITRATE+NITRITE-N	0.206
9/12/2016 8:20	Grab	TOTAL NITROGEN	1.24
9/12/2016 8:20	Grab	PHOSPHATE, TOTAL AS P	0.11
9/26/2016 9:18	Grab	NITRATE+NITRITE-N	0.174
9/26/2016 9:18	Grab	TOTAL NITROGEN	1.2
9/26/2016 9:18	Grab	PHOSPHATE, TOTAL AS P	0.108
10/10/2016 9:47	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/10/2016 9:47	Grab	NITRATE+NITRITE-N	-0.005
10/10/2016 9:47	Grab	TOTAL NITROGEN	-0.02
10/10/2016 9:47	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/10/2016 9:50	Grab	KJELDAHL NITROGEN, TOTAL	1.16
10/10/2016 9:50	Grab	NITRATE+NITRITE-N	0.2
10/10/2016 9:50	Grab	TOTAL NITROGEN	1.38
10/10/2016 9:50	Grab	PHOSPHATE, TOTAL AS P	0.089
10/10/2016 10:06	Grab	KJELDAHL NITROGEN, TOTAL	1.13
10/10/2016 10:06	Grab	NITRATE+NITRITE-N	0.2
10/10/2016 10:06	Grab	TOTAL NITROGEN	1.38
10/10/2016 10:06	Grab	PHOSPHATE, TOTAL AS P	0.092

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
10/10/2016 10:14	Grab	KJELDAHL NITROGEN, TOTAL	1.1
10/10/2016 10:14	Grab	NITRATE+NITRITE-N	0.204
10/10/2016 10:14	Grab	TOTAL NITROGEN	1.33
10/10/2016 10:14	Grab	PHOSPHATE, TOTAL AS P	0.087
10/10/2016 10:26	Grab	KJELDAHL NITROGEN, TOTAL	-0.05
10/10/2016 10:26	Grab	NITRATE+NITRITE-N	-0.005
10/10/2016 10:26	Grab	TOTAL NITROGEN	-0.02
10/10/2016 10:26	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/24/2016 11:14	Grab	NITRATE+NITRITE-N	0.148
10/24/2016 11:14	Grab	TOTAL NITROGEN	1.12
10/24/2016 11:14	Grab	PHOSPHATE, TOTAL AS P	0.07
11/7/2016 9:13	Grab	KJELDAHL NITROGEN, TOTAL	1.04
11/7/2016 9:13	Grab	NITRATE+NITRITE-N	0.192
11/7/2016 9:13	Grab	TOTAL NITROGEN	1.25
11/7/2016 9:13	Grab	PHOSPHATE, TOTAL AS P	0.074
11/21/2016 11:19	Grab	NITRATE+NITRITE-N	0.312
11/21/2016 11:19	Grab	TOTAL NITROGEN	1.24
11/21/2016 11:19	Grab	PHOSPHATE, TOTAL AS P	0.086
12/7/2016 11:37	Grab	NITRATE+NITRITE-N	0.311
12/7/2016 11:37	Grab	TOTAL NITROGEN	1.12
12/7/2016 11:37	Grab	PHOSPHATE, TOTAL AS P	0.08
1/5/2017 12:39	Grab	KJELDAHL NITROGEN, TOTAL	0.86
1/5/2017 12:39	Grab	NITRATE+NITRITE-N	0.267
1/5/2017 12:39	Grab	TOTAL NITROGEN	1.13
1/5/2017 12:39	Grab	PHOSPHATE, TOTAL AS P	0.076
1/11/2017 11:18	Grab	NITRATE+NITRITE-N	0.29
1/11/2017 11:18	Grab	TOTAL NITROGEN	1.14
1/11/2017 11:18	Grab	PHOSPHATE, TOTAL AS P	0.086
1/11/2017 11:40	Grab	NITRATE+NITRITE-N	-0.005
1/19/2017 10:42	Grab	PHOSPHATE, TOTAL AS P	0.081
1/25/2017 11:21	Grab	NITRATE+NITRITE-N	0.268
1/25/2017 11:21	Grab	TOTAL NITROGEN	1.05
1/25/2017 11:21	Grab	PHOSPHATE, TOTAL AS P	0.078
2/1/2017 10:43	Grab	NITRATE+NITRITE-N	0.243
2/1/2017 10:43	Grab	TOTAL NITROGEN	1.05
2/1/2017 10:43	Grab	PHOSPHATE, TOTAL AS P	0.08
2/8/2017 11:41	Grab	NITRATE+NITRITE-N	0.15
2/8/2017 11:41	Grab	TOTAL NITROGEN	1.31
2/8/2017 11:41	Grab	PHOSPHATE, TOTAL AS P	0.078
2/15/2017 11:28	Grab	NITRATE+NITRITE-N	0.12
2/15/2017 11:28	Grab	TOTAL NITROGEN	1.06
2/15/2017 11:28	Grab	PHOSPHATE, TOTAL AS P	0.068
2/22/2017 10:01	Grab	NITRATE+NITRITE-N	0.16
2/22/2017 10:01	Grab	TOTAL NITROGEN	1.06
2/22/2017 10:01	Grab	PHOSPHATE, TOTAL AS P	0.078
3/1/2017 11:05	Grab	NITRATE+NITRITE-N	0.065
3/1/2017 11:05	Grab	TOTAL NITROGEN	0.983

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
3/1/2017 11:05	Grab	PHOSPHATE, TOTAL AS P	0.072
3/8/2017 11:34	Grab	NITRATE+NITRITE-N	0.091
3/8/2017 11:34	Grab	TOTAL NITROGEN	0.962
3/8/2017 11:34	Grab	PHOSPHATE, TOTAL AS P	0.076
3/15/2017 12:02	Grab	NITRATE+NITRITE-N	0.049
3/15/2017 12:02	Grab	TOTAL NITROGEN	0.962
3/15/2017 12:02	Grab	PHOSPHATE, TOTAL AS P	0.076
3/15/2017 12:13	Grab	NITRATE+NITRITE-N	-0.005
3/15/2017 12:13	Grab	TOTAL NITROGEN	-0.02
3/15/2017 12:13	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/22/2017 10:37	Grab	NITRATE+NITRITE-N	0.063
3/22/2017 10:37	Grab	TOTAL NITROGEN	0.957
3/22/2017 10:37	Grab	PHOSPHATE, TOTAL AS P	0.073
3/29/2017 10:18	Grab	NITRATE+NITRITE-N	-0.005
3/29/2017 10:18	Grab	TOTAL NITROGEN	0.959
3/29/2017 10:18	Grab	PHOSPHATE, TOTAL AS P	0.078
4/5/2017 11:09	Grab	NITRATE+NITRITE-N	0.014
4/5/2017 11:09	Grab	TOTAL NITROGEN	0.939
4/5/2017 11:09	Grab	PHOSPHATE, TOTAL AS P	0.067
4/12/2017 10:33	Grab	NITRATE+NITRITE-N	0.012
4/12/2017 10:33	Grab	TOTAL NITROGEN	0.88
4/12/2017 10:33	Grab	PHOSPHATE, TOTAL AS P	0.082
4/19/2017 11:44	Grab	NITRATE+NITRITE-N	-0.005
4/19/2017 11:44	Grab	TOTAL NITROGEN	0.988
4/19/2017 11:44	Grab	PHOSPHATE, TOTAL AS P	0.092
4/26/2017 10:46	Grab	NITRATE+NITRITE-N	0.033
4/26/2017 10:46	Grab	TOTAL NITROGEN	1.03
4/26/2017 10:46	Grab	PHOSPHATE, TOTAL AS P	0.1
5/3/2017 10:46	Grab	NITRATE+NITRITE-N	-0.005
5/3/2017 10:46	Grab	TOTAL NITROGEN	1.05
5/3/2017 10:46	Grab	PHOSPHATE, TOTAL AS P	0.096
5/10/2017 12:19	Grab	NITRATE+NITRITE-N	-0.005
5/10/2017 12:19	Grab	TOTAL NITROGEN	1.22
5/10/2017 12:19	Grab	PHOSPHATE, TOTAL AS P	0.122
5/17/2017 11:29	Grab	NITRATE+NITRITE-N	-0.005
5/17/2017 11:29	Grab	TOTAL NITROGEN	1.31
5/17/2017 11:29	Grab	PHOSPHATE, TOTAL AS P	0.129
5/24/2017 11:20	Grab	NITRATE+NITRITE-N	-0.005
5/24/2017 11:20	Grab	TOTAL NITROGEN	1.37
5/24/2017 11:20	Grab	PHOSPHATE, TOTAL AS P	0.142
5/31/2017 11:28	Grab	NITRATE+NITRITE-N	0.048
5/31/2017 11:28	Grab	TOTAL NITROGEN	1.64
5/31/2017 11:28	Grab	PHOSPHATE, TOTAL AS P	0.181
6/7/2017 11:08	Grab	NITRATE+NITRITE-N	0.125
6/7/2017 11:08	Grab	TOTAL NITROGEN	1.43
6/7/2017 11:08	Grab	PHOSPHATE, TOTAL AS P	0.231
6/14/2017 11:51	Grab	NITRATE+NITRITE-N	0.353

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/14/2017 11:51	Grab	TOTAL NITROGEN	1.68
6/14/2017 11:51	Grab	PHOSPHATE, TOTAL AS P	0.238
6/21/2017 11:48	Grab	NITRATE+NITRITE-N	0.26
6/21/2017 11:48	Grab	TOTAL NITROGEN	1.64
6/21/2017 11:48	Grab	PHOSPHATE, TOTAL AS P	0.312
6/28/2017 12:15	Grab	NITRATE+NITRITE-N	0.194
6/28/2017 12:15	Grab	TOTAL NITROGEN	1.52
6/28/2017 12:15	Grab	PHOSPHATE, TOTAL AS P	0.259
7/6/2017 10:46	Grab	NITRATE+NITRITE-N	0.062
7/6/2017 10:46	Grab	TOTAL NITROGEN	1.42
7/6/2017 10:46	Grab	PHOSPHATE, TOTAL AS P	0.229
7/12/2017 8:55	Grab	NITRATE+NITRITE-N	0.142
7/12/2017 8:55	Grab	TOTAL NITROGEN	1.2
7/12/2017 8:55	Grab	PHOSPHATE, TOTAL AS P	0.213
7/12/2017 9:00	Grab	NITRATE+NITRITE-N	-0.005
7/12/2017 9:00	Grab	TOTAL NITROGEN	-0.02
7/12/2017 9:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/19/2017 11:56	Grab	NITRATE+NITRITE-N	0.272
7/19/2017 11:56	Grab	TOTAL NITROGEN	1.36
7/19/2017 11:56	Grab	PHOSPHATE, TOTAL AS P	0.255
7/26/2017 11:48	Grab	NITRATE+NITRITE-N	0.054
7/26/2017 11:48	Grab	TOTAL NITROGEN	1.27
7/26/2017 11:48	Grab	PHOSPHATE, TOTAL AS P	0.219
8/2/2017 10:57	Grab	NITRATE+NITRITE-N	0.193
8/2/2017 10:57	Grab	TOTAL NITROGEN	1.38
8/2/2017 10:57	Grab	PHOSPHATE, TOTAL AS P	0.224
8/9/2017 11:32	Grab	NITRATE+NITRITE-N	0.106
8/9/2017 11:32	Grab	TOTAL NITROGEN	1.61
8/9/2017 11:32	Grab	PHOSPHATE, TOTAL AS P	0.2
8/14/2017 10:39	Grab	NITRATE+NITRITE-N	0.213
8/14/2017 10:39	Grab	TOTAL NITROGEN	1.36
8/14/2017 10:39	Grab	PHOSPHATE, TOTAL AS P	0.168
8/21/2017 11:27	Grab	NITRATE+NITRITE-N	0.369
8/21/2017 11:27	Grab	TOTAL NITROGEN	1.56
8/21/2017 11:27	Grab	PHOSPHATE, TOTAL AS P	0.203
8/28/2017 8:58	Grab	NITRATE+NITRITE-N	0.279
8/28/2017 8:58	Grab	TOTAL NITROGEN	1.39
8/28/2017 8:58	Grab	PHOSPHATE, TOTAL AS P	0.163
8/28/2017 9:17	Grab	NITRATE+NITRITE-N	0.02
8/28/2017 9:17	Grab	TOTAL NITROGEN	0.053
8/28/2017 9:17	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/5/2017 12:22	Grab	NITRATE+NITRITE-N	0.229
9/5/2017 12:22	Grab	TOTAL NITROGEN	1.48
9/5/2017 12:22	Grab	PHOSPHATE, TOTAL AS P	0.187
9/13/2017 13:32	Grab	NITRATE+NITRITE-N	0.11
9/13/2017 13:32	Grab	TOTAL NITROGEN	1.22
9/13/2017 13:32	Grab	PHOSPHATE, TOTAL AS P	0.232

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/18/2017 11:38	Grab	NITRATE+NITRITE-N	0.011
9/18/2017 11:38	Grab	TOTAL NITROGEN	1.46
9/18/2017 11:38	Grab	PHOSPHATE, TOTAL AS P	0.338
9/25/2017 10:56	Grab	NITRATE+NITRITE-N	0.071
9/25/2017 10:56	Grab	TOTAL NITROGEN	1.58
9/25/2017 10:56	Grab	PHOSPHATE, TOTAL AS P	0.248
10/2/2017 12:22	Grab	NITRATE+NITRITE-N	0.089
10/2/2017 12:22	Grab	TOTAL NITROGEN	1.54
10/2/2017 12:22	Grab	PHOSPHATE, TOTAL AS P	0.184
10/9/2017 12:10	Grab	NITRATE+NITRITE-N	0.195
10/9/2017 12:10	Grab	TOTAL NITROGEN	1.79
10/9/2017 12:10	Grab	PHOSPHATE, TOTAL AS P	0.194
10/16/2017 11:29	Grab	NITRATE+NITRITE-N	0.139
10/16/2017 11:29	Grab	TOTAL NITROGEN	1.38
10/16/2017 11:29	Grab	PHOSPHATE, TOTAL AS P	0.117
10/23/2017 11:58	Grab	NITRATE+NITRITE-N	0.164
10/23/2017 11:58	Grab	TOTAL NITROGEN	1.75
10/23/2017 11:58	Grab	PHOSPHATE, TOTAL AS P	0.17
10/30/2017 11:23	Grab	NITRATE+NITRITE-N	0.191
10/30/2017 11:23	Grab	TOTAL NITROGEN	1.56
10/30/2017 11:23	Grab	PHOSPHATE, TOTAL AS P	0.145
11/6/2017 12:20	Grab	NITRATE+NITRITE-N	0.223
11/6/2017 12:20	Grab	TOTAL NITROGEN	1.78
11/6/2017 12:20	Grab	PHOSPHATE, TOTAL AS P	0.158
11/13/2017 12:19	Grab	NITRATE+NITRITE-N	0.169
11/13/2017 12:19	Grab	TOTAL NITROGEN	1.38
11/13/2017 12:19	Grab	PHOSPHATE, TOTAL AS P	0.123
11/20/2017 12:00	Grab	NITRATE+NITRITE-N	0.217
11/20/2017 12:00	Grab	TOTAL NITROGEN	1.5
11/20/2017 12:00	Grab	PHOSPHATE, TOTAL AS P	0.124
11/27/2017 11:08	Grab	NITRATE+NITRITE-N	0.168
11/27/2017 11:08	Grab	TOTAL NITROGEN	1.32
11/27/2017 11:08	Grab	PHOSPHATE, TOTAL AS P	0.118
12/4/2017 10:55	Grab	NITRATE+NITRITE-N	0.23
12/4/2017 10:55	Grab	TOTAL NITROGEN	1.48
12/4/2017 10:55	Grab	PHOSPHATE, TOTAL AS P	0.141
12/11/2017 10:59	Grab	NITRATE+NITRITE-N	0.258
12/11/2017 10:59	Grab	TOTAL NITROGEN	1.34
12/11/2017 10:59	Grab	PHOSPHATE, TOTAL AS P	0.129
12/18/2017 11:22	Grab	NITRATE+NITRITE-N	0.261
12/18/2017 11:22	Grab	TOTAL NITROGEN	1.4
12/18/2017 11:22	Grab	PHOSPHATE, TOTAL AS P	0.13
12/27/2017 10:44	Grab	NITRATE+NITRITE-N	0.291
12/27/2017 10:44	Grab	TOTAL NITROGEN	1.38
12/27/2017 10:44	Grab	PHOSPHATE, TOTAL AS P	0.123
1/3/2018 10:49	Grab	NITRATE+NITRITE-N	0.291
1/3/2018 10:49	Grab	TOTAL NITROGEN	1.38

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
1/3/2018 10:49	Grab	PHOSPHATE, TOTAL AS P	0.128
1/8/2018 10:33	Grab	NITRATE+NITRITE-N	0.347
1/8/2018 10:33	Grab	TOTAL NITROGEN	1.36
1/8/2018 10:33	Grab	PHOSPHATE, TOTAL AS P	0.136
1/18/2018 12:10	Grab	NITRATE+NITRITE-N	0.435
1/18/2018 12:10	Grab	TOTAL NITROGEN	1.38
1/18/2018 12:10	Grab	PHOSPHATE, TOTAL AS P	0.132
1/22/2018 10:48	Grab	NITRATE+NITRITE-N	0.424
1/22/2018 10:48	Grab	TOTAL NITROGEN	1.67
1/22/2018 10:48	Grab	PHOSPHATE, TOTAL AS P	0.203
1/29/2018 11:08	Grab	NITRATE+NITRITE-N	0.418
1/29/2018 11:08	Grab	TOTAL NITROGEN	1.25
1/29/2018 11:08	Grab	PHOSPHATE, TOTAL AS P	0.129
2/5/2018 9:30	Grab	NITRATE+NITRITE-N	0.45
2/5/2018 9:30	Grab	TOTAL NITROGEN	1.31
2/5/2018 9:30	Grab	PHOSPHATE, TOTAL AS P	0.122
2/5/2018 9:42	Grab	NITRATE+NITRITE-N	-0.005
2/5/2018 9:42	Grab	TOTAL NITROGEN	-0.02
2/5/2018 9:42	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/12/2018 11:02	Grab	NITRATE+NITRITE-N	0.367
2/12/2018 11:02	Grab	TOTAL NITROGEN	1.27
2/12/2018 11:02	Grab	PHOSPHATE, TOTAL AS P	0.124
2/19/2018 11:13	Grab	NITRATE+NITRITE-N	0.253
2/19/2018 11:13	Grab	TOTAL NITROGEN	1.24
2/19/2018 11:13	Grab	PHOSPHATE, TOTAL AS P	0.108
2/26/2018 11:44	Grab	NITRATE+NITRITE-N	0.196
2/26/2018 11:44	Grab	TOTAL NITROGEN	1.14
2/26/2018 11:44	Grab	PHOSPHATE, TOTAL AS P	0.099
3/5/2018 11:55	Grab	NITRATE+NITRITE-N	0.186
3/5/2018 11:55	Grab	TOTAL NITROGEN	1.24
3/5/2018 11:55	Grab	PHOSPHATE, TOTAL AS P	0.111
3/12/2018 10:35	Grab	NITRATE+NITRITE-N	0.205
3/12/2018 10:35	Grab	TOTAL NITROGEN	1.17
3/12/2018 10:35	Grab	PHOSPHATE, TOTAL AS P	0.114
3/19/2018 9:37	Grab	NITRATE+NITRITE-N	0.267
3/19/2018 9:37	Grab	TOTAL NITROGEN	1.31
3/19/2018 9:37	Grab	PHOSPHATE, TOTAL AS P	0.141
3/19/2018 9:47	Grab	NITRATE+NITRITE-N	-0.005
3/19/2018 9:47	Grab	TOTAL NITROGEN	-0.02
3/19/2018 9:47	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/26/2018 11:33	Grab	NITRATE+NITRITE-N	0.201
3/26/2018 11:33	Grab	TOTAL NITROGEN	1.22
3/26/2018 11:33	Grab	PHOSPHATE, TOTAL AS P	0.123
4/2/2018 9:22	Grab	NITRATE+NITRITE-N	0.179
4/2/2018 9:22	Grab	TOTAL NITROGEN	1.15
4/2/2018 9:22	Grab	PHOSPHATE, TOTAL AS P	0.115
4/9/2018 10:30	Grab	NITRATE+NITRITE-N	0.112

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
4/9/2018 10:30	Grab	TOTAL NITROGEN	1.22
4/9/2018 10:30	Grab	PHOSPHATE, TOTAL AS P	0.101
4/16/2018 11:21	Grab	NITRATE+NITRITE-N	0.217
4/16/2018 11:21	Grab	TOTAL NITROGEN	1.22
4/16/2018 11:21	Grab	PHOSPHATE, TOTAL AS P	0.123
4/23/2018 12:34	Grab	NITRATE+NITRITE-N	0.077
4/23/2018 12:34	Grab	TOTAL NITROGEN	1.15
4/23/2018 12:34	Grab	PHOSPHATE, TOTAL AS P	0.11
4/30/2018 10:20	Grab	NITRATE+NITRITE-N	0.182
4/30/2018 10:20	Grab	TOTAL NITROGEN	1.28
4/30/2018 10:20	Grab	PHOSPHATE, TOTAL AS P	0.129
5/7/2018 10:44	Grab	NITRATE+NITRITE-N	0.258
5/7/2018 10:44	Grab	TOTAL NITROGEN	1.26
5/7/2018 10:44	Grab	PHOSPHATE, TOTAL AS P	0.124
5/14/2018 11:06	Grab	NITRATE+NITRITE-N	0.244
5/14/2018 11:06	Grab	TOTAL NITROGEN	1.23
5/14/2018 11:06	Grab	PHOSPHATE, TOTAL AS P	0.123
5/21/2018 10:55	Grab	NITRATE+NITRITE-N	0.215
5/21/2018 10:55	Grab	TOTAL NITROGEN	1.26
5/21/2018 10:55	Grab	PHOSPHATE, TOTAL AS P	0.136
5/30/2018 12:00	Grab	NITRATE+NITRITE-N	0.479
5/30/2018 12:00	Grab	TOTAL NITROGEN	1.75
5/30/2018 12:00	Grab	PHOSPHATE, TOTAL AS P	0.199
6/4/2018 11:32	Grab	NITRATE+NITRITE-N	-0.005
6/4/2018 11:32	Grab	TOTAL NITROGEN	-0.02
6/4/2018 11:32	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/4/2018 11:50	Grab	NITRATE+NITRITE-N	0.414
6/4/2018 11:50	Grab	TOTAL NITROGEN	1.81
6/4/2018 11:50	Grab	PHOSPHATE, TOTAL AS P	0.203
6/11/2018 10:36	Grab	NITRATE+NITRITE-N	0.286
6/11/2018 10:36	Grab	TOTAL NITROGEN	1.44
6/11/2018 10:36	Grab	PHOSPHATE, TOTAL AS P	0.204
6/18/2018 10:49	Grab	NITRATE+NITRITE-N	0.319
6/18/2018 10:49	Grab	TOTAL NITROGEN	1.63
6/18/2018 10:49	Grab	PHOSPHATE, TOTAL AS P	0.221
6/18/2018 11:02	Grab	NITRATE+NITRITE-N	-0.005
6/18/2018 11:02	Grab	TOTAL NITROGEN	-0.02
6/18/2018 11:02	Grab	PHOSPHATE, TOTAL AS P	-0.002
6/25/2018 12:33	Grab	NITRATE+NITRITE-N	0.136
6/25/2018 12:33	Grab	TOTAL NITROGEN	2.52
6/25/2018 12:33	Grab	PHOSPHATE, TOTAL AS P	0.274
7/5/2018 11:30	Grab	NITRATE+NITRITE-N	0.196
7/5/2018 11:30	Grab	TOTAL NITROGEN	1.56
7/5/2018 11:30	Grab	PHOSPHATE, TOTAL AS P	0.234
7/5/2018 11:40	Grab	NITRATE+NITRITE-N	0.023
7/5/2018 11:40	Grab	TOTAL NITROGEN	-0.02
7/5/2018 11:40	Grab	PHOSPHATE, TOTAL AS P	-0.002

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
7/9/2018 12:00	Grab	NITRATE+NITRITE-N	0.233
7/9/2018 12:00	Grab	TOTAL NITROGEN	1.58
7/9/2018 12:00	Grab	PHOSPHATE, TOTAL AS P	0.193
7/9/2018 12:15	Grab	NITRATE+NITRITE-N	0.013
7/9/2018 12:15	Grab	TOTAL NITROGEN	-0.02
7/9/2018 12:15	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/16/2018 11:42	Grab	NITRATE+NITRITE-N	0.228
7/16/2018 11:42	Grab	TOTAL NITROGEN	1.72
7/16/2018 11:42	Grab	PHOSPHATE, TOTAL AS P	0.225
7/23/2018 12:07	Grab	NITRATE+NITRITE-N	0.269
7/23/2018 12:07	Grab	TOTAL NITROGEN	1.64
7/23/2018 12:07	Grab	PHOSPHATE, TOTAL AS P	0.187
7/23/2018 12:22	Grab	NITRATE+NITRITE-N	-0.005
7/23/2018 12:22	Grab	TOTAL NITROGEN	-0.02
7/23/2018 12:22	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/30/2018 11:40	Grab	NITRATE+NITRITE-N	0.284
7/30/2018 11:40	Grab	TOTAL NITROGEN	1.8
7/30/2018 11:40	Grab	PHOSPHATE, TOTAL AS P	0.194
8/6/2018 11:25	Grab	NITRATE+NITRITE-N	0.221
8/6/2018 11:25	Grab	TOTAL NITROGEN	1.39
8/6/2018 11:25	Grab	PHOSPHATE, TOTAL AS P	0.152
8/13/2018 11:37	Grab	NITRATE+NITRITE-N	0.383
8/13/2018 11:37	Grab	TOTAL NITROGEN	1.7
8/13/2018 11:37	Grab	PHOSPHATE, TOTAL AS P	0.181
8/20/2018 11:12	Grab	NITRATE+NITRITE-N	0.273
8/20/2018 11:12	Grab	TOTAL NITROGEN	1.37
8/20/2018 11:12	Grab	PHOSPHATE, TOTAL AS P	0.145
8/20/2018 11:23	Grab	NITRATE+NITRITE-N	-0.005
8/20/2018 11:23	Grab	TOTAL NITROGEN	-0.02
8/20/2018 11:23	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/27/2018 10:53	Grab	NITRATE+NITRITE-N	0.217
8/27/2018 10:53	Grab	TOTAL NITROGEN	1.35
8/27/2018 10:53	Grab	PHOSPHATE, TOTAL AS P	0.143
9/6/2018 11:17	Grab	NITRATE+NITRITE-N	0.236
9/6/2018 11:17	Grab	TOTAL NITROGEN	1.39
9/6/2018 11:17	Grab	PHOSPHATE, TOTAL AS P	0.128
9/10/2018 11:51	Grab	NITRATE+NITRITE-N	0.281
9/10/2018 11:51	Grab	TOTAL NITROGEN	1.41
9/10/2018 11:51	Grab	PHOSPHATE, TOTAL AS P	0.124
9/17/2018 11:05	Grab	NITRATE+NITRITE-N	-0.005
9/17/2018 11:05	Grab	TOTAL NITROGEN	-0.02
9/17/2018 11:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/17/2018 11:17	Grab	NITRATE+NITRITE-N	0.214
9/17/2018 11:17	Grab	TOTAL NITROGEN	1.28
9/17/2018 11:17	Grab	PHOSPHATE, TOTAL AS P	0.143
9/17/2018 11:41	Grab	NITRATE+NITRITE-N	0.218
9/17/2018 11:41	Grab	TOTAL NITROGEN	1.28

Table C-3. S-79 Water Quality Data			
Collection Date	**Collection Method**	**Test Name**	**Value (mg/L)**
9/17/2018 11:41	Grab	PHOSPHATE, TOTAL AS P	0.147
9/17/2018 11:55	Grab	NITRATE+NITRITE-N	0.221
9/17/2018 11:55	Grab	TOTAL NITROGEN	1.26
9/17/2018 11:55	Grab	PHOSPHATE, TOTAL AS P	0.146
9/17/2018 12:10	Grab	NITRATE+NITRITE-N	-0.005
9/17/2018 12:10	Grab	TOTAL NITROGEN	0.03
9/17/2018 12:10	Grab	PHOSPHATE, TOTAL AS P	-0.002
9/24/2018 11:23	Grab	NITRATE+NITRITE-N	0.244
9/24/2018 11:23	Grab	TOTAL NITROGEN	1.43
9/24/2018 11:23	Grab	PHOSPHATE, TOTAL AS P	0.172
9/24/2018 11:35	Grab	NITRATE+NITRITE-N	-0.005
9/24/2018 11:35	Grab	TOTAL NITROGEN	-0.02
9/24/2018 11:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/1/2018 10:33	Grab	NITRATE+NITRITE-N	0.28
10/1/2018 10:33	Grab	TOTAL NITROGEN	1.33
10/1/2018 10:33	Grab	PHOSPHATE, TOTAL AS P	0.15
10/1/2018 10:45	Grab	NITRATE+NITRITE-N	-0.005
10/1/2018 10:45	Grab	TOTAL NITROGEN	-0.02
10/1/2018 10:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/8/2018 11:07	Grab	NITRATE+NITRITE-N	0.297
10/8/2018 11:07	Grab	TOTAL NITROGEN	1.34
10/8/2018 11:07	Grab	PHOSPHATE, TOTAL AS P	0.119
10/8/2018 11:15	Grab	NITRATE+NITRITE-N	-0.005
10/8/2018 11:15	Grab	TOTAL NITROGEN	0.036
10/8/2018 11:15	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/15/2018 11:14	Grab	NITRATE+NITRITE-N	0.245
10/15/2018 11:14	Grab	TOTAL NITROGEN	1.23
10/15/2018 11:14	Grab	PHOSPHATE, TOTAL AS P	0.11
10/22/2018 11:29	Grab	NITRATE+NITRITE-N	0.29
10/22/2018 11:29	Grab	TOTAL NITROGEN	1.27
10/22/2018 11:29	Grab	PHOSPHATE, TOTAL AS P	0.114
10/29/2018 11:11	Grab	NITRATE+NITRITE-N	0.288
10/29/2018 11:11	Grab	TOTAL NITROGEN	1.28
10/29/2018 11:11	Grab	PHOSPHATE, TOTAL AS P	0.114
10/29/2018 11:23	Grab	NITRATE+NITRITE-N	0.006
10/29/2018 11:23	Grab	TOTAL NITROGEN	-0.02
10/29/2018 11:23	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/5/2018 11:09	Grab	NITRATE+NITRITE-N	0.172
11/5/2018 11:09	Grab	TOTAL NITROGEN	1.13
11/5/2018 11:09	Grab	PHOSPHATE, TOTAL AS P	0.103
11/5/2018 11:18	Grab	NITRATE+NITRITE-N	-0.005
11/5/2018 11:18	Grab	TOTAL NITROGEN	-0.02
11/5/2018 11:18	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/14/2018 12:41	Grab	NITRATE+NITRITE-N	0.225
11/14/2018 12:41	Grab	TOTAL NITROGEN	1.45
11/14/2018 12:41	Grab	PHOSPHATE, TOTAL AS P	0.112
11/19/2018 10:20	Grab	NITRATE+NITRITE-N	0.393

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
11/19/2018 10:20	Grab	TOTAL NITROGEN	1.51
11/19/2018 10:20	Grab	PHOSPHATE, TOTAL AS P	0.122
11/26/2018 10:51	Grab	NITRATE+NITRITE-N	0.441
11/26/2018 10:51	Grab	TOTAL NITROGEN	1.48
11/26/2018 10:51	Grab	PHOSPHATE, TOTAL AS P	0.115
11/26/2018 11:08	Grab	NITRATE+NITRITE-N	-0.005
11/26/2018 11:08	Grab	TOTAL NITROGEN	-0.02
11/26/2018 11:08	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/3/2018 11:04	Grab	NITRATE+NITRITE-N	0.4
12/3/2018 11:04	Grab	TOTAL NITROGEN	1.4
12/3/2018 11:04	Grab	PHOSPHATE, TOTAL AS P	0.096
12/3/2018 11:17	Grab	NITRATE+NITRITE-N	-0.005
12/3/2018 11:17	Grab	TOTAL NITROGEN	-0.02
12/3/2018 11:17	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/10/2018 11:21	Grab	NITRATE+NITRITE-N	0.148
12/10/2018 11:21	Grab	TOTAL NITROGEN	1.23
12/10/2018 11:21	Grab	PHOSPHATE, TOTAL AS P	0.085
12/10/2018 11:36	Grab	NITRATE+NITRITE-N	-0.005
12/10/2018 11:36	Grab	TOTAL NITROGEN	-0.02
12/10/2018 11:36	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/17/2018 10:19	Grab	NITRATE+NITRITE-N	0.079
12/17/2018 10:19	Grab	TOTAL NITROGEN	1.19
12/17/2018 10:19	Grab	PHOSPHATE, TOTAL AS P	0.084
12/17/2018 10:32	Grab	NITRATE+NITRITE-N	-0.005
12/17/2018 10:32	Grab	TOTAL NITROGEN	-0.02
12/17/2018 10:32	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/26/2018 10:57	Grab	NITRATE+NITRITE-N	0.033
12/26/2018 10:57	Grab	TOTAL NITROGEN	1.13
12/26/2018 10:57	Grab	PHOSPHATE, TOTAL AS P	0.088
1/3/2019 10:52	Grab	NITRATE+NITRITE-N	-0.005
1/3/2019 10:52	Grab	TOTAL NITROGEN	1.06
1/3/2019 10:52	Grab	PHOSPHATE, TOTAL AS P	0.071
1/7/2019 11:25	Grab	NITRATE+NITRITE-N	0.035
1/7/2019 11:25	Grab	TOTAL NITROGEN	1.1
1/7/2019 11:25	Grab	PHOSPHATE, TOTAL AS P	0.095
1/14/2019 11:57	Grab	NITRATE+NITRITE-N	0.074
1/14/2019 11:57	Grab	TOTAL NITROGEN	1.05
1/14/2019 11:57	Grab	PHOSPHATE, TOTAL AS P	0.096
1/23/2019 13:46	Grab	NITRATE+NITRITE-N	0.124
1/23/2019 13:46	Grab	TOTAL NITROGEN	1.22
1/23/2019 13:46	Grab	PHOSPHATE, TOTAL AS P	0.1
1/28/2019 11:50	Grab	NITRATE+NITRITE-N	0.141
1/28/2019 11:50	Grab	TOTAL NITROGEN	1.1
1/28/2019 11:50	Grab	PHOSPHATE, TOTAL AS P	0.101
2/4/2019 11:39	Grab	NITRATE+NITRITE-N	0.425
2/4/2019 11:39	Grab	TOTAL NITROGEN	1.52
2/4/2019 11:39	Grab	PHOSPHATE, TOTAL AS P	0.116

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/11/2019 10:54	Grab	NITRATE+NITRITE-N	0.422
2/11/2019 10:54	Grab	TOTAL NITROGEN	1.55
2/11/2019 10:54	Grab	PHOSPHATE, TOTAL AS P	0.112
2/11/2019 11:05	Grab	NITRATE+NITRITE-N	-0.005
2/11/2019 11:05	Grab	TOTAL NITROGEN	-0.02
2/11/2019 11:05	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/18/2019 11:51	Grab	NITRATE+NITRITE-N	0.66
2/18/2019 11:51	Grab	TOTAL NITROGEN	1.9
2/18/2019 11:51	Grab	PHOSPHATE, TOTAL AS P	0.116
2/25/2019 11:17	Grab	NITRATE+NITRITE-N	0.425
2/25/2019 11:17	Grab	TOTAL NITROGEN	1.61
2/25/2019 11:17	Grab	PHOSPHATE, TOTAL AS P	0.084
2/25/2019 11:30	Grab	NITRATE+NITRITE-N	-0.005
2/25/2019 11:30	Grab	TOTAL NITROGEN	-0.02
2/25/2019 11:30	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/4/2019 10:25	Grab	NITRATE+NITRITE-N	0.107
3/4/2019 10:25	Grab	TOTAL NITROGEN	1.34
3/4/2019 10:25	Grab	PHOSPHATE, TOTAL AS P	0.109
3/4/2019 10:40	Grab	NITRATE+NITRITE-N	-0.005
3/4/2019 10:40	Grab	TOTAL NITROGEN	-0.02
3/4/2019 10:40	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/11/2019 11:08	Grab	NITRATE+NITRITE-N	0.244
3/11/2019 11:08	Grab	TOTAL NITROGEN	1.34
3/11/2019 11:08	Grab	PHOSPHATE, TOTAL AS P	0.103
3/11/2019 11:28	Grab	NITRATE+NITRITE-N	-0.005
3/11/2019 11:28	Grab	TOTAL NITROGEN	-0.02
3/11/2019 11:28	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/18/2019 11:05	Grab	NITRATE+NITRITE-N	0.195
3/18/2019 11:05	Grab	TOTAL NITROGEN	1.19
3/18/2019 11:05	Grab	PHOSPHATE, TOTAL AS P	0.094
3/18/2019 11:35	Grab	NITRATE+NITRITE-N	0.006
3/18/2019 11:35	Grab	TOTAL NITROGEN	-0.02
3/18/2019 11:35	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/25/2019 11:07	Grab	NITRATE+NITRITE-N	0.102
3/25/2019 11:07	Grab	TOTAL NITROGEN	1.16
3/25/2019 11:07	Grab	PHOSPHATE, TOTAL AS P	0.089
3/25/2019 11:20	Grab	NITRATE+NITRITE-N	-0.005
3/25/2019 11:20	Grab	TOTAL NITROGEN	-0.02
3/25/2019 11:20	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/1/2019 10:54	Grab	NITRATE+NITRITE-N	-0.005
4/1/2019 10:54	Grab	TOTAL NITROGEN	1.18
4/1/2019 10:54	Grab	PHOSPHATE, TOTAL AS P	0.078
4/8/2019 10:46	Grab	NITRATE+NITRITE-N	0.03
4/8/2019 10:46	Grab	TOTAL NITROGEN	1.09
4/8/2019 10:46	Grab	PHOSPHATE, TOTAL AS P	0.078
4/8/2019 11:03	Grab	NITRATE+NITRITE-N	0.024
4/8/2019 11:03	Grab	TOTAL NITROGEN	1.08

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
4/8/2019 11:03	Grab	PHOSPHATE, TOTAL AS P	0.078
4/8/2019 11:12	Grab	NITRATE+NITRITE-N	0.056
4/8/2019 11:12	Grab	TOTAL NITROGEN	1.16
4/8/2019 11:12	Grab	PHOSPHATE, TOTAL AS P	0.081
4/8/2019 11:23	Grab	NITRATE+NITRITE-N	-0.005
4/8/2019 11:23	Grab	TOTAL NITROGEN	-0.02
4/8/2019 11:23	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/15/2019 11:54	Grab	NITRATE+NITRITE-N	0.138
4/15/2019 11:54	Grab	TOTAL NITROGEN	1.19
4/15/2019 11:54	Grab	PHOSPHATE, TOTAL AS P	0.105
4/15/2019 12:08	Grab	NITRATE+NITRITE-N	-0.005
4/15/2019 12:08	Grab	TOTAL NITROGEN	0.04
4/15/2019 12:08	Grab	PHOSPHATE, TOTAL AS P	-0.002
4/22/2019 12:01	Grab	NITRATE+NITRITE-N	0.085
4/22/2019 12:01	Grab	TOTAL NITROGEN	1.23
4/22/2019 12:01	Grab	PHOSPHATE, TOTAL AS P	0.17
4/29/2019 11:06	Grab	NITRATE+NITRITE-N	0.018
4/29/2019 11:06	Grab	TOTAL NITROGEN	1.24
4/29/2019 11:06	Grab	PHOSPHATE, TOTAL AS P	0.164
4/29/2019 11:19	Grab	NITRATE+NITRITE-N	-0.005
4/29/2019 11:19	Grab	TOTAL NITROGEN	-0.05
4/29/2019 11:19	Grab	PHOSPHATE, TOTAL AS P	-0.002
5/6/2019 10:42	Grab	NITRATE+NITRITE-N	-0.005
5/6/2019 10:42	Grab	TOTAL NITROGEN	1.24
5/6/2019 10:42	Grab	PHOSPHATE, TOTAL AS P	0.13
5/13/2019 11:14	Grab	NITRATE+NITRITE-N	-0.005
5/13/2019 11:14	Grab	TOTAL NITROGEN	1.36
5/13/2019 11:14	Grab	PHOSPHATE, TOTAL AS P	0.143
5/20/2019 9:30	Grab	NITRATE+NITRITE-N	-0.005
5/20/2019 9:30	Grab	TOTAL NITROGEN	1.22
5/20/2019 9:30	Grab	PHOSPHATE, TOTAL AS P	0.142
5/29/2019 10:54	Grab	NITRATE+NITRITE-N	-0.005
5/29/2019 10:54	Grab	TOTAL NITROGEN	1.2
5/29/2019 10:54	Grab	PHOSPHATE, TOTAL AS P	0.142
6/3/2019 11:17	Grab	NITRATE+NITRITE-N	-0.005
6/3/2019 11:17	Grab	TOTAL NITROGEN	1.28
6/3/2019 11:17	Grab	PHOSPHATE, TOTAL AS P	0.168
6/10/2019 11:00	Grab	NITRATE+NITRITE-N	-0.005
6/10/2019 11:00	Grab	TOTAL NITROGEN	1.25
6/10/2019 11:00	Grab	PHOSPHATE, TOTAL AS P	0.177
6/17/2019 10:08	Grab	NITRATE+NITRITE-N	0.19
6/17/2019 10:08	Grab	TOTAL NITROGEN	1.48
6/17/2019 10:08	Grab	PHOSPHATE, TOTAL AS P	0.17
6/24/2019 10:44	Grab	NITRATE+NITRITE-N	-0.005
6/24/2019 10:44	Grab	TOTAL NITROGEN	1.57
6/24/2019 10:44	Grab	PHOSPHATE, TOTAL AS P	0.183
6/24/2019 11:00	Grab	NITRATE+NITRITE-N	-0.005

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
6/24/2019 11:00	Grab	TOTAL NITROGEN	-0.05
6/24/2019 11:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/1/2019 10:28	Grab	NITRATE+NITRITE-N	0.076
7/1/2019 10:28	Grab	TOTAL NITROGEN	1.33
7/1/2019 10:28	Grab	PHOSPHATE, TOTAL AS P	0.148
7/8/2019 11:28	Grab	NITRATE+NITRITE-N	0.123
7/8/2019 11:28	Grab	TOTAL NITROGEN	1.36
7/8/2019 11:28	Grab	PHOSPHATE, TOTAL AS P	0.151
7/15/2019 10:29	Grab	NITRATE+NITRITE-N	0.103
7/15/2019 10:29	Grab	TOTAL NITROGEN	1.38
7/15/2019 10:29	Grab	PHOSPHATE, TOTAL AS P	0.136
7/15/2019 10:41	Grab	NITRATE+NITRITE-N	0.104
7/15/2019 10:41	Grab	TOTAL NITROGEN	1.36
7/15/2019 10:41	Grab	PHOSPHATE, TOTAL AS P	0.143
7/15/2019 10:48	Grab	NITRATE+NITRITE-N	0.107
7/15/2019 10:48	Grab	TOTAL NITROGEN	1.35
7/15/2019 10:48	Grab	PHOSPHATE, TOTAL AS P	0.137
7/15/2019 11:04	Grab	NITRATE+NITRITE-N	-0.005
7/15/2019 11:04	Grab	TOTAL NITROGEN	-0.05
7/15/2019 11:04	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/22/2019 10:48	Grab	NITRATE+NITRITE-N	0.101
7/22/2019 10:48	Grab	TOTAL NITROGEN	1.48
7/22/2019 10:48	Grab	PHOSPHATE, TOTAL AS P	0.13
7/22/2019 11:00	Grab	NITRATE+NITRITE-N	-0.005
7/22/2019 11:00	Grab	TOTAL NITROGEN	-0.05
7/22/2019 11:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
7/29/2019 12:07	Grab	NITRATE+NITRITE-N	0.024
7/29/2019 12:07	Grab	TOTAL NITROGEN	1.45
7/29/2019 12:07	Grab	PHOSPHATE, TOTAL AS P	0.132
8/5/2019 10:38	Grab	NITRATE+NITRITE-N	0.014
8/5/2019 10:38	Grab	TOTAL NITROGEN	-0.05
8/5/2019 10:38	Grab	PHOSPHATE, TOTAL AS P	-0.002
8/5/2019 10:49	Grab	NITRATE+NITRITE-N	0.157
8/5/2019 10:49	Grab	TOTAL NITROGEN	1.46
8/5/2019 10:49	Grab	PHOSPHATE, TOTAL AS P	0.142
8/12/2019 11:01	Grab	NITRATE+NITRITE-N	0.254
8/12/2019 11:01	Grab	TOTAL NITROGEN	1.64
8/12/2019 11:01	Grab	PHOSPHATE, TOTAL AS P	0.149
8/19/2019 10:40	Grab	NITRATE+NITRITE-N	0.196
8/19/2019 10:40	Grab	TOTAL NITROGEN	1.55
8/19/2019 10:40	Grab	PHOSPHATE, TOTAL AS P	0.192
8/26/2019 11:13	Grab	NITRATE+NITRITE-N	0.298
8/26/2019 11:13	Grab	TOTAL NITROGEN	1.52
8/26/2019 11:13	Grab	PHOSPHATE, TOTAL AS P	0.203
9/4/2019 11:04	Grab	NITRATE+NITRITE-N	0.396
9/4/2019 11:04	Grab	TOTAL NITROGEN	1.71
9/4/2019 11:04	Grab	PHOSPHATE, TOTAL AS P	0.163

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
9/9/2019 10:43	Grab	NITRATE+NITRITE-N	0.334
9/9/2019 10:43	Grab	TOTAL NITROGEN	1.33
9/9/2019 10:43	Grab	PHOSPHATE, TOTAL AS P	0.129
9/16/2019 10:24	Grab	NITRATE+NITRITE-N	0.412
9/16/2019 10:24	Grab	TOTAL NITROGEN	1.42
9/16/2019 10:24	Grab	PHOSPHATE, TOTAL AS P	0.132
9/23/2019 11:35	Grab	NITRATE+NITRITE-N	0.455
9/23/2019 11:35	Grab	TOTAL NITROGEN	1.41
9/23/2019 11:35	Grab	PHOSPHATE, TOTAL AS P	0.133
9/30/2019 10:47	Grab	NITRATE+NITRITE-N	0.463
9/30/2019 10:47	Grab	TOTAL NITROGEN	1.47
9/30/2019 10:47	Grab	PHOSPHATE, TOTAL AS P	0.126
9/30/2019 11:00	Grab	NITRATE+NITRITE-N	-0.005
9/30/2019 11:00	Grab	TOTAL NITROGEN	-0.05
9/30/2019 11:00	Grab	PHOSPHATE, TOTAL AS P	-0.002
10/7/2019 11:14	Grab	NITRATE+NITRITE-N	0.556
10/7/2019 11:14	Grab	TOTAL NITROGEN	1.57
10/7/2019 11:14	Grab	PHOSPHATE, TOTAL AS P	0.126
10/14/2019 10:46	Grab	NITRATE+NITRITE-N	0.49
10/14/2019 10:46	Grab	TOTAL NITROGEN	1.45
10/14/2019 10:46	Grab	PHOSPHATE, TOTAL AS P	0.133
10/21/2019 11:26	Grab	NITRATE+NITRITE-N	0.559
10/21/2019 11:26	Grab	TOTAL NITROGEN	1.64
10/21/2019 11:26	Grab	PHOSPHATE, TOTAL AS P	0.14
10/28/2019 11:08	Grab	NITRATE+NITRITE-N	0.513
10/28/2019 11:08	Grab	TOTAL NITROGEN	1.82
10/28/2019 11:08	Grab	PHOSPHATE, TOTAL AS P	0.157
11/4/2019 10:41	Grab	NITRATE+NITRITE-N	0.52
11/4/2019 10:41	Grab	TOTAL NITROGEN	1.79
11/4/2019 10:41	Grab	PHOSPHATE, TOTAL AS P	0.163
11/4/2019 10:55	Grab	NITRATE+NITRITE-N	-0.005
11/4/2019 10:55	Grab	TOTAL NITROGEN	-0.05
11/4/2019 10:55	Grab	PHOSPHATE, TOTAL AS P	-0.002
11/13/2019 11:33	Grab	NITRATE+NITRITE-N	0.472
11/13/2019 11:33	Grab	TOTAL NITROGEN	1.67
11/13/2019 11:33	Grab	PHOSPHATE, TOTAL AS P	0.164
11/18/2019 11:20	Grab	NITRATE+NITRITE-N	0.518
11/18/2019 11:20	Grab	TOTAL NITROGEN	1.71
11/18/2019 11:20	Grab	PHOSPHATE, TOTAL AS P	0.191
11/25/2019 9:24	Grab	NITRATE+NITRITE-N	0.493
11/25/2019 9:24	Grab	TOTAL NITROGEN	1.65
11/25/2019 9:24	Grab	PHOSPHATE, TOTAL AS P	0.174
12/2/2019 10:39	Grab	NITRATE+NITRITE-N	0.298
12/2/2019 10:39	Grab	TOTAL NITROGEN	1.42
12/2/2019 10:39	Grab	PHOSPHATE, TOTAL AS P	0.121
12/2/2019 10:55	Grab	NITRATE+NITRITE-N	-0.005
12/2/2019 10:55	Grab	TOTAL NITROGEN	-0.05

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
12/2/2019 10:55	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/9/2019 10:36	Grab	NITRATE+NITRITE-N	0.139
12/9/2019 10:36	Grab	TOTAL NITROGEN	1.17
12/9/2019 10:36	Grab	PHOSPHATE, TOTAL AS P	0.099
12/9/2019 10:48	Grab	NITRATE+NITRITE-N	-0.005
12/9/2019 10:48	Grab	TOTAL NITROGEN	-0.05
12/9/2019 10:48	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/16/2019 10:31	Grab	NITRATE+NITRITE-N	0.065
12/16/2019 10:31	Grab	TOTAL NITROGEN	1.06
12/16/2019 10:31	Grab	PHOSPHATE, TOTAL AS P	0.071
12/16/2019 10:45	Grab	NITRATE+NITRITE-N	-0.005
12/16/2019 10:45	Grab	TOTAL NITROGEN	-0.05
12/16/2019 10:45	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/23/2019 10:13	Grab	NITRATE+NITRITE-N	0.049
12/23/2019 10:13	Grab	TOTAL NITROGEN	1.16
12/23/2019 10:13	Grab	PHOSPHATE, TOTAL AS P	0.09
12/23/2019 10:25	Grab	NITRATE+NITRITE-N	-0.005
12/23/2019 10:25	Grab	TOTAL NITROGEN	-0.05
12/23/2019 10:25	Grab	PHOSPHATE, TOTAL AS P	-0.002
12/30/2019 10:21	Grab	NITRATE+NITRITE-N	0.013
12/30/2019 10:21	Grab	TOTAL NITROGEN	1.29
12/30/2019 10:21	Grab	PHOSPHATE, TOTAL AS P	0.093
1/6/2020 10:08	Grab	NITRATE+NITRITE-N	0.04
1/6/2020 10:08	Grab	TOTAL NITROGEN	1.31
1/6/2020 10:08	Grab	PHOSPHATE, TOTAL AS P	0.099
1/6/2020 10:22	Grab	NITRATE+NITRITE-N	-0.005
1/6/2020 10:22	Grab	TOTAL NITROGEN	-0.05
1/6/2020 10:22	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/13/2020 12:13	Grab	NITRATE+NITRITE-N	0.199
1/13/2020 12:13	Grab	TOTAL NITROGEN	1.18
1/13/2020 12:13	Grab	PHOSPHATE, TOTAL AS P	0.102
1/13/2020 12:37	Grab	NITRATE+NITRITE-N	-0.005
1/13/2020 12:37	Grab	TOTAL NITROGEN	-0.05
1/13/2020 12:37	Grab	PHOSPHATE, TOTAL AS P	-0.002
1/21/2020 11:06	Grab	NITRATE+NITRITE-N	0.286
1/21/2020 11:06	Grab	TOTAL NITROGEN	1.34
1/21/2020 11:06	Grab	PHOSPHATE, TOTAL AS P	0.101
1/27/2020 11:05	Grab	NITRATE+NITRITE-N	0.33
1/27/2020 11:05	Grab	TOTAL NITROGEN	1.35
1/27/2020 11:05	Grab	PHOSPHATE, TOTAL AS P	0.101
2/3/2020 11:04	Grab	NITRATE+NITRITE-N	0.149
2/3/2020 11:04	Grab	TOTAL NITROGEN	1.22
2/3/2020 11:04	Grab	PHOSPHATE, TOTAL AS P	0.08
2/10/2020 10:57	Grab	NITRATE+NITRITE-N	0.074
2/10/2020 10:57	Grab	TOTAL NITROGEN	1.18
2/10/2020 10:57	Grab	PHOSPHATE, TOTAL AS P	0.088
2/17/2020 11:09	Grab	NITRATE+NITRITE-N	0.025

Table C-3. S-79 Water Quality Data

Collection Date	Collection Method	Test Name	Value (mg/L)
2/17/2020 11:09	Grab	TOTAL NITROGEN	1.07
2/17/2020 11:09	Grab	PHOSPHATE, TOTAL AS P	0.07
2/17/2020 11:21	Grab	NITRATE+NITRITE-N	-0.005
2/17/2020 11:21	Grab	TOTAL NITROGEN	-0.05
2/17/2020 11:21	Grab	PHOSPHATE, TOTAL AS P	-0.002
2/24/2020 10:58	Grab	NITRATE+NITRITE-N	0.046
2/24/2020 10:58	Grab	TOTAL NITROGEN	1.08
2/24/2020 10:58	Grab	PHOSPHATE, TOTAL AS P	0.084
2/24/2020 11:14	Grab	NITRATE+NITRITE-N	-0.005
2/24/2020 11:14	Grab	TOTAL NITROGEN	-0.05
2/24/2020 11:14	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/2/2020 10:46	Grab	NITRATE+NITRITE-N	-0.005
3/2/2020 10:46	Grab	TOTAL NITROGEN	1.14
3/2/2020 10:46	Grab	PHOSPHATE, TOTAL AS P	0.095
3/2/2020 10:56	Grab	NITRATE+NITRITE-N	-0.005
3/2/2020 10:56	Grab	TOTAL NITROGEN	-0.05
3/2/2020 10:56	Grab	PHOSPHATE, TOTAL AS P	-0.002
3/9/2020 11:49	Grab	NITRATE+NITRITE-N	-0.005
3/9/2020 11:49	Grab	TOTAL NITROGEN	1.14
3/9/2020 11:49	Grab	PHOSPHATE, TOTAL AS P	0.09
3/16/2020 10:41	Grab	NITRATE+NITRITE-N	-0.005
3/16/2020 10:41	Grab	TOTAL NITROGEN	1.14
3/16/2020 10:41	Grab	PHOSPHATE, TOTAL AS P	0.076

Appendix D: C-43 WBSR 2008 Draft Operations Plan

to the estuary during the dry season. Reducing the variability of freshwater releases to the estuary will support the restoration of salinity ranges and habitat in the estuary.

10.8.2 Overall Plan for Water Control

Operational criteria for the many structures in this project are designed to enable the C-43 WBSR Project to best aid in meeting the specified hydrologic performance measures (SFWMD, 2005). In general, the performance targets are as follows:

- Maintain a minimum flow of 450 cubic feet per second (cfs) at the S-79 structure; and
- Meet the frequency distribution of flows associated with EST05 (without tidal basin contribution) as identified in the following Table 10.1.

Table 10.1 Target EST05 Flow Range at S-79

Discharge Range (cfs) From S-79	Percent Distribution Of Flows From S-79
0 to 450	0%
450 to 500	42.8%
500 to 800	31.7%
800 to 1500	19.2%
1500 to 2800	5.6%
2800 to 4500	0.7%
>4500	0%

It is noted that the EST05 daily distribution of flow provides no allowances for monthly average discharges from S-79 that are below 450 cfs. However, the Reservoir can still achieve estuarine protection and restoration success if the final selected alternative has flow occurrences beyond the distribution limits, including those below 450 cfs.

The operational criteria described in this document are designed to capture the maximum amount of high flows from the Caloosahatchee River and release the stored water during low flow periods in order to provide flow attenuation to the estuary.

In general, the C-43 WBSR will do the following:

- Pump water into the WBSR from the Caloosahatchee River via the Townsend Canal;
- Store water in the WBSR to attenuate freshwater flows to the CRE and as a secondary benefit, to gain residence time to reduce nutrient concentrations; and
- Release water back to the Caloosahatchee River via discharge structures and C-470 during the dry season to meet minimum flow requirements at the S-79 structure.

The normal operation of the Reservoir is dependent upon flows and water levels at the S-79 structure. In general, the goal is to capture water during high flows events, store it, and then release the water during periods of low flow. High flow events may be the result of releases from Lake Okeechobee, or the result of rainfall events within the watershed.

The challenge in establishing an operational plan for the C-43 WBSR is to find the balance between the timing and volume of pumping and the timing and volume of releases from the

Reservoir. If the pumping strategy is overly aggressive, the Reservoir will fill early in the wet season. This would result in late wet season high flows being released in their entirety to the estuary. If the pump strategy is under aggressive, the Reservoir may not fill; under-utilizing the Reservoir storage capacity and making less water available for release to the estuary during the dry season.

The description of operational criteria described in this document will include all structures proposed as part of the C-43 WBSR. The structure description and information for each structure has been purposely separated to provide an easy means of separating the information for each structure.

C43PS-1 (S-470) PUMP STATION

Location

The S-470 Pump Station is located in the northwest corner of the C-43 WBSR Project, adjacent to the Townsend Canal.

Description

S-470 is a 1500 cfs capacity pump station. S-470 has two 250 cfs pumps and two 500 cfs pumps. All pumps are diesel powered. The number of pumps operating at any given time is controlled by flows over the S-79 structure located downstream in the Caloosahatchee River. The pump station engines are diesel powered.

Purpose

The purpose of the S-470 Pump Station is to reduce wet season flows over S-79 by pumping from the Caloosahatchee River via the Townsend Canal into the C-43 WBSR as per the operational tables provided below.

Normal Regulation

The following tables provide a conceptual overview of the operational strategy for the S-470 structure as a function of water level in the Reservoir, flow at S-79, and the time of year. The operations presented here for the S-470 represent the strategy implemented in the "Spread Sheet" model developed by the Interagency Modeling Center (IMC) and adapted to the pump station pumping capabilities. The optimized model runs completed in MIKE SHE/MIKE 11 uses an identical approach.

Operations are dependent upon three variables; water level in the reservoir, month of the year, and flow at S-79.

The following table provides a summary of how the pump will operate. In the table, the reservoir is defined as empty, medium, or full. These criteria are defined as follows:

Empty – Water Level between 19.2 and 29 feet
Medium – Water Level between 29 and 41.1 feet
Full – Water Level between 41.1 and 42 feet

Also in the table, pump operations are defined based on the season of the year. In the table, the seasons are defined as Early Wet Season, Late Wet Season, Early Dry Season and Late Dry Season. These criteria are defined as follows:

Early Wet Season – The months of June and July
Late Wet Season – The months of August, September, and October
Early Dry Season – The months of November, December, and January
Late Dry Season – The months of February, March, April, and May

The pump will operate according to the following schedule:

WL in Reservoir (19.2– 29 ft)	S-79 Flows	Pump Rate			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Empty	520	0	0	0	0
Empty	650	0	250	250	250
Empty	850	0	250	250	250
Empty	1000	250	500	500	500
Empty	1200	500	500	500	500
Empty	1500	750	750	750	750
Empty	2000	1000	1250	1000	1000
Empty	2800	1250	1500	1500	1500
Empty	3800	1500	1500	1500	1500
Empty	5000	1500	1500	1500	1500
Empty	99999	1500	1500	1500	1500

WL in Reservoir (29 – 41.1 ft)	S-79 Flows	Pump Rate			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Medium	520	0	0	0	0
Medium	650	0	250	0	0
Medium	850	0	250	250	0
Medium	1000	250	250	250	0
Medium	1200	500	500	500	0
Medium	1500	750	750	750	750
Medium	2000	750	1250	1000	1000
Medium	2800	1000	1500	1500	1500
Medium	3800	1500	1500	1500	1500
Medium	5000	1500	1500	1500	1500
Medium	99999	1500	1500	1500	1500

WL in Reservoir (41.1 – 42 ft)	S-79 Flows	Pump Rate			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Full	520	0	0	0	0
Full	650	0	0	0	0
Full	850	0	250	0	0

Full	1000	0	250	250	0
Full	1200	0	500	500	0
Full	1500	250	750	750	0
Full	2000	500	1000	1000	500
Full	2800	750	1250	1250	750
Full	3800	1500	1500	1500	1500
Full	5000	1500	1500	1500	1500
Full	99999	1500	1500	1500	1500

Flood Control Regulation

There is no separate regulation for flood control. Typically, and unless the Reservoir is at the Normal Full Storage Level, the Pump Station will be pumping based on the above tables and will reduce downstream flows in the Townsend Canal and the Caloosahatchee River.

Low Water Regulation

There is no separate regulation for low water. The Pump Station will not be operating during low flow conditions in the Caloosahatchee River.

PERTINENT DATA TABLE - S-470

Location: Northwest corner of C-43 West Basin Storage Reservoir, Hendry County, FL

Design Capacity:	1500 cfs (673,500 gpm)
Pump Type:	Mixed Flow
Number of Pumps	4
Pump Design Capacity:	2 @ 500 cfs (224,500 gpm) 2 @ 250 cfs (112,250 gpm)
Power Source:	Diesel Engines

Pool Conditions:

	normal (ft.)	maximum (ft.)	minimum (ft.)
Suction	0.80	3.85	0.80
Discharge	36.50	45.60 (startup) 42.00 (operating)	28.00

All stage elevations as per NAVD 88 Datum.

Pump Curve Design Criteria

Design (0.8 ft. HW to 36.5 ft TW)	500 cfs @ 40.2 ft TDH 250 cfs @ 40.2 ft TDH
Rated (0.8 ft HW to 42.0 ft TW)	>400 cfs @ 44 ft TDH >200 cfs @ 44 ft TDH
Low Head (3.85 ft HW to 28.0 ft TW)	<560 cfs @ 30 ft TDH <290 cfs @ 30 ft TDH
Startup (0.8 ft HW to 36.5 ft TW)	>250 cfs @ 52 ft TDH >125 cfs @ 50 ft TDH

Control: Local control through SCADA system with remote capability.

STRUCTURE C43S-1 (S-471)

Location

S-471 is located in the northwest corner of the Cell 1 Perimeter Dam (D-470).

Description

Main outlet S-471 is a 10 feet wide by 6 feet high conduit passing through the earth dam. The outlet consists of a multilevel intake structure, gated conduit through the dam section, stilling basin and channel leading to the C-470. Two identical outlets have been provided, one for normal operation and the other for standby. Only gates associated with the outlet structure being utilized will be opened during operations.

Purpose

The outlet has been provided to release flows up to the **maximum project discharge of 600 cfs when the Reservoir is at or near NFSL (elevation 42.0 feet) and 500 cfs under normal operating conditions,** as well as, enabling reservoir drainage per USACE ER1110-2-50 requirements. The outlet will also function as a conduit spillway in conjunction with the crest spillway structure S-472 to release excess flood flows.

Operation

The multilevel intake of S-471 has three tiers of gates. These gates will be either fully open or fully closed. Again, only gates associated with the outlet structure being utilized will be opened during operations. The upper tier and the middle tier gates will be operated to enable selective withdrawal of water from the reservoir for water quality purposes. The gate level to be opened is to be determined based on the highest water quality level in the Reservoir at the time of beginning discharge as determined by the vertical profilers. Flows up to the maximum project requirement of 600 cfs will be withdrawn through either the upper tier gates or the middle tier gates, or both tiers, depending upon the pool elevation. The number of tiers open for a given flowrate should be estimated assuming a maximum flow velocity of 4 ft/sec through the intake structure in order to avoid unfavorable flow conditions at the conduit inlet. For flows higher than 500 cfs both tier 1 and tier 2 will be open. The lowest tier gate will normally be operated at low reservoir levels for the purpose of draining the reservoir. Flow rate is dependent upon the gate opening and the water surface elevation of the Reservoir.

The gate well located in the body of the D-470 houses two gates, one service gate for normal operation and one gate for emergency and maintenance purposes. The emergency gate will operate either fully closed or fully opened. The service gate can be set at various openings. A gate size of 5-feet wide by 6-feet high allows for operation at typical release flows (up to 600 cfs) and conveys the necessary flows to manage the reservoir level. Sustained operation of the gate at very low gate openings should be avoided as cavitation potential in the vicinity of the gate is higher at low gate openings.

The maximum discharge through the outlet should be limited to 600 cfs under normal operating conditions as well as during reservoir emptying. Higher discharges should be released through the outlet only to pass flood flows under extreme storm events in order to expeditiously lower the reservoir water elevation to the normal pool.

Normal Regulation

As with the pumps, challenges exist to determine the timing and volume of releases from the Reservoir to meet minimum flow requirements at S-79. The S-471 and S-473 underflow gates are each designed to release a maximum of 600 cfs. The operational strategy is to release water from Cell 2 (S-473) as first priority. This strategy will increase the residence time in the Reservoir and may provide a water quality benefit. If flows from Cell 2 do not meet the combined release target then additional flows will be released from Cell 1 through S-471. Operations are dependent upon three variables; water level in the reservoir, month of the year, and flow at S-79.

The following table provides a summary of how the gates will operate. In the table, the reservoir is defined as empty, medium, or full. These criteria are defined as follows:

Empty – Water Level between 19.2 and 29 feet
Medium – Water Level between 29 and 41.1 feet
Full – Water Level between 41.1 and 42 feet

Also in the table, gate operations are defined based on the season of the year. In the table, the seasons are defined as Early Wet Season, Late Wet Season, Early Dry Season and Late Dry Season. These criteria are defined as follows:

Early Wet Season – The months of June and July
Late Wet Season – The months of August, September, and October
Early Dry Season – The months of November, December, and January
Late Dry Season – The months of February, March, April, and May

The following table shows the result of the combined gate operations. When the reservoir is either medium or full, flows up to 600 cfs will be released from Structure S-473. The balance will be provided from Structure S-471.

During those periods, when the reservoir is empty (between 19.2 and 29 feet), the following distribution will occur:

1) Flows will be released entirely from S-473 if the water level is greater than 25 feet and flow requirements are met.
2) If flow requirements can not be met entirely from S-473, water will be released from S-471 to met total flow requirements.
3) If the water level is less than 25 feet, releases would be made from S-471.

Opening the Gates: The Intake Structure Gates should be opened slowly (0.1 feet increments at one minute intervals). The Intake Structure Gates to be opened are to be based on water quality of the Reservoir water column. The Intake Structure Gates opened will provide the highest water quality available. Once opened, the Intake Structure Gates are to be fully opened and to remain open until the Service Gate (discharge control gate) is closed.

The Service Gate should be opened slowly (0.1 feet increments at one minute intervals). The Service Gate should be opened to the gate opening that will provide the desired flow at S-79 based on the flow rating curve and Reservoir level. The Service Gate should be fully opened.

Closing the Gates: The Intake Structure Gates should be closed slowly (0.1 feet increments at one minute intervals). After the Intake Structure Gates are closed and the structure tower and culvert are empty, the Service Gate can be closed.

The following schedule provides the combined operational strategy of the Service Gates:

WL in Reservoir (19.2 – 29 ft)	S-79 Flows	Combined Releases (S-471 and S-473)			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Empty	250	450	450	450	450
Empty	350	290	290	275	290
Empty	450	100	100	50	100
Empty	550	0	0	0	0
Empty	800	0	0	0	0
Empty	1000	0	0	0	0
Empty	1500	0	0	0	0
Empty	2800	0	0	0	0
Empty	99999	0	0	0	0

WL in Reservoir (29 – 41.1 ft)	S-79 Flows	Combined Releases (S-471 and S-473)			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Medium	250	1100	450	450	700
Medium	350	900	275	275	600
Medium	450	700	150	100	500
Medium	550	400	0	0	450
Medium	800	250	0	0	200
Medium	1000	0	0	0	0
Medium	1500	0	0	0	0
Medium	2800	0	0	0	0
Medium	99999	0	0	0	0

WL in Reservoir (41.1 – 42 ft)	S-79 Flows	Combined Releases (S-471 and S-473)			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
High	250	1200	500	500	900
High	350	1100	400	400	850
High	450	900	400	400	750
High	550	650	350	350	700
High	800	500	0	0	500
High	1000	350	0	0	350
High	1500	150	0	0	150

High	2800	0	0	0	0
High	99999	0	0	0	0

Flood Control Regulation

Unless the Reservoir is above the Normal Full Storage Level (elevation 42.0 feet there will be no releases from the Reservoir during flood events. During an extreme flood event, and after periods of extreme high water, releases can be made from the Reservoir as long as the water surface elevation in the C-470 is less than elevation 19.5 feet at S-473 and the water surface elevation in the Townsend Canal at the SR 80 Bridge is less than elevation 8.0 feet. The releases of S-471 and S-473 should be limited to 600 cfs for each structure and will be proportionately less if the discharges from S-472 and S-474 are 200 cfs or more.

Low Water Regulation

There is not a separate low water regulation.

PERTINENT DATA TABLE - S-471

Type of structure		Cell 1 Discharge Structure
Design discharge		600 cfs at NFSL
Maximum discharge		930 cfs (1 gate PMP storm)
Normal reservoir water elevation		42
Maximum reservoir water elevation		46
TW elevation	(design discharge)	15.5
TW elevation	(maximum discharge)	17
Invert elevation at gated section		18
Gates:		
Gatewell:		4 – 5' w x 6' h slide gate
Intake:		10 – 10' w x 6' h slide gates
Type of control		Slide gate (electric actuator)
Stilling basin floor elevation		4
Stilling basin width		10 ft
Stilling basin length		41.6 ft
Stilling basin type		USBR Type III

Note: All elevations are in feet NAVD

STRUCTURE C43S-8 (S-473)

Location

S-473 is located in the northwest corner of the Cell 2 D-470.

Description

Main outlet S-473 is a 10 feet wide by 6 feet high conduit passing through the earth dam. The outlet consists of a multilevel intake structure, gated conduit through the dam section, stilling basin and channel leading to the C-470. Two identical outlets have been provided, one for normal operation and the other for standby. Only gates associated with the outlet structure being utilized will be opened during operations.

Purpose

The outlet has been provided to release flows up to the **maximum project discharge of 600 cfs when the Reservoir is at or near NFSL (elevation 42.0 feet) and 500 cfs under normal operating conditions,** as well as, enabling reservoir drainage per USACE ER1110-2-50 requirements. The outlet will also function as a conduit spillway in conjunction with the crest spillway structure S-474 to release excess flood flows.

Operation

The multilevel intake of S-473 has three tiers of gates. These gates will be either fully open or fully closed. Again, only gates associated with the outlet structure being utilized will be opened during operations. The upper tier and the middle tier gates will be operated to enable selective withdrawal of water from the reservoir for water quality purposes. The gate level to be opened is to be determined based on the highest water quality level in the Reservoir at the time of beginning discharge as determined by the vertical profilers. Flows up to the maximum project requirement of 600 cfs will be withdrawn through either the upper tier gates or the middle tier gates, or both tiers, depending upon the pool elevation. The number of tiers open for a given flowrate should be estimated assuming a maximum flow velocity of 4 ft/sec through the intake structure in order to avoid unfavorable flow conditions at the conduit inlet. For flows higher than 500 cfs both tier 1 and tier 2 will be open. The lowest tier gate will normally be operated at low reservoir levels for the purpose of draining the reservoir. Flow rate is dependent upon the gate opening and the water surface elevation of the Reservoir.

The gate well located in the body of the D-470 houses two gates, one service gate for normal operation and one gate for emergency and maintenance purposes. The emergency gate will operate either fully closed or fully opened. The service gate can be set at various openings. A gate size of 5-feet wide by 6-feet high allows for operation at typical release flows (up to 600 cfs) and conveys the necessary flows to manage the reservoir level. Sustained operation of the gate at very low gate openings should be avoided as cavitation potential in the vicinity of the gate is higher at low gate openings.

The maximum discharge through the outlet should be limited to 500 cfs under normal operating conditions, as well as, during reservoir emptying. Higher discharges should be released through the outlet only to pass flood flows under extreme storm events in order to expeditiously lower the reservoir water elevation to the normal pool.

Normal Regulation

As with the pumps, challenges exist to determine the timing and volume of releases from the Reservoir to meet minimum flow requirements at S-79. The S-471 and S-473 underflow gates are each designed to release a maximum of 500 cfs. The operational strategy is to release water from Cell 2 (S-473) as first priority. This strategy will increase the residence time in the Reservoir and may provide a water quality benefit. If flows from Cell 2 do not meet the combined release target then additional flows will be released from Cell 1 through S-471.

Operations are dependent upon three variables; water level in the reservoir, month of the year, and flow at S-79.

The following table provides a summary of how the gates will operate. In the table, the reservoir is defined as empty, medium, or full. These criteria are defined as follows:

Empty – Water Level between 19.2 and 29 feet
Medium – Water Level between 29 and 41.1 feet
Full – Water Level between 41.1 and 42 feet

Also in the table, gate operations are defined based on the season of the year. In the table, the seasons are defined as Early Wet Season, Late Wet Season, Early Dry Season and Late Dry Season. These criteria are defined as follows:

Early Wet Season – The months of June and July
Late Wet Season – The months of August, September, and October
Early Dry Season – The months of November, December, and January
Late Dry Season – The months of February, March, April, and May

The following table shows the result of the combined gate operations. When the reservoir is either medium or full, flows up to 600 cfs will be released from Structure S-473. The balance will be provided from Structure S-471.

During those periods, when the reservoir is empty (between 19.2 and 29 feet), the following distribution will occur:

1) Flows will be released entirely from S-473 if the water level is greater than 25 feet and flow requirements are met.
2) If flow requirements can not be met entirely from S-473, water will be released from S-471 to meet total flow requirements.
3) If the water level is less than 25 feet, releases would be made from S-471.

Opening the Gates: The Intake Structure Gates should be opened slowly (0.1 feet increments at one minute intervals). The Intake Structure Gates to be opened are to be based on water quality of the Reservoir water column. The Intake Structure Gates opened will provide the highest water quality available. Once opened, the Intake Structure Gates are to be fully opened and to remain open until the Service Gate (discharge control gate) is closed.

The Service Gate should be opened slowly (0.1 feet increments at one minute intervals). The Service Gate should be opened to the gate opening that will provide the desired flow at S-79 based on the flow rating curve and Reservoir level. The Service Gate should be fully opened.

Closing the Gates: The Intake Structure Gates should be closed slowly (0.1 feet increments at one minute intervals). After the Intake Structure Gates are closed and the structure tower and culvert are empty, the Service Gate can be closed.

The following schedule provides the combined operational strategy of the Service Gates:

WL in Reservoir (19.2 – 29 ft)	S-79 Flows	Combined Releases (S-471 and S-473)			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Empty	250	450	450	450	450
Empty	350	290	290	275	290
Empty	450	100	100	50	100
Empty	550	0	0	0	0
Empty	800	0	0	0	0
Empty	1000	0	0	0	0
Empty	1500	0	0	0	0
Empty	2800	0	0	0	0
Empty	99999	0	0	0	0

WL in Reservoir (29 – 41.1 ft)	S-79 Flows	Combined Releases (S-471 and S-473)			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
Medium	250	1100	450	450	700
Medium	350	900	275	275	600
Medium	450	700	150	100	500
Medium	550	400	0	0	450
Medium	800	250	0	0	200
Medium	1000	0	0	0	0
Medium	1500	0	0	0	0
Medium	2800	0	0	0	0
Medium	99999	0	0	0	0

WL in Reservoir (41.1 – 42 ft)	S-79 Flows	Combined Releases (S-471 and S-473)			
		Early Wet Season June to July	Late Wet Season August to October	Early Dry Season November to January	Late Dry Season February to May
High	250	1200	500	500	900
High	350	1100	400	400	850
High	450	900	400	400	750
High	550	650	350	350	700
High	800	500	0	0	500
High	1000	350	0	0	350
High	1500	150	0	0	150
High	2800	0	0	0	0
High	99999	0	0	0	0

Flood Control Regulation

Unless the Reservoir is above the Normal Full Storage Level (elevation 42.0 feet there will be no releases from the Reservoir during flood events. During an extreme flood event, and after periods of extreme high water, releases can be made from the Reservoir as long as the water surface elevation in the C-470 is less than elevation 19.5 feet at S-473 and the water surface elevation in the Townsend Canal at the SR 80 Bridge is less than elevation 8.0 feet. The releases of S-471 and S-473 should be limited to 600 cfs for each structure and will be proportionately less if the discharges from S-472 and S-474 are 200 cfs or more.

Low Water Regulation

The C-470 between S-477 and S-482 is a source of water for LPDD Pump Station No. 3 (Bryan Paul), the Banana Branch, the Ft. Simmons Branch, and District Property north of the FPL Power Line. The water surface in this section of the C-470 is to be maintained at or near elevation 19.0 feet. When the water surface elevation in Cell 2 is greater than 25.0 feet, discharge from Cell 2 through S-473 is to be used to maintain the water surface in the C-470.

Opening and closing the gates is to be accomplished as indicated above.

The criterion for operating the gates is as follows:

Open the Gate:

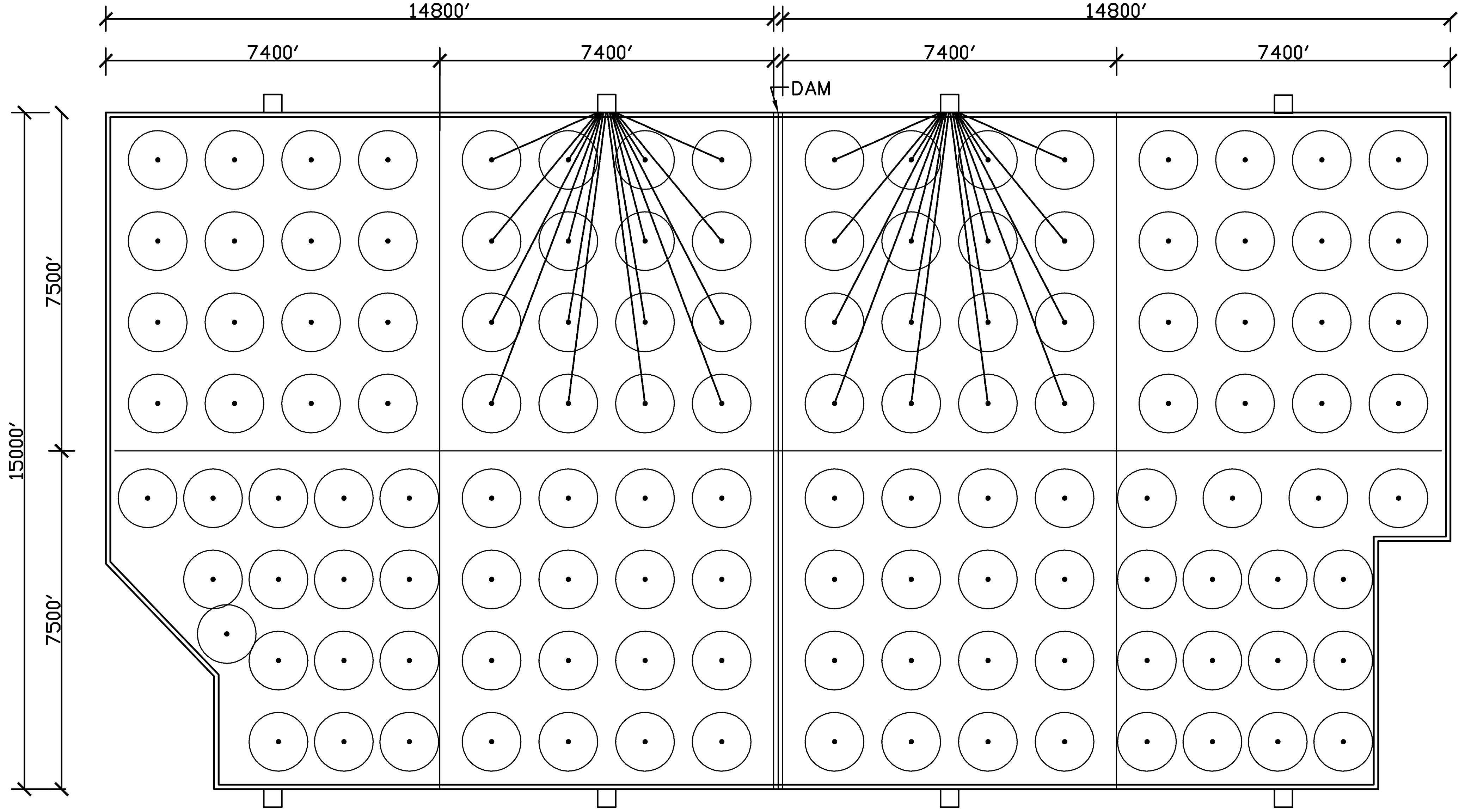
1) If the water level in the C-470 at S-473 is less than 18.5 feet release 100 cfs.
2) If the water level in the C-470 at S-473 is less than 18.3 ft release 200 cfs.
3) If the water level in the C-470 at S-473 is less than 18.0 ft release 300 cfs.

Close the Gate:

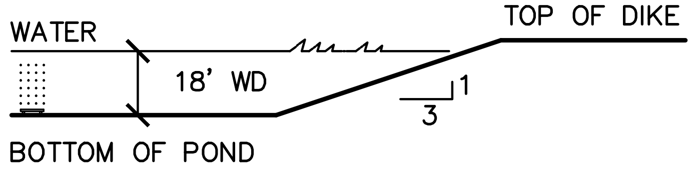
1) When the water level in the C-470 at S-473 reaches 19.0 ft, close the gate.

Appendix E Vendor Responses

Air Diffusion System (ADS)



PHASE 1 AERATION EQUIPMENT	
128	ADS LTC STAINLESS STEEL DISK MODULE WITH LEGS 100' ADS WEIGHTED AERATION TUBE
500,000'	ADS 3/4" REINFORCED SELF SINK FEEDER TUBE
8	30 HP COMPRESSORS WITH VFD EACH TO DELIVER 156 SCFM OF FILTERED OIL FREE AIR AT 100 PSI 460 V; 3-PHASE; 60 HZ ATLAS COPCO GA 22 VSD



SECTION

AERATION PLAN

0 1500' 3000'

SCALE IN FEET

AIR DIFFUSION SYSTEMS

T.847-782-0044 F.847-782-0055 WWW.AIRDIFFUSION.COM

DATE
4-29-2020

ADS SYSTEM # 2019-168

AERATION PLAN
C43 RESERVOIR, FL

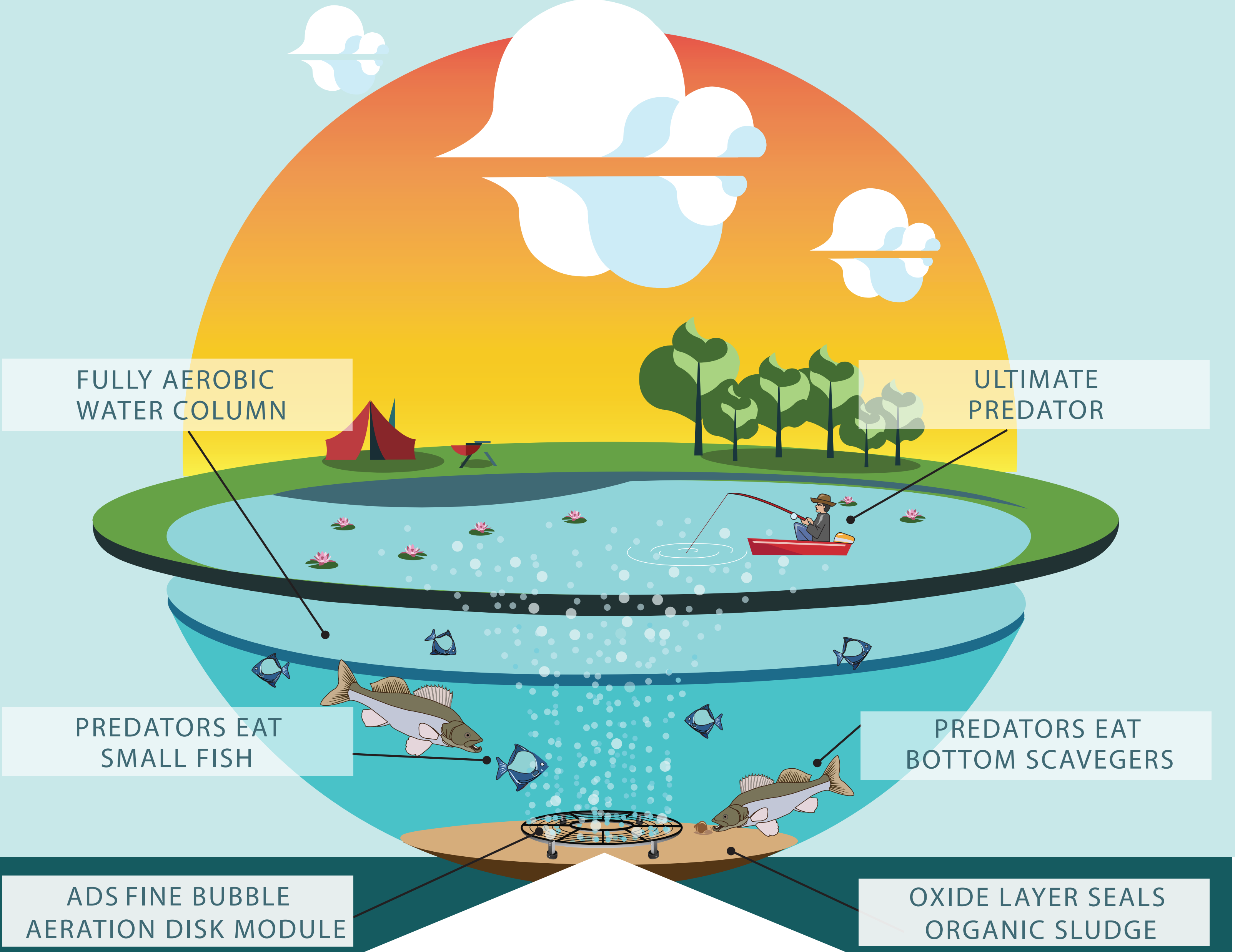
1

AIR DIFFUSION SYSTEMS

AERATED LAKE OR RESERVOIR

FINE BUBBLE AERATION . . . REJUVENATES EUTROPHIC LAKES

fully aerobic watercolumn with high dissolved oxygen



ADS Fine Bubble Aeration

Oxygenates the Water, Inducing Complete Circulation

OXIDIZES

Mineral and Dead Organic Matter in Suspension and in Bottom Sediments

→

ELIMINATES

Undesirable Tastes and Odors from Decaying Organic Matter

CONVERTS

Organic Matter into Useful Food

→

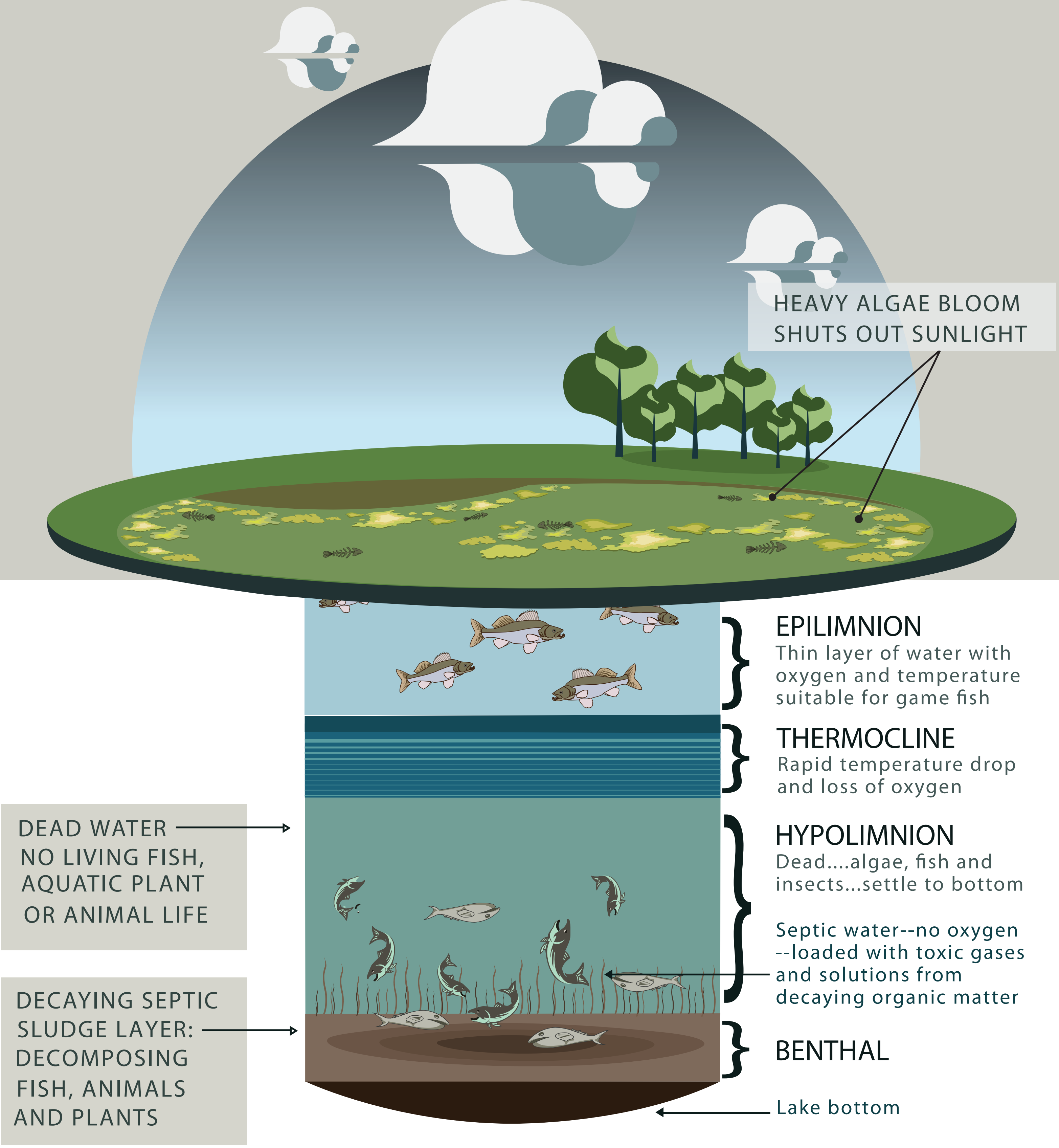
SUPPORTS

the Desirable Mixed Biota of the Lake or Reservoir

AIR DIFFUSION SYSTEMS

EUTOPHIC LAKE / RESERVOIR

STRATIFIED WATER COLUMN WITH LOW DISSOLVED OXYGEN



HEAVY ALGAE BLOOM
SHUTS OUT SUNLIGHT

EPILIMNION
Thin layer of water with oxygen and temperature suitable for game fish

THERMOCLINE
Rapid temperature drop and loss of oxygen

HYPOLIMNION
Dead....algae, fish and insects...settle to bottom

Septic water--no oxygen --loaded with toxic gases and solutions from decaying organic matter

BENTHAL

Lake bottom

DEAD WATER
NO LIVING FISH,
AQUATIC PLANT
OR ANIMAL LIFE

DECAYING SEPTIC
SLUDGE LAYER:
DECOMPOSING
FISH, ANIMALS
AND PLANTS

Air Diffusion Systems

Fine Bubble Aeration For Water & Wastewater Treatment
3964 Grove Avenue, Gurnee, Illinois 60031 USA
Phone: (847) 782-0044 Fax: (847) 782-0055 Email: info@airdiffusion.com

Mauna Lani Hawaii Resort Lagoon Wastewater Treatment Report

Overview

Air Diffusion Systems set up the following treatment at Mauna Lani lagoon with a 30-day program of Sludge and TSS reducing bacteria. This lagoon is 40 years old and has lost treatment ability to reduce total suspended solids (TSS) in their effluent water.

Challenge

- High TSS in effluent
- Heavy surface growth and floating sludge

Method

Dosing of SRB (Sludge reducing bacteria) was applied followed by an ongoing dose along with installation of Air Diffusion fine bubble aeration. Bacteria were dosed at 1ppm of influent water.

Image 1: Before Treatment of Sludge Reducing Bacteria and Air Diffusion aeration.

Results

Testimonial from site manager: "Note the effluent went from a dark green (very High TSS) to the current state…Single digit to low double digit TSS and improving…"

Effluent Quality (TSS)	
Before	Dark Green Very High TSS
After	Single Digit low TSS

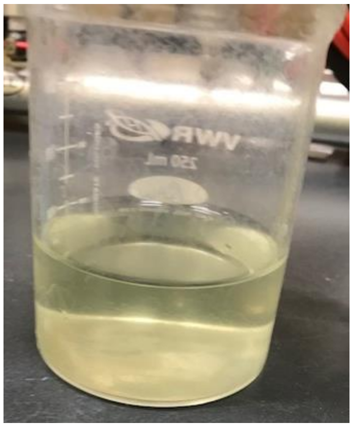


Image 2: Effluent water sample after treatment

Image 3: After one month of treatment with Sludge Reducing Bacteria and Air Diffusion aeration.

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AIR DIFFUSION SYSTEMS:

Lagoon Sludge Removal with Sludge Reducing Bacteria

Abstract:

A large pulp and paper mill in the upper Midwest was experiencing accumulation of solids in a wastewater treatment lagoon following their aeration basin and secondary clarifier. Core sampling was used to measure changes in sludge before and after the lagoon was dosed with Sludge Reducing Bacteria (SRB). Results included reduced sludge volume and increased hydraulic space.

Background:

The buildup of sludge was leading to hydraulic short-circuiting and loss of treatment capacity in the lagoon. The cause of excessive solids loading in the lagoon was due to unsettled solids and high BOD in the secondary clarifier effluent, as well as poor facultative digestion within the lagoon. A survey conducted in 2013, by a third party indicated that the entirety of the lagoon is 238 million gallons at 8’8” deep and 43.5% filled with sludge. Surveying and samples taken by MDG on Oct 7th, 2015 illustrated that solids loading in SSE portions of the lagoon were the most dramatic.

A recommendation in fall of 2015 was made to use bioaugmentation product, SRB, to enhance biological digestion of accumulated solids in the lagoon. In June of 2016, the SSE portion of the lagoon was treated with SRB in an effort to remove accumulated organic solids. The objective of treatment was to demonstrate with quantifiable results, the digestion of accumulated solids after addition of SRB in a portion of the lagoon. Success is measured by increased hydraulic space (depth to sludge blanket) and removal of solids in the portion of the lagoon treated and monitored after 90 days.

Methods:

Vertical core samples of the strata in the top 3' of the lagoon (surface elevation 698.5') were taken from designated location numbers 1, 2, 3 & 4 within the treated area (Figure 1). Surface area of treated section is approximately 384,250 ft2 (725'x530'). Only the top 3' of the lagoon was sampled because greater depths could not be consistently reached due to sludge density. The volume of the 3' strata of the lagoon monitored within the treated area is approximately 42,700 cubic yards. Core samples were taken prior to treatment with SRB and then again 90 days after to determine changes in sludge. Data recorded from core sampling included depth to sludge blanket (inches), total solids (mg/l) and % volatile solids.

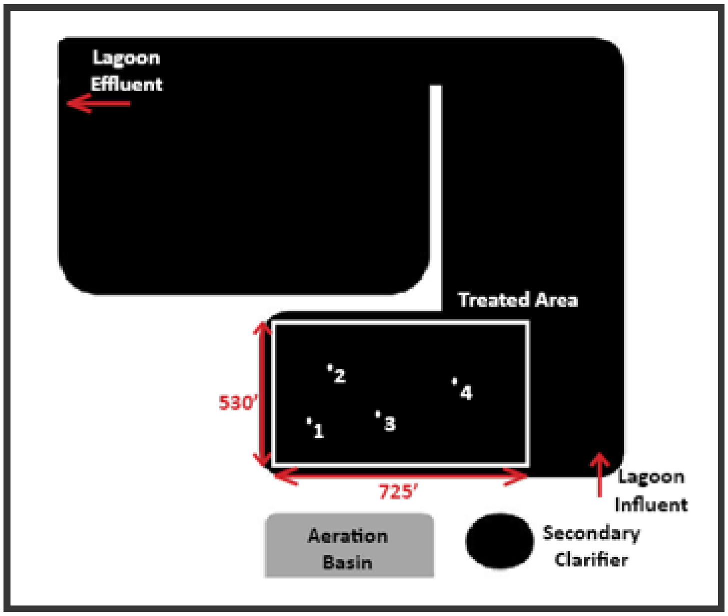


Figure 1: Map of lagoon with sampling locations marked

Product Application Procedure:

SRB was applied to treat the SSE portion of the lagoon directly north of activated sludge basin and west of the influent area (Figure 1) on June 20th, 2016. This section was chosen for its high sludge build-up and because it is a smaller, somewhat hydraulically short circuited from the rest of lagoon. The lagoon in this section was recorded to be approximately 9' deep; however solids were coming very near the surface. To dose this section, 22.5 kg of SRB was diluted with water in a 55-gallon drum, mixed with an electric mixer, and allowed to rest for one hour. After resting period, solution was re-mixed and the entire solution was poured into the lagoon by pails along the west bank of the treated section.

Core Sampling Procedure:

Prior to the collection of the baseline samples, the lagoon depth was determined by recording the level at the point of discharge. A 1.5" clear, graduated, PVC sampler, equipped with a 1.5" ball valve on the bottom, was used for taking core samples. At each sampling location, the sampler was slowly lowered into the lagoon until it reached a level of 3' below the lagoon surface (elev. 698.5). The ball valve was then closed and the sampler removed from the lagoon. The core sample was released from the sampler into a 5-gallon bucket by opening the ball valve. Once the sample was collected in the bucket it was mixed via gentle swirling. A subsample of the mixture (~500 ml) was collected into a labeled plastic sample bottle and sent off to a third-party laboratory for analysis of total solids (mg/l) and % volatile solids.

The core sampling process was repeated 90 days after treatment. Due to the lagoon level being approximately 0.5' higher than it was for baseline sampling, the sampler was slowly lowered to a depth of 3.5' below the surface before the ball valve was closed. The sampler was removed from the lagoon and placed into a 5-gallon bucket. The ball valve was slowly opened and only the bottom 3' of the core sample was allowed to release into the bucket by closing the ball valve with the last 0.5' of liquid inside the sampler. The sampler was then removed from the bucket and the remaining contents emptied back into the lagoon. Mixing, testing and subsampling of core sample was then conducted following the same procedure as before.

Results:

By every measure, sludge was reduced in the treated section 90 days after application of SRB. The sludge blanket was lower, the amount of solids in the sludge blanket was reduced and the amount of organic content in the sludge was reduced. The sludge blanket within the strata lowered 8.4". This drop in sludge blanket equates to freeing up ~9,900 cubic yards of hydraulic space (Figure 2). The concentration of solids within the monitored strata reduced 89% after treatment. This equates to ~1290 dry tons of solids being removed from the measured strata alone (Figure 4 & Table 1). Of the 1290 dry tons of solids removed from the measured strata, 557 tons were volatile (organic) and 733 tons were inorganic (Table 1). Ninety (90) days after treatment the content of the sludge in the strata also changed. Prior to treatment, 43% of the sludge was volatile (organic), 90 days after treatment the volatile portion of the remaining sludge reduced to 41%.

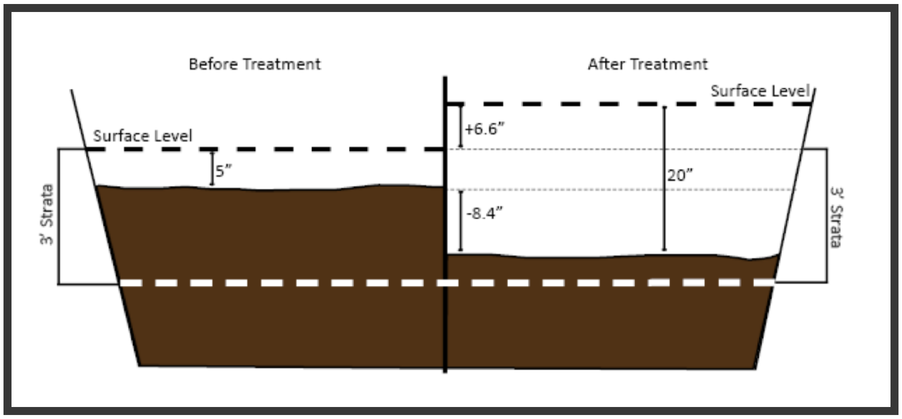
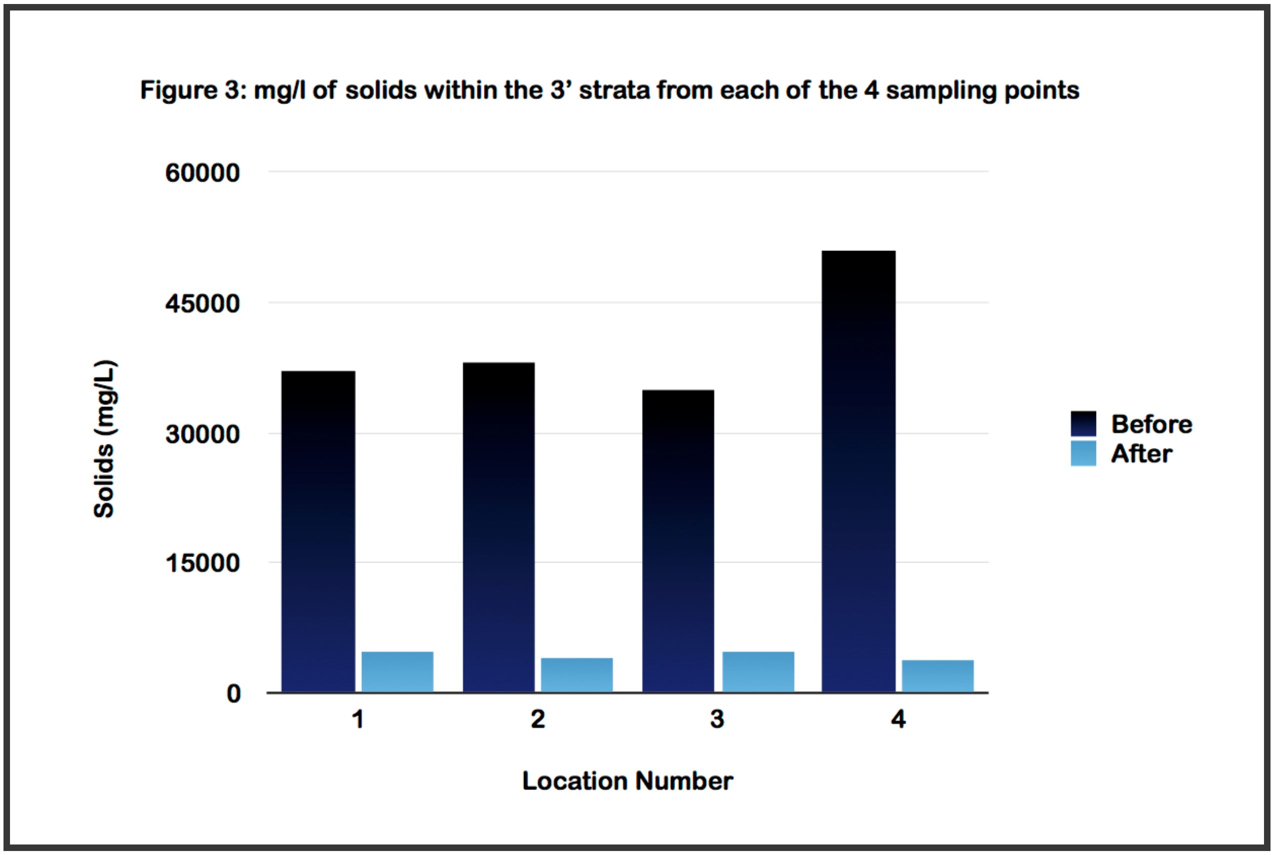


Figure 2: Depth to sludge blanket from 698.5' elevation before and after treatment

Figures 3 and 4:



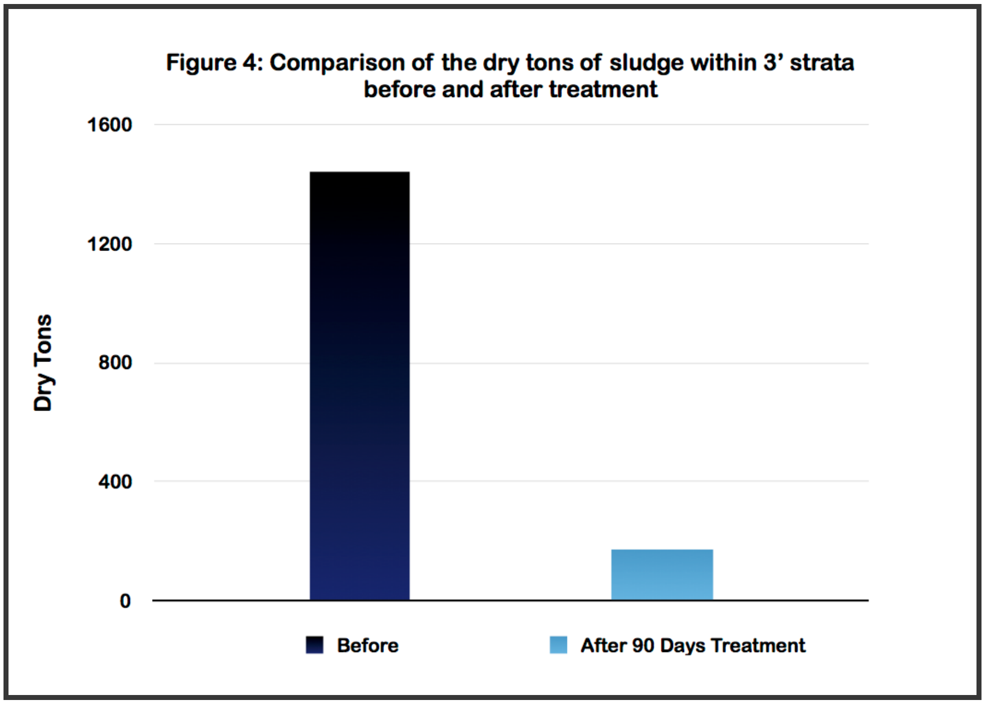


Table 1: Dry tons of sludge in measured strata by content

	Before	After	Removed
Organic	623	66	557
Inorganic	827	94	733
TOTAL	**1450**	**160**	**1290**

Conclusion:

Treatment of the lagoon with SRB was a success as there was a quantifiable increase in hydraulic capacity accompanied by significant solids removal within 90 days of a single treatment. It is important to understand that only the organic portion (volatile) of the solids is capable of being digested by the bacteria in SRB. The decrease in the percent volatile solids of the sludge remaining in the measured strata supports that the mode of action for solids removal was biological digestion. Of the 1290 dry tons of solids removed from the monitored strata, 557 were organic and likely digested by the bacteria. The 733 dry tons of inorganic sludge that was removed from the strata likely precipitated to lower depths as the organic sludge around it was digested. This precipitation of inorganic solids out of the 3' strata measured is also an indication that organic content below the measured strata was digested which allowed room for the inorganic portion to precipitate. This is further supported by the anecdotal evidence that during the second core sampling it was much easier to reach deeper depths of the lagoon.

It seems unlikely that the effects of the product were confined to the area of the lagoon monitored. Sludge that existed adjacent to the treated area and at depths lower than those measured were likely affected by the treatment and simply not captured by our data. Therefore, it is reasonable to assume that the estimation of 557 dry tons of sludge removed from the lagoon is conservative.

Even at the conservative estimate of 557 dry tons of solids being removed, the customer received a return on investment in excess of 6:1 in comparison to their alternative of dredging the solids from the lagoon. Moving forward the paper mill chose to continue with treatments in order to further improve hydraulic capacity and reduce accumulated solids. Now that sludge has been removed, solids sampling can happen at greater depths for monitor solids reduction and success of SRB throughout ongoing treatment.

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AIR DIFFUSION SYSTEMS:

Sludge Reducing Bacteria [SRB] Reduces Odors and Sludge Volume in Industrial Lagoon

Summary:

An industrial wastewater treatment plant dosed with Sludge Reducing Bacteria (SRB) showed a significant reduction in odors and sludge volume over the course of a 12 month study. Sludge volume was reduced by 52% in the first 90 days and 84% by the end of 12 months. Working volume of the lagoon increased allowing for increased organic decomposition and a reduction in odors. This reduction in odors was especially noticeable during the semi-annual lagoon turnover.

Background:

The industrial wastewater plant, located in the Midwest, was experiencing reoccurring odor complaints from the community. The wastewater system consisted of two facultative lagoons composed of a primary (6 million gallons) and secondary cell (4 million gallons). The facultative lagoons were less than two (2) years old and had a daily BOD loading rate of 3400 lbs/day.

Objective:

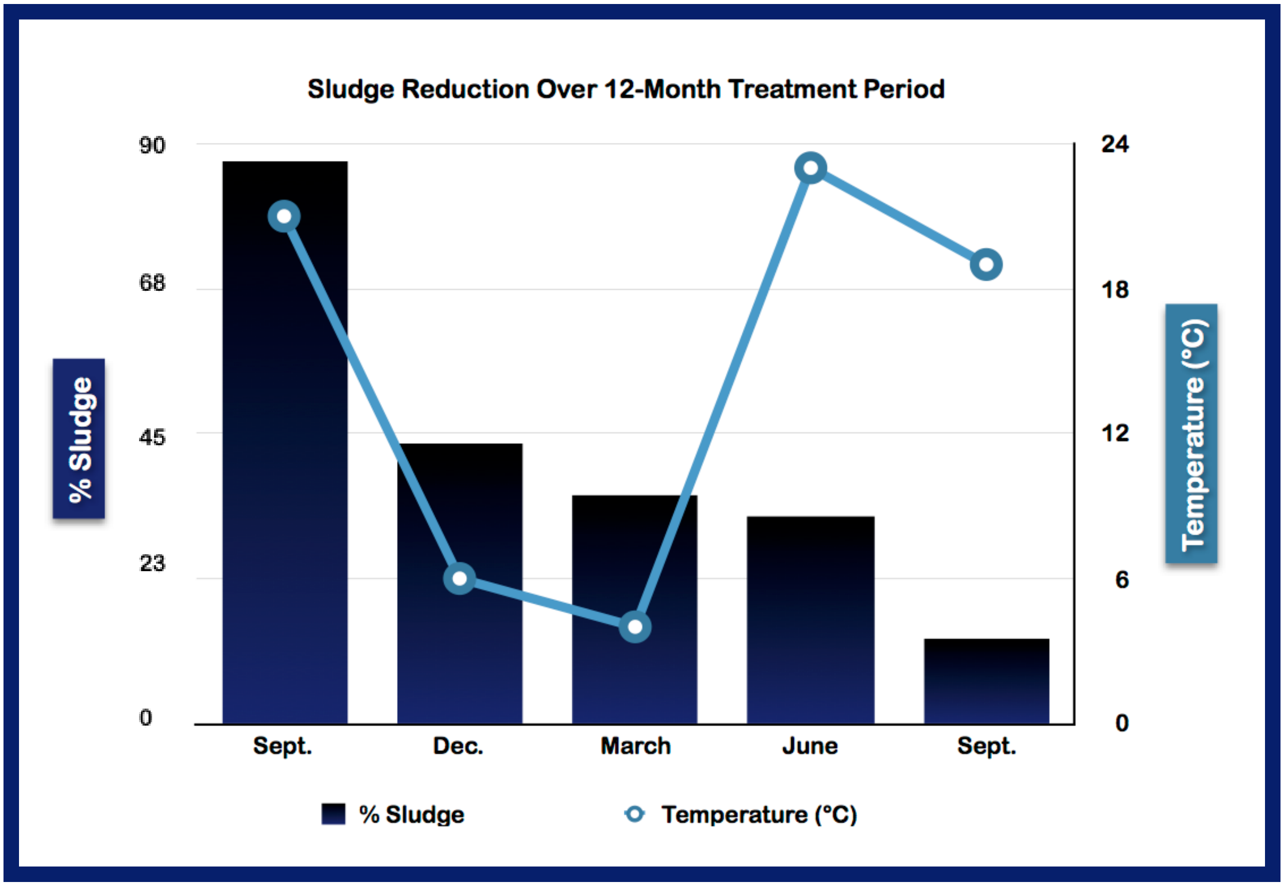
The case study objective was to reduce the odors being emitted from the lagoon, reduce the sludge volume and regain lagoon working capacity.

Materials and Methods:

Baseline sampling was conducted in the primary cell with a sludge judge sampling device. Total depth of the primary cell was 180 inches (15 feet) and primary cell working volume did not vary more than ± 6 inches during the 12-month study. To better understand the true effect of treatment and the cause of odors, only the bottom 60 inches (5 feet) of the primary cell was sampled during each sampling. Sampling of the primary cell was conducted every 60 to 90 days for a period of 12 months. Water temperatures were taken during each sampling and samples were sent out to a 3rd party lab for analysis. Treatments were based on primary cell volume with the initial treatment of SRB at 5.0 ppm followed by a monthly dose at 0.5 ppm.

Results:

Baseline sampling of the primary cell indicated that the bottom sludge level was 7.75% in total sludge with water temperatures at 21°C. During the first 90 days, a 52% reduction in sludge was observed along with a drop in water temperature of 15°C (21°C - 6°C). Sludge reduction continued to decrease, although at a slower pace during the winter months. After 12 months of treatment, bottom sludge was reduced by 84% and odors were reduced significantly. (See chart below)



PHONE	FAX	EMAIL
(847) 782-0044	(847) 782-0055	info@airdiffusion.com

Sludge Reducing Bacteria (SRB)

Product Specifications

Microbiological Specifications
- Total count available - 4 Billion CFU/g of active *Bacillus*
- Coliforms < 10 CFU/g
- Salmonella negative/25g

Physical Properties
- Color: Tan
- Form: Powder

Carrier Options
Water soluble packets in bran form

Concentration
4 Billion CFU/g

Storage & Handling
Dry and cool (36-77°F/2-25°C)
**Note: Keep container closed tightly when not in use*

Shelf Life
Two years when stored as recommended

Packaging
- Dried powder on bran carrier

Industrial Applications

- Pulp/Paper
- Beverage
- Food Ingredient
- Meat
- Dairy
- Petroleum
- Pharmaceutical

Key Features

- Six (6) strain *Bacillus* blend providing a broad range of activity and enzyme production across a broad range of environmental conditions.
- Enhances the effectiveness of most biological waste treatment systems used to treat organic material
- Effective growth and treatment across broad pH and
- temperature ranges
- Facultative organisms - works in both aerobic and anaerobic
- environments
- All natural, non-toxic, and non-GMO
- Stable - two year shelf life

Key Benefits

Improves Operations:

- Improves facility stability and upset recovery
- Reduces COD/BOD levels
- Reduces sludge yield and accumulation
- Reduces foaming
- Improves facility treatment capacity
- Improves floc formation and settling characteristics
- Reduces odor generation
- Improves FOG removal
- Improves nutrient removal

Decreases Costs:

- Reduces energy cost
- Reduces chemical costs
- Reduces sludge handling and removal costs

Application Guidelines

Usage Rates
Apply 0.5 - 5.0 mg/l (ppm) depending on level of site optimization, load and flow characteristics and other facility treatment needs.

Optimization Considerations

	Range	Optimum
pH Range	4.5-9.0	6.0-8.0
Temperature	45-120°F (7-49°C)	59-104°F (15-40°C)

**Note: Avoid use with bleach.*

Mixing Directions
For optimal performance and ease of distribution, dissolve (or pour) 1 packet of SRB into a 3 - 5 gallon pail filled with dechlorinated water. Allow the solution to rest for a **minimum of 30 minutes**, but **no longer than eight hours** before application. Once rehydrated, apply directly to wastewater using a cup or pump sprayer. If situation does not allow for rehydration and activation, the product can be applied directly to wastewater. Puncturing the dissolvable bag with several small holes is recommended when tossing packets directly into wastewater.

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john@airdiffusion.com www.airdiffusion.com

SUBJECT: Lake and Reservoir Destratification and Oxygenation, for systems approximately 100,000,000 gallons and over, utilizing the "ADS" Fine Bubble Controlled Aeration System.

Stratification, by definition, is a layering of water based on temperature-induced density differences with accompanying chemical variations. This is a natural occurrence every summer and winter. Since water is at maximum density at 4° C, the winter stratification is in reverse order of summer with the warmest water on the bottom. Maximum stratification may be considered maximum stability.

A stratification impoundment is divided into three basis layers or zones: the epilimnion, thermocline and hypolimnion from top to bottom. The epilimnion is that layer which is penetrated by sunlight. The result is increased temperature, photosynthesis, and thus animal life requiring oxygen can live only in this zone. The thermocline is that layer of rapid temperature difference, usually defined as at least 1° C difference per vertical meter. The hypolimnion is the cold anaerobic zone in a state of equilibrium with the benthic layer floor in the reservoir.

The effects of stratification on impoundment water quality are many. Some of the more important ones are directly affecting man's use of water. One of the most important, depending on whether the reservoir is recreation oriented or a potable water supply, is the increased biological activity. In the epilimnion, where sunlight penetrates and temperatures reach 90° F, plankton grows rapidly, phytoplankton produces oxygen. The "Q-10" effect may also be applied to the biologic reaction as algae reproduction double with 10° C increase in temperature. On a hot summer day, a thousand of pounds of carbon are assimilated by algae and oxygen content nears supersaturation.

Since most aquatic animals are cold-blooded, their metabolism increases at the same rate. In the presence of sunlight algae produces more oxygen than they consume, thus the saturation. However, at night algal cells must utilize oxygen to reduce the storage products metabolized during the day.

This fantastic oxygen demand coupled with the nearly constant demand by animals can cause an **oxygen depletion** resulting in what is commonly referred to as a **summer fish kill.**

The oxygen imbalance does not end here. The dead algae and aquatic animals fall to the reservoir floor. The hypolimnion is already oxygen depleted and this additional loading creates a septic condition. Without oxygen anaerobic organisms of decay attempt to decompose these once living organisms. However, the hypolimnion may be less that 5° C in midsummer and biologic activity is reduced to almost a standstill. That metabolism, which is taking place evolves by-products such as H_2S, CH_4, NH_4, and organic acids. Slowly at first, then more rapidly, the size of the hypolimnion increase while the epilimnion decreases due to increase turbidity reducing the light penetration. This state then exists until fall.

As temperatures decline the epilimnion sinks while the hypolimnion rises. This natural phenomenon is called **"over-turn" or "turnover."** Now the oxygen depletion would be replenished, however, several other factors must be considered. As the epilimnion sinks much of its oxygen is diffused before it reaches the bottom. Also with man's activity compounding nature, chemical stratification has occurred so that the entire hypolimnion does not rise. The net effect is oxygen depletion throughout the water volume. Some sunlight penetrated the ices and algae produce oxygen. However, depending on the size of the hypolimnion, the epilimnion is relatively shallow. If snow cover blocks the remaining light, oxygen production ceases, and the result is a **winter fish kill.**

While I have simplified this to a very great extent, the important aspect is the oxygen cycle and its balance. Many other elements are also cyclic and their balance also plays a part in impoundment stratification. Man's influences on an impoundment are equally important. Eutrophication or fertilization is a natural process greatly accelerated by man's activities. Additional nutrients added to a body of water increases the carrying capacity of an impoundment, but eventually lead to an even greater oxygen demand. If left alone, nature would eventually fill in a reservoir with solid earth and organic material. Nature transforms mountains and depressions and spends her time eroding the former and filling the latter.

The solution to retarding Eutrophication is restoring the natural balance. Since **oxygen** is of primary importance, this should be considered first.

Obviously external nutrient sources from sewage, agriculture and natural runoff should be controlled as well as industrial toxic compounds and minerals. How then can oxygen be added to a body of water? There are two general ways:

1. Physically add a predetermined volume of liquid oxygen or a calculated volume of gaseous pure oxygen, considering solubility etc.
2. **Physical mixing the water volume so that the bottom oxygen depleted water is exposed to surface reaeration and photo synthetic activity.**

These two methods have been extensively studied by several researchers, notably Dr. James M. Symons of the U.S. Department of Health, Education and Welfare. His conclusions as well as most others confer that **mixing** is far more economical and practical compared to pure oxygen diffusion.

Fluid Turnover Rate = Pumping (MGD) / Volume (MG)

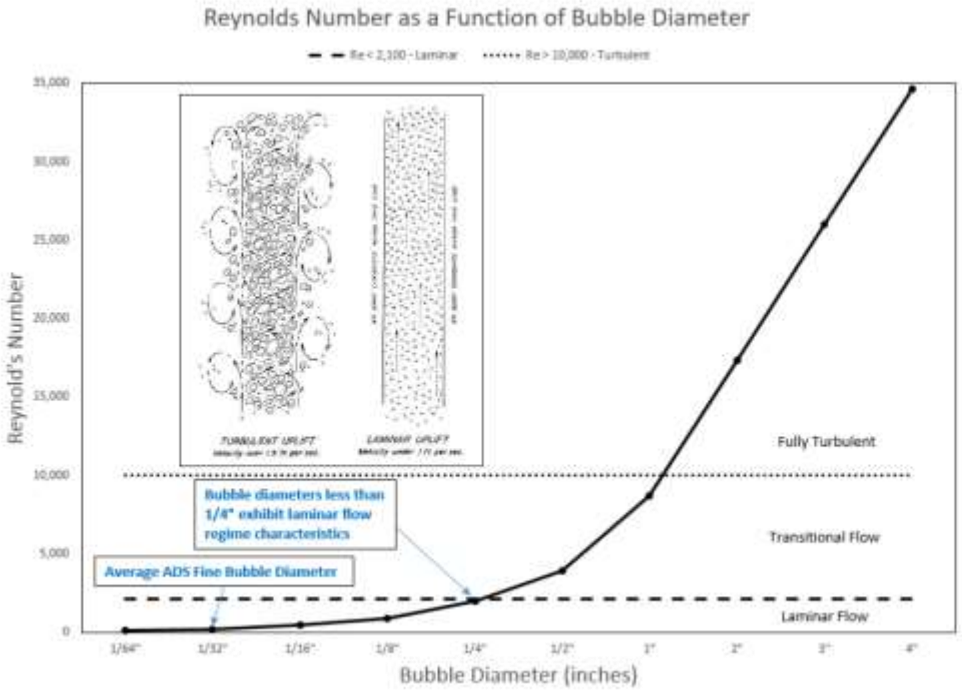
Each LTC Aeration Disk Module can pump 25.8 MGD in 15’ or deeper water. As water depth increases, pumping rates will also increase. For example at 24’ diffuser depth, the estimated pumping will be = 24’/ 15’ (25.8 MGD) = 41.28 MGD.
A 200 MG reservoir with 5 LTC diffusers installed at 29’ deep will mix the equivalent volume as follows:

5 x 41.28 MGD / 200 MG = 1.03 times per day or once a day

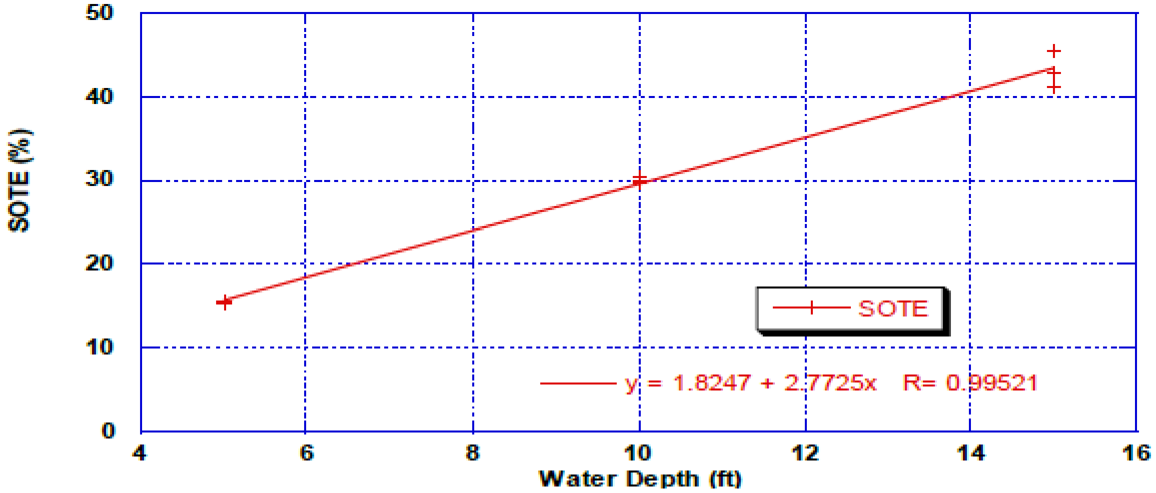
A laminar bubble uplift is accomplished using a predetermined volume of air distributed through precise orifices in the diffusers. The upward velocity of this bubble has been measured at 0.8 foot per second. This unconfined bubble plume column of water may approach a width of 50’ to 100’ at the surface. While the velocity varies across the bubble column diameter, the net overall average rise is approximately 0.8 feet per second. Laminar flow is considered less than one foot per second.

The pumping is accomplished in two ways; the physical cohesion of water to bubbles, and secondly, thru establishing density currents. Both are dependent on two very important aspects. This low velocity, non-turbulent laminar flow reduces slippage of the bubble through the liquid. A turbulent “point-source” diffuser will impair distribution thru what the Federal EPA refers to as the “coning effect.”

The tiny bubble size (less than 1/8" diameter) allows greater surface area per unit volume. The net effect is greater cohesion with less slippage due to friction resulting in a rising curtain of water the length of the aeration tubing.



"ADS" LTC Diffusers also pumps water through density currents. The same factors of low velocity and small bubble size which allows excellent physical pumping also to insure excellent oxygen transfer efficiency. "ASCE" OXYGEN TESTING certifies that under clean water laboratory conditions, "ADS" diffusers have 45% oxygen transfer efficiency in a fifteen-foot water depth.



This oxygen transfer capability aids mixing and destratification. The bottom water void of oxygen readily accepts it from the bubble. The water now is less dense than the water surrounding it and begins to rise. While its vertical ascent may be only an inch, subsequent bubble contact brings the water to the surface.

Each LTC Aeration Diffuser will produce One Billion Bubbles per Day

THERE ARE ONE BILLION BUBBLES
RELEASED PER DAY FROM EACH
AIR DIFFUSION DISK MODULE

EACH "LTC" DISK HAS 2,400 ORIFICES

EACH ORIFICE RELEASES 5
MICROBUBBLES
PER SECOND

THERE ARE 86,400 SECONDS PER DAY

2,400 X 5 X 86,400 =

1,036,800,000 BUBBLES PER DAY

Each LTC diffuser only requires approximately 2 horsepower (depending upon depth). The basis of design of an "ADS" lake & reservoir destratification system considers several factors, including:

1. Volume
2. Depth
3. Surface area
4. Contours (basin geometry)
5. Turnover rates
6. Chemical analysis
7. Sludge Depths
8. Detention Time
9. Inflow and Outfall

We have found through over 40 years of experience that a turnover rate of one to five days is required to maintain good water quality. If the reservoir is used as a potable water supply, the higher turnover is used. If the reservoir is recreation oriented, then less time to complete a turnover is required. These figures will also vary according to how much pollution, IE, a highly polluted multiple use reservoir may be designed to mix the water several times per day.

Very large reservoirs can have retention time of over 100 days. In other words the daily outflow is less than 1% of the impoundment volume. At fifteen days per turnover, the equivalent volume is mixed almost seven times in that 100-day retention period. Should a reservoir have only half that volume but the same outflow rate, the turnover rate would have to be adjusted accordingly to compensate for the lesser detention time. On the other hand, an extremely large body of water poses some economical considerations. Here, the equipment can be concentrated to achieve a treatment zone or aeration field through which the volume of the reservoir must pass.

These are extreme cases however, so let us consider a typical design.
GIVEN DATA:
Volume = 12 Billion Gallons
Maximum Diffuser Depth = 40 Feet
Surface Acreage = 250 Acres
Potable Water Supply = Yes
No known pollution discharge into the reservoir (low nutrient addition)

DESIGN:

1. 12 Billion Gallon turnover rate = every 15 days
   Daily Aeration Pumping Rate per LTC Diffuser = 68.8 MGD
   ADS Pumping Rate for 12 Diffusers = 825.6 MGD
   Fluid Turnover Rate = 0.8256 BGD / 12 BG = 14.5 days

2. Air to be applied at 8 cfm/ LTC Diffuser
   ∴ 96 CFM oil-free air required (Estimated HP = 25 HP)

3. Hydrostatic pressure at 40' = 18 pounds
   Select a compressor to overcome hydrostatic pressure plus sufficient pressure to relieve water from the diffusers, should power failure occur; choose a compressor capable of over 30 PSI. Typically, engineers require 100 to 125 PSI compressors.

4. To insure the most efficient oxygen transfer and mixing, the diffusers must be located in the deepest portion of the lake. In this location, the bubbles have the greatest contact time and are delivered to the heaviest water. This dense water will naturally flow by gravity, to the deepest portion. This occurs because it has no oxygen.

5. Connect the diffusers to an oil-less air supply with self-sink reinforced feeder tubing so that the flow of air is to the deep water.

Air Diffusion Systems has *HUNDREDS* of lake installations varying in size from small fish rearing ponds to very large potable water supplies. In our experiences, we have noted many other advantages to a destratification system. Of particular and extreme interest are the beneficial effects of the "ADS" FBA system on the control of algae and the virtual elimination of the noxious blue green forms. The U.S. EPA Northwest Water Laboratory has studies "ADS" lake aeration systems effect on algae. The blue-green forms were significantly reduced, while the green forms were controlled without the massive blooms which usually occur.

"ADS" FBA systems, by restoring aerobic conditions in the hypolimnion, precipitate iron and manganese which are always a problem in water treatment plants. These are straight forward chemical oxidation equations. H_2S and other by-products of anaerobic bacteria are also eliminated, so taste and odor problems no longer occur every spring and fall due to natural "overturn". A destratification system maintains the reservoir in a state of continuous overturn, but the associated nuisance conditions are eliminated.

By restoring aerobic conditions, the odorless aerobic bacteria decompose aquatic animal and vegetable material. Since the bottom temperature is significantly elevated, metabolic activity increases. Organic sludge reductions have been noted at a rate of one foot per year, on the average.

Another aspect of the destratification system is the cooling of the surface temperature. In addition to slowing the reproductive activity of algae, a 2° C lowering of surface temperature will reduce the evaporation rates significantly enough to save billions of gallons of water in arid and semi-arid regions annually.

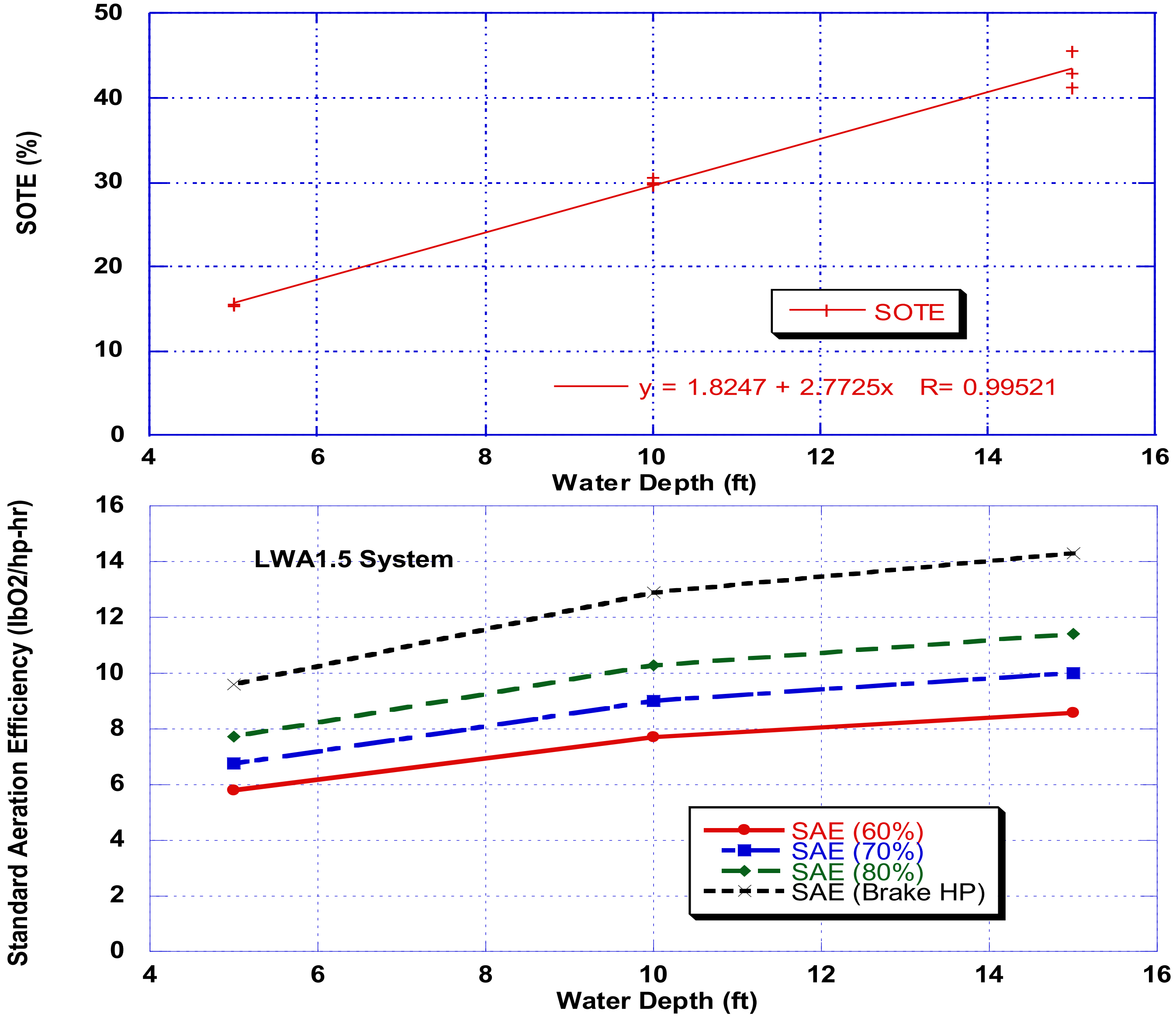
In conclusion, two points merit consideration. "ADS" only incorporates fine bubble aeration equipment with precise "die-cut" air releases. Other types of aeration equipment have failed for two important reasons. These systems have primarily "hole-type" orifices and therefore allow solids to enter when the system is off. Secondly, these systems rely on turbulence which necessitates high energy output. This turbulence can do more harm than good because they bring up sediment and organic matter from the bottom resulting in a high turbidity. They also influence only a small volume so that the anaerobic water is mixed so rapidly that the dilution may cause extensive oxygen depletion resulting in fish kill.

The "ADS" Fine Bubble Aeration System is a practical, economical solution to one of our greatest ecological problems, the deterioration of our water resources. The absolute solution relies on sustainable and natural treatment wherever possible.

Air Diffusion Systems

Fine Bubble Aeration For Water & Wastewater Treatment
3964 Grove Avenue, Gurnee, Illinois 60031 USA
Phone: (847) 782-0044 Fax: (847) 782-0055 Email: info@airdiffusion.com

Air Diffusion Systems “ASCE” Clean Water Testing using 98% DO saturation for LWA-1.5 weighted fine bubble tubing



Independent Testing Preformed By Dr. Michael Stenstrom (Former Federal EPA Oxygen Chairman). All Testing Preformed In Accordance With ASCE (American Society of Civil Engineers) Standards.

Air Diffusion Systems Wire-Drawn Horsepower at different motor efficiencies for LWA-1.5 weighted fine bubble aeration

Table 1. Summary of Test Results

Test	Water Depth (ft)	Diffuser Slits	Air Flow (SCFM)	K_LA (hr^{-1})	C^*_∞ (mg/L)	SOTE (%)	SOTR (lb/hr)	de (ft)	SAE (60%)	SAE (70%)	SAE (80%)	SAE (Brake HP)
4	15	14	0.0236	2.73	10.61	46.3	0.0113	5.6	9.2	10.8	12.3	15.4
1	15	14	0.0472	5.52	10.67	47.1	0.0230	5.8	9.1	10.6	12.2	15.2
2	15	14	0.0472	5.53	10.67	47.1	0.0230	5.8				
3	15	14	0.0472	5.49	10.79	47.4	0.0232	6.2				
5	15	14	0.0944	6.76	10.75	29.1	0.0285	6.1	5.4	6.3	7.2	9.0
12	10	14	0.0236	2.86	10.04	30.5	0.0075	3.5	7.8	9.2	10.5	13.1
9	10	14	0.0472	4.35	10.08	23.3	0.0114	3.6	5.7	6.7	7.6	9.5
10	10	14	0.0472	4.34	10.06	23.2	0.0114	3.5				
11	10	14	0.0472	4.27	10.06	22.9	0.0112	3.6				
13	10	14	0.0944	6.33	10.13	17.1	0.0167	3.8	4.0	4.7	5.3	6.7
23	5	14	0.0236	3.38	9.560	17.6	0.0043	1.7	6.6	7.7	8.8	11.0
20	5	14	0.0472	5.27	9.489	13.3	0.0065	1.5	4.6	5.4	6.2	7.7
21	5	14	0.0472	5.24	9.473	13.2	0.0065	1.4				
22	5	14	0.0472	5.08	9.526	12.9	0.0063	1.6				
24	5	14	0.0944	7.45	9.525	9.7	0.0095	1.6	3.2	3.7	4.2	5.3
6	15	6	0.02025	2.01	10.94	41.1	0.0086	6.8	8.6	10.0	11.4	14.3
7	15	6	0.02025	2.23	10.93	45.5	0.0095	6.7				
8	15	6	0.02025	2.11	10.90	42.9	0.0090	6.6				
14	10	6	0.02025	2.42	10.18	30.6	0.0064	4.0	7.7	9.0	10.3	12.9
15	10	6	0.02025	2.35	10.16	29.6	0.0062	3.9				
16	10	6	0.02025	2.37	10.17	29.9	0.0063	3.9				
17	5	6	0.02025	2.64	9.504	15.6	0.0033	1.5	5.8	6.8	7.7	9.6
18	5	6	0.02025	2.61	9.507	15.4	0.0032	1.5				
19	5	6	0.02025	2.61	9.463	15.4	0.0032	1.4				

All data was independently analyzed using American Society of Civil Engineers (ASCE) recommended procedures. In fact, the example "Visual Basic/Excel program" referenced in the "ASCE" oxygen transfer testing standards is the same program used for evaluating ADS fine bubble aeration. This program and additional details are available for download at: http://www.seas.ucla.edu/stenstro/

TEST RESULTS

The graph shows Standard Oxygen Transfer Rates (SOTE, as defined by the ASCE Standard, which is the mass transfer efficiency at standard conditions: 0 mg/L DO, 20^{o}C, tap water, 760 mm Hg, etc.) for LWA1.5 tubing. The efficiency is approximately 3% per foot. The replicate test results at the 5-foot depth are so similar that the 3 symbols appear as a single symbol. At the 15-foot depth, greater variation is observed. The straight line on the graph is a best-fit, least squares regression of the test results. It is provided for convenience in scaling for different depths.

Technology Information Request Outline
C43 Water Quality Feasibility Study
April 14 2020

I. Treatment Process

This email is a request for additional information on performance and cost of an Air Diffusion System for treating water from the C-43 West Basin Storage Reservoir (WBSR). Our project has led us to a final subset of ten (10) potentially suitable technologies for feasibility evaluation, which includes Air Diffusion Systems as a candidate technology.

The next step of our study includes a cost benefit analysis. To facilitate that comparison, we are asking the vendors to provide additional information. We would greatly appreciate receiving a technical description, performance projection, and cost information (capital, annual operations and maintenance, and 20-year net present value) for a system designed to the following criteria:

- Flow:
  - Average: 457 cfs
  - Range: 300 cfs to 600 cfs
- Inflow:
  - Total Phosphorus
    - Average: 0.16 (± 0.05 mg/L)
  - Total Nitrogen
    - Average: 1.5 mg/L (± 0.5 mg/L)
  - Total Suspended Solids
    - Average: 20 mg/L (± 5.0 mg/L)
- Discharge Treatment Objectives (These objectives are provided only for the purposes of preparing a standard comparison between technologies and are not specified criteria for the C-43 West Basin Storage Reservoir project).
  - Total Phosphorus
    - Average: 0.08 mg/L (± 0.05 mg/L)
    - Concentration Reduction: 50%
  - Total Nitrogen
    - Average: 1.0 mg/L (± 0.5 mg/L)
    - Concentration Reduction: 33%
  - Total Suspended Solids
    - Average: 10 mg/L (± 5.0 mg/L)
    - Concentration Reduction: 50%
  - Water Quality
    - Meets Narrative and Quantitative Class III Criteria

The conceptual technical description cost will need to include the information summarized in the following outline. Please include additional information that may be useful for technology evaluation.

A. Process Flow Diagram See

ADS Revised Plan View Drawing

B. Flow Equalization - (Temporary detention of water volume or reduction in flow rate required to implement the treatment process using storage tanks, basins, or other means).

C. Distribution: by others

D. Pre-Treatment Processes: by others (Perhaps Alum applications to reduce P)

All pretreatment by others; ADS recommends coarse screening to remove large surface debris, such as floating material and non-biological material

E. Treatment

1. Provide information demonstrating prior pilot/project capability to achieve the project water quality criteria

ADS fine bubble aeration has proven results for reservoir treatment.

Air Diffusion Systems' unique fine bubble aeration (FBA) technology is a proven treatment method to reduce and remove soluble and solid wastes in any body of water "The Natural-Way" using energy-efficient, biological, sustainable processes. Using in-series reaction kinetics calculations, and partial plug-flow technology, organic and mineral wastes are converted to clean water and inert ash. The reasons for selecting ADS FBA are based on superior oxygenation and mixing rates with hundreds of successful case studies for over 60 years. HAB's are controlled by laminar mixing and reducing & shifting nutrients away from algae and cyanobacteria towards aquatic life.

For example, based on the following estimated reservoir water depth and volume below:

Dimension	Lagoon 1
L Bottom (ft)	29800
W Bottom (ft)	15000
Lagoon ht (ft.)	19
Freeboard (ft.)	1
Water ht. (ft.)	18
L Top (ft)	29914
W Top (ft)	15114
Slope LI (x/z)	3
Slope L2 (x/z)	3
Slope WI (x/z)	3
Slope W2 (x/z)	3
L @ Water (ft)	29908
W @ Water (ft)	15108
Excavation (cuft)	8,541,595,695
Treatment Volume (gal)	60,510,292,676

ADS can estimate the air supply to reduce 1.5 mg/l Nitrogen ammonia at an average flow rate of 295 MGD (457 cfs) as follows:

The air supply design for nitrogen ammonia is based on 4.6 pounds of oxygen per pound of Nitrogen ammonia applied.

Load of Nitrogen NH3 = 295 MGD x 1.5 mg/l x 8.34 = 3,690 PPD NH3
The estimated oxygen demand = 3,690 PPD NH3 x 4.6# O2 / # NH3 = 16,976 PPD O2

AIR REQUIREMENTS

Cdc Calculations

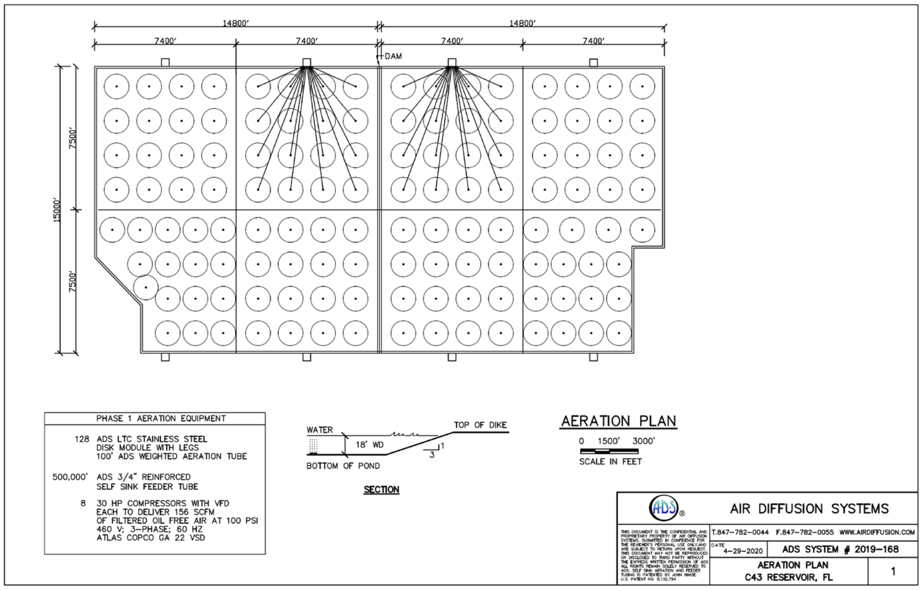
Lagoon I	At Job Site	At Sea Level
Water Depth:	18	18
x:	403.56	403.56
Elevation (ft):	30	Sea level
Pressure (mmHg):	759.968	760
Temp. (C):	20	20
Cs:	9.07	9.07
Cdc (mg/l)	11.48	11.48

AOR Calculations

SOTE	54.00%
O(2) Conc.	0
Temp	20
Alpha	1
Beta	1
Theta	1.024
Cdc @ JS	11.48
Cdc @ SL	11.48
AOR	54.00%

At 18 feet water depth the estimated oxygen transfer rate = 54%
The estimated air supply design = 16,976 PPD O2 / 1440 x 0.075 x 0.232 x 0.54 = 1,254 SCFM air. See ADS Certified Oxygen Test

The estimated compressors required = 8 x 30 HP Atlas Copco GA22VSD each to deliver 158 SCFM at 90 PSI. The air flow rate will be regulated with pressure regulators and variable frequency drives; there are several options to the final air supply design and compressor selection. The revised ADS diffuser layout requires 128 LTC Weighted Aeration Disk Modules each to deliver one billion bubbles per day. Each diffuser will have individual self-sink feeder tubes to connect the compressor to the diffusers Final layout will be dependent on electrical and access point on the reservoir.



The estimated Fluid Turnover Rate at 18 feet WD is as follows:
Each LTC Diffuser will mix 30.96 MGD
128 LTC diffusers x 30.96 MGD = 3.963 Billion gallons per day
Fluid Turnover Rate = Pumping / Volume = 3.963 BGD / 60 BG Volume = 0.066 times per day or about once every 15 days the reservoir will be mixed.

The estimated retention time = 60 BG volume / 0.295 BGD flow = 203 days
Based on long retention time, the fluid turnover rate at 15 days is adequate for reservoir treatment and nitrogen ammonia removal. See Lake & Reservoir Fluid Turnover File

The estimated daily electrical costs for the compressors at $0.10 a KWh are as follows:
8 x 30 HP x 0.746 KW/HP x $0.10KWh x 24HR / 0.95 motor eff = $452 a day

Treatment Beneficial Bacteria: and/or media required for the process will be described

The below system is based on an average flow of 295 MGD (457 cfs) and 0.10 PPM of Beneficial Bacteria applied daily with automated liquid delivery system into the incoming flow and into the reservoir.

The non-pathogenic bacteria has proven success studies in biological reduction in soluble and solid wastes in the presence of highly aerobic water as produced by ADS FBA. Beneficial bacteria will reduce BOD, TSS (green water), NH3, FOG and P by converting the nutrients and the carbon into aquatic life that shifts the food away from algae and cyanobacteria.

The application rate will be at 0.10 PPM of the average daily flow = 295 MGD
The daily dose rate will be approximately 50 gallons per day or 1500 gallons per month.
The 2,000-gallon tank will be filled with 1500 gallons by our local Florida water treatment technician every month and ADS will supply and install the automatic liquid delivery system and take care of all the supplied equipment.
See data safety sheets

A. Pre & Post-Treatment Processes by others
B. Collection by Others
C. Chemical Supply None
II. Residuals Process None
A. Collection or Removal See Above
B. Volume Reduction/Dewatering None
C. Storage ADS to Store Bacteria in prefab shelter
D. Transfer Bacteria delivery by local technician
E. Disposal Process and Location
F. Centrate Management None
III. Land Area (total) Compressor and bacteria building = 2000 sqft

A. Treatment Facility (including process tanks or basins, chemical storage, electrical system, buildings) See land aera

B. Supporting Facilities (Vehicle Access Roads, Fencing, Security, Equipment Garage, Storage, Parking, and Administration) ADS will require access roar, fencing security, and parking

C. Residuals Handling and Solids Storage None

D. Stormwater Management None

IV. Power (annual) the estimated ADS Compressor power = 200 to 300 KW at 460 volts and 60 HZ

A. Process requirements Compressors and Liquid delivery pumps

B. Site requirements 2000 sqft building

C. Monitoring Work Boat and trolling motor required for DO, Temp, ORPO and pH measurements Plus water sample's taken monthly

V. Fuel Consumption (annual) none

A. Chemical Supply, Storage, and Transport None

B. Site Vehicle Operation none

C. Residuals Transport and Disposal None

VI. Other Beneficial Attributes ADS is a natural biological energy-efficient and sustainable treatment system

A. Additional Vendor Provided Information Yes Atlas Copco and Microbial Discovery Group

VII. Capital Cost (2020 Dollars)

The budget pricing for all the ADS modifications as outlined above will be $6,756,000 for 128 ADS FBA aeration modules 8 x 30 HP compressors / VFD's & shelters, 500,000 feet of reinforced self-sink tubing, SS manifolds, 20,000 gallons of beneficial bacteria and storage tank, installation supervision and work boats and all freight to site, plus 5-Year warranty on ADS aeration system with full service included.

All pricing based on 2020 delivery. Additional details available upon request.

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& Owner Gurnee, IL 60031 john@airdiffusion.com

Aquafiber

AquaFiber Technologies Corporation
and
Anuvia Plant Nutrients

Response to C-43 Working Group Request for Additional Information on Performance and Cost

April 30, 2020

Technology Information Request Outline
C43 Water Quality Feasibility Study
April 14 2020

I. Treatment Process

A. Process Flow Diagram

For the purposes of this exercise, it is assumed that the water to be treated will be delivered via point source from the C-43 Reservoir (Reservoir) 300 days per year. AquaFiber®™ will employ a dissolved air flotation (DAF) system modified in a trade secret way (i.e., AquaLutions®™), spread across a series of basins to achieve a minimum 50% reduction in total phosphorus (TP), 33% reduction in total nitrogen (TN), and 50% reduction in total suspended solids (TSS), at three different influent flow rates (300 cfs, 457 cfs, and 600 cfs). The Reservoir's water will be delivered to a Flow Equalization Basin (FEB) or Algal Reservoir that will then distribute the water to each AquaLutions®™ basin. In each basin, AquaFiber®™ will separate the algal biomass from the water. The nutrient-rich biomass will be dewatered and taken offsite for beneficial reuse while the "clean" water returns in real time to the downstream system. A preliminary Conceptual Plan is included as **Attachment A**.

B. Flow Equalization - (Temporary detention of water volume or reduction in flow rate required to implement the treatment process using storage tanks, basins, or other means).

A 50-acre FEB or Algal Reservoir as shown on the Conceptual Plan will be used to moderate the flow to and provide head for the treatment basins.

C. Distribution

The water will be processed across a series of up to 20 basins, depending on the influent flow volume and quality. Each basin will be capable of flowing approximately 30 cfs (~20 MGD) for a maximum system capacity of up to 600 cfs (~400 MGD). The influent flow rate necessary to produce the desired effluent concentration will determine the number of basins that are online at any one time.

D. Pre-Treatment Processes

The FEB will double as a pre-treatment process by allowing heavy suspended particles to fall out. It will also allow native algae to grow and consume nutrients and other pollutants in the FEB water. AquaFiber's®™ process is most efficient when the density of algae in the water is highest, so the FEB will be inoculated with supernatant coming from the biomass dewatering process and enhance the growth curve to encourage as much algae growth as possible.

E. Treatment

1. Provide information demonstrating prior pilot/project capability to achieve the project water quality criteria.

AquaFiber's®™ technology called AquaLutions®™ is designed specifically to harvest algae and cyanobacteria from the water column at a commercial scale using a modified DAF system. Harvesting the algae from the water removes the nutrients and pollutants absorbed by or attached to the algae. The clean water returns to the source healthier, free from excess nutrients, saturated with oxygen, and with clarity close to drinking water. AquaLutions'®™ effectiveness has been proven at several locations, and most prominently at Lake Jesup where it operated a commercial scale facility for five (5) years while under contract with the SJRWMD. **Attachment B** contains a report that evaluates the Lake Jesup facility's performance over its entire life span.

Using performance efficiencies seen at Lake Jesup and the influent nutrient concentrations given for this exercise, it is estimated that the C-43 system will achieve a minimum 75% reduction in TP concentration and a minimum 50% reduction in TN concentration. **Table 1** demonstrates the system performance at all three influent flow rates over a 300-day operating period, using TP and TN concentrations of 0.16 mg/L and 1.5 mg/L, respectively.

Table 1: AquaLutions®™ Annual TP and TN Removal Estimates at C-43

	Rate		
	300 cfs	**457 cfs**	**600 cfs**
TP (lb)	58,226	88,539	116,451
TN (lb)	363,910	553,369	727,820

This system will harvest millions of pounds of dry weight algal biomass per year. The biomass will be reused by Anuvia Plant Nutrients (Anuvia) and converted into commercial, slow-release fertilizer granules customized for specific crops. Anuvia's process keeps the beneficial nutrients while destroying many of the unwanted pollutants, including cyanotoxins (e.g., microcystins). If the fertilizer is placed on crops outside the watershed, then those nutrients are removed from it permanently. If the fertilizer is placed on crops within the watershed, then those nutrients are being recycled instead of imported. **Attachment C** contains a summary of Anuvia's manufacturing process and resulting product.

Using performance efficiencies seen at Lake Jesup, a 300-day operating period, and the influent nutrient concentrations given for this exercise, it is estimated that the C-43 system will achieve a minimum 50% reduction in TSS concentration. **Table 2** demonstrates the system performance at all three influent flow rates, using a TSS concentration of 20 mg/L.

Table 2: AquaLutions®™ Annual TSS Removal Estimates at C-43

	Rate		
	300 cfs	**457 cfs**	**600 cfs**
TSS (lb)	4,852,137	7,378,249	9,704,273

2. Treatment chemicals and/or media required for the process will be described.

In 2008, AquaFiber®™ was awarded a contract with the SJRWMD for TP removal on Lake Jesup in Seminole County. In order to receive the required permitting for such contract, the FDEP and SJRWMD required that all components of AquaFiber's®™ Trade Secret process be disclosed. AquaFiber®™ worked closely with the FDEP and agreed to meet with the FDEP's former Bureau of Laboratories, Bill Coppenger to discuss the AquaLutions®™ process. In December of 2008, AquaFiber personnel (Former CEO, Tom Bland; Former Sr. Vice President, Ron Allen; and Former Counsel, Ken Wright) met with FDEP personnel (Former Bureau of Laboratories, Bill Coppenger; Current Assistant Deputy General Counsel, Betsy Hewitt; Current Laboratory Department Director, David Whiting; and Current Program Administrator of the Chemistry Program, Tim Fitzpatrick) at the FDEP headquarters in Tallahassee. In this closed-door meeting, AquaFiber®™ disclosed all components of its AquaLutions®™ process, to include the Trade Secret components. FDEP personnel agreed to keep all aspects of this process undisclosed under a verbal non-disclosure agreement, unless ordered by a judge to disclose. FDEP personnel also agreed to provide AquaFiber®™ with the necessary permits, as long as AquaFiber®™ performed and passed quarterly Chronic Toxicity Testing to ensure the treated water going back into the lake was non-toxic. AquaFiber completed and passed seventeen (17) Chronic Toxicity Tests. **Attachment B** contains the results of those tests.

On July 28, 2011, FDEP personnel (David Whiting and Tim Fitzpatrick) visited the AquaFiber®™ Lake Jesup treatment facility and personally signed Non-Disclosure Agreements (Appendix 2) to coincide with their original verbal agreement to keep the AquaLutions®™ Trade Secret process undisclosed. These two individuals collected a series of samples (3 times/day) to evaluate the efficacy of the AquaLutions process and determine if the discharge water and resultant biomass had any potentially hazardous constituents. Results from the FDEP Bureau of Laboratories determined that there were no adverse effects anticipated from the discharge of AquaFiber's®™ treated water. They also determined that the AquaLutions®™ treatment process improved water clarity and water quality, appeared effective at removing significant amounts of nitrogen, phosphorus, and biomass, and posed little or no risk to the lake. Verification from the FDEP Bureau of Laboratories Division of Environmental Assessment and Restoration is provided in **Attachment D**.

Since the time of the original disclosure of AquaFiber's®™ Trade Secret process and the testing performed by FDEP personnel at Lake Jesup, AquaFiber's®™ Trade Secret process has remained unchanged. The Trade Secret components of the AquaLutions®™ process remain the same and the information that would be disclosed for this RFI is the same as the information previously disclosed to the FDEP. AquaFiber®™ urges the reviewers of this response to review the attached documentation and confirm all results and approvals with the FDEP personnel mentioned above. Should the State decide to enter into a licensing agreement with AquaFiber®™, the Trade Secret can be divulged to a wider group.

F. Post-Treatment Processes

Following the algae harvest but before leaving each basin, the water will flow over a section of limestone to allow the flow to quiesce and give a final polish before being returned to the downstream system. The basins, including the limestone area, will be drained, dried, and cleaned periodically. Biomass residuals will be sent to the dewatering system (**Section II.B**) to keep the maximum amount of solids within the treatment system.

As described in **Section II.F**, the supernatant (or centrate) from the dewatering system will be sent through a biological filter (e.g., floating plant mats) and then to the Algal Reservoir to initiate or enhance algal biomass growth, or to the beginning of the AquaLutions®™ system to stimulate in-system growth. In either case, additional trips through the system will give additional chances for algae to uptake the available, dissolved nutrients and pollutants.

G. Collection

Algal biomass is collected within the DAF basins. To achieve nutrient reductions, the project uses the principle of dissolved air flotation (DAF) to bring floc, algae in the case of the C-43 Reservoir, to the water surface through attachment of air bubbles to the floc[1]. A small subset of the main influent stream is saturated with pressurized air. This side stream is added to the DAF basin where it is mixed back into the main influent stream. As the pressure returns to normal atmosphere, the dissolved air comes out of solution forming fine bubbles. These bubbles float to the surface bringing algae, cyanobacteria and other fine particles with them. The floc accumulated on the surface, known as the 'float', is skimmed off as sludge and sent to the dewatering system. The clarified water, also called the subnatant or 'floated' water, is removed from the bottom and returned to the source.

The float is dominated by algae and cyanobacteria. Based on principles pioneered by Dr. Walter Adey during the development of his algal turf scrubber, AquaLutions®™ takes advantage of the idea that algae can consume excess nutrients, and if these algae are removed from the water, then the nutrients (and other pollutants) are removed with them[2]. Because algae and cyanobacteria grow naturally in surface waters already, AquaLutions®™ takes advantage of this activity by providing the algae enough time to take up the excess nutrients in the water such that when they are harvested, a significant reduction in nutrients occurs.

H. Chemical Supply

Please see the response to **Section I.E.2.**

II. Residuals Process

A. Collection or Removal

Please see the response to **Section I.G.**

B. Volume Reduction/Dewatering

The biomass will be pumped at 3% - 5% solids to the biomass handling area. A screw press filter and a series of vertical hoppers will dewater the biomass to a minimum of 20% solids. The estimated volumes of biomass generated daily at this solids content are as follows:

---

[1] (Ratnayaka, Brandt and Johnson 2009)

[2] (Craggs, et al. 1996)

300 cfs – 10,000 gallons
457 cfs – 15,000 gallons
600 cfs – 20,000 gallons

C. Storage

Biomass residuals will not be stored onsite except for those being processed for transfer to Anuvia. A series of 10,000-gallon vertical hoppers will be fed by the screw press. Capacity will be built in so that a minimum of five (5) days' worth of the maximum estimated amount of biomass can be maintained onsite in the event daily delivery is not possible.

D. Transfer

Biomass will be offloaded onto multi-axle trucks from the vertical hoppers. All dewatered algal biomass will be delivered to Anuvia's manufacturing plant in Plant City. The number of 30 cu-yd trucks needed to transport the dewatered material are as follows:

300 cfs – 3 trucks per day
457 cfs – 5 trucks per day
600 cfs – 7 trucks per day

E. Disposal (Reuse) Process and Location

Biomass will be delivered to 10609 Paul Buchman Hwy, Plant City, FL, 33565, a one-way distance of approximately 160 miles. Biomass disposal, or rather reuse, will be conducted by Anuvia. Anuvia will manufacture, package and distribute the resultant fertilizer product for sale nationwide. Anuvia's process keeps the beneficial nutrients while destroying many of the unwanted pollutants, including cyanotoxins (e.g., microcystins). More information regarding their technology can be found in **Attachment C**.

F. Centrate Management

Approximately 1 M gallons of centrate or supernatant will be decanted from the biomass each day. This water will be mostly clear and any nutrients contained within it will be mostly dissolved. This water will be redirected through a biological filter (e.g., floating plant mats) and then to the FEB to initiate or enhance algal biomass growth, or to the beginning of the AquaLutions®™ system to stimulate in-system growth. In either case, additional trips through the system will give additional chances for it to uptake the available, dissolved nutrients and pollutants and enhance the overall efficiency.

III. Land Area (total)

AquaFiber®™ can fit the entire project to treat 600 cfs within the SFWMD land available at the Reservoir's northwest corner. Please see **Table 3** for a breakdown of the land requirements.

Table 3: AquaLutions®™ Land Area Estimates at C-43

	Rate		
Component	**300 cfs**	**457 cfs**	**600 cfs**
Treatment Facility	100 ac	120 ac	150 ac
Supporting Facilities	10 ac	10 ac	10 ac
Residuals	40 ac	40 ac	40 ac
Stormwater (18%)	18 ac	22 ac	27 ac
Total	168 ac	188 ac	227 ac

A. Treatment Facility (including process tanks or basins, chemical storage, electrical system, buildings)

Please see **Table 3**.

B. Supporting Facilities (Vehicle Access Roads, Fencing, Security, Equipment Garage, Storage, Parking, and Administration)

Please see **Table 3**.

C. Residuals Handling and Solids Storage

Please see **Table 3**.

D. Stormwater Management

Please see **Table 3**.

IV. Power (annual)

A. Process requirements

Table 4: AquaLutions Total Annual Power Use at C-43

	Rate		
	300 cfs	**457 cfs**	**600 cfs**
Power (kWh/yr)	30,000,000	45,000,000	58,000,000

B. Site requirements

Site power is minor compared to the process requirements and has been accounted for in **Table 4.**

C. Monitoring

Monitoring power is minor compared to the process requirements and has been accounted for in **Table 4.**

V. Fuel Consumption (annual)

A. Chemical Supply, Storage, and Transport

To be determined

B. Site Vehicle Operation

AquaFiber®™ assumes the use of two, wheel loader-type vehicles and one diesel pickup truck (e.g., Ford F550 6.8L). Estimating excavator fuel usage depends on many factors. Assuming each is under medium load and operates 300 days per year for an average six hours per day, using between 2.6 – 3.1 gallons of fuel per hour, the annual fuel usage for both vehicles would be approximately 9,400 gallons to 11,200 gallons.

Assuming an average of 12,000 miles driven per year using an average fuel efficiency of 10 miles per gallon, the annual pickup truck fuel usage would be approximately 1,200 gallons.

C. Residuals Transport and Disposal

AquaFiber®™ uses a $2.00 fee per mile per truck for residuals transport. The trucks identified in **Section II.D** will consume more diesel fuel loaded than unloaded. Assuming an average fuel efficiency of approximately 5 MPG for the 320-mile roundtrip and a 300-day period, then the annual fuel consumption estimates are as follows:

300 cfs – 58,000 gallons
457 cfs – 96,000 gallons
600 cfs – 135,000 gallons.

VI. Other Beneficial Attributes

Additional Vendor Provided Information

The proposed project will not only remove excess nutrients at commercial scale, but will also improve dissolved oxygen concentrations, remove algae including harmful cyanobacteria, reduce TSS, and improve water health and clarity. The resultant product water is not just free of excess nutrients, it can serve as the foundation for aquatic ecosystem and trophic state index (TSI) level changes. The biomass is a sustainable source of organic material from which a slow-release fertilizer that has its own additional benefits is produced and sold nationwide. If the fertilizer is placed on crops outside the watershed, then the excess nutrients removed from the water are removed from it permanently. If the fertilizer is placed on crops within the watershed, then those nutrients are being recycled instead of imported. In either case, the cyanotoxins within the original source material have been destroyed, making the fertilizer safe to use and the AquaLutions®™ return water healthier.

VII. Capital Cost (2020 Dollars)

A. Process Facility (including components described under Items I and II)

The cost to treat water flowing into an AquaLutions®™ water treatment system from the C-43 Reservoir depends on many factors including, but not limited to, existing water quality, the end goals, the amount of water (or scale) required to meet those end goal targets, and the ultimate use of any organic biomass collected. It is also dependent on the funding source and the length of any financial agreement. The C-43 Reservoir water treatment unit cost will vary as a result of these factors, and are averaged here based on assumptions from the limited information that was provided.

The cost estimates provided herein for this project not only include the cost to build the facility, but also to operate it as necessary to provide proposed treatment for the proposed contract duration (20 years).

The capital costs for the facility include design, permitting, and construction on a total of 230 acres, with the ability to treat between 300 cfs and 600 cfs. The costs for each of the three prescribed flow rates can be found below in **Table 5**.

Table 5: Total Capital Cost Estimates for AquaLutions at C-43

	Rate		
	300 cfs	**457 cfs**	**600 cfs**
Cost	$72.46M	$97.97M	$123.75M

The only pumps included in the cost estimates are those contained within the AquaLutions®™ treatment system. The estimates above use assumptions provided by the Project Manager as a foundation for this exercise: 1) Water will be delivered to the AquaLutions®™ system from the C-43 Reservoir using existing infrastructure; 2) The site already has available sewer, three-phase electrical power, potable water, roads, and any other utilities pre-installed, and; 3) The only earthwork required is for the development of the AquaLutions®™ treatment system itself.

This response assumes that the capital costs will be paid for by the State; a financing agreement for the term of the project can be incorporated, if desired.

B. Land (including components under Item III)

For the purpose of this response, AquaFiber®™ assumes that land will be available for lease from the SFWMD at an annual cost per acre of land utilized (approximately 230 acres). Therefore, the capital cost figures for this project do not include land purchase cost. The land rental will be an annual expense and can be found in **Section VIII** below.

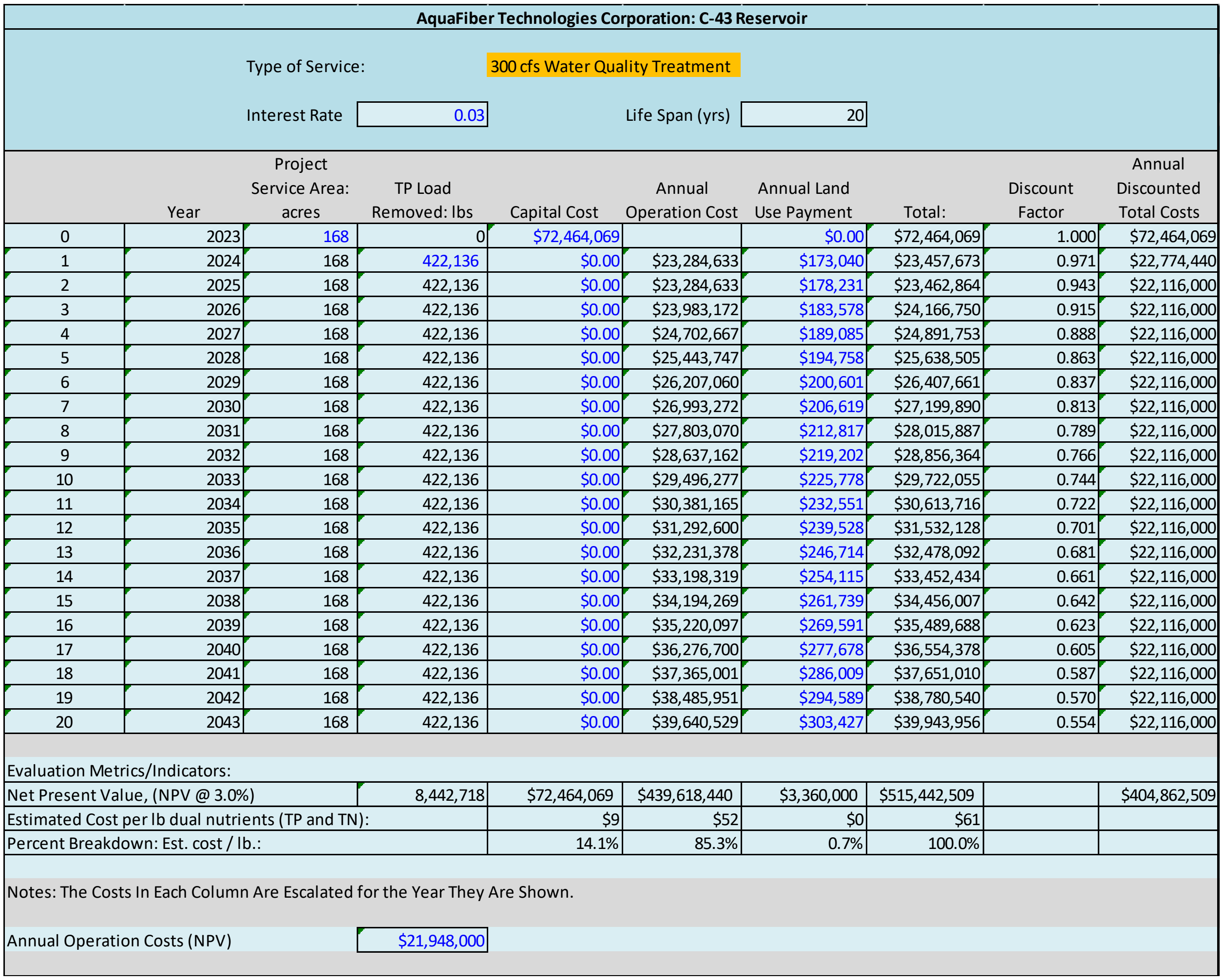
VIII. Operations and Maintenance (Annual)

AquaFiber's®™ costs for this exercise are based on its previous commercial-scale experience. The major O&M factors included in the below figures include electrical use for the AquaLutions®™ treatment system and the biomass disposal system only, repairs and replacements of all equipment, general and administrative costs, biomass conversion and disposal, rental of land (approximately 230 acres), water quality monitoring, proper insurance requirements (workers compensation, liability, property, auto, etc.), labor and labor burden, fuel, office expenses, and more. When considering all of these factors, the O&M costs can vary widely.

The AquaLutions®™ facility will remove TN and TP concurrently and permanently. It will also improve the oxygen content of water returned to the Caloosahatchee, remove harmful algae and toxins, enhance water clarity, and more. It is a true water quality restoration and has much more value than that generated by removing just one nutrient as is typical with a traditional water treatment system. Algal biomass is transported and given to Anuvia rather than sequestered in a landfill. Once the biomass is transferred, Anuvia assumes all costs to produce their unique nutrient delivery product. ***AquaFiber®™ has not and will not generate revenue from the biomass or any product resulting from the biomass***. It costs AquaFiber®™ money for the biomass to be transported to Anuvia, and a per-ton fee for its conversion. These costs are included in the below estimates.

The estimate to operate the facility will require a Net Present Value O&M cost of $61/lb of total dual nutrient (TP and TN) removal for a 300cfs treatment system, $50/lb of total dual nutrient (TP and TN) removal for a 457cfs treatment system, and $46/lb of total dual nutrient (TP and TN) removal for a 600cfs treatment system. An annual breakdown of cost is provided in **Tables 6, 7 and 8** below, separated by flow. AquaFiber®™ recognizes that the State is interested in owning successful projects and not binding taxpayers to a private party in perpetuity. To that end, AquaLutions®™ may be licensed, so that the water treatment system can be owned and operated by the State.

Table 6: AquaLutions NPV O&M for C-43 at 300 cfs



AquaFiber Technologies Corporation: C-43 Reservoir

Type of Service: 300 cfs Water Quality Treatment

Interest Rate 0.03 Life Span (yrs) 20

	Year	Project Service Area: acres	TP Load Removed: lbs	Capital Cost	Annual Operation Cost	Annual Land Use Payment	Total:	Discount Factor	Annual Discounted Total Costs
0	2023	168	0	$72,464,069		$0.00	$72,464,069	1.000	$72,464,069
1	2024	168	422,136	$0.00	$23,284,633	$173,040	$23,457,673	0.971	$22,774,440
2	2025	168	422,136	$0.00	$23,284,633	$178,231	$23,462,864	0.943	$22,116,000
3	2026	168	422,136	$0.00	$23,983,172	$183,578	$24,166,750	0.915	$22,116,000
4	2027	168	422,136	$0.00	$24,702,667	$189,085	$24,891,753	0.888	$22,116,000
5	2028	168	422,136	$0.00	$25,443,747	$194,758	$25,638,505	0.863	$22,116,000
6	2029	168	422,136	$0.00	$26,207,060	$200,601	$26,407,661	0.837	$22,116,000
7	2030	168	422,136	$0.00	$26,993,272	$206,619	$27,199,890	0.813	$22,116,000
8	2031	168	422,136	$0.00	$27,803,070	$212,817	$28,015,887	0.789	$22,116,000
9	2032	168	422,136	$0.00	$28,637,162	$219,202	$28,856,364	0.766	$22,116,000
10	2033	168	422,136	$0.00	$29,496,277	$225,778	$29,722,055	0.744	$22,116,000
11	2034	168	422,136	$0.00	$30,381,165	$232,551	$30,613,716	0.722	$22,116,000
12	2035	168	422,136	$0.00	$31,292,600	$239,528	$31,532,128	0.701	$22,116,000
13	2036	168	422,136	$0.00	$32,231,378	$246,714	$32,478,092	0.681	$22,116,000
14	2037	168	422,136	$0.00	$33,198,319	$254,115	$33,452,434	0.661	$22,116,000
15	2038	168	422,136	$0.00	$34,194,269	$261,739	$34,456,007	0.642	$22,116,000
16	2039	168	422,136	$0.00	$35,220,097	$269,591	$35,489,688	0.623	$22,116,000
17	2040	168	422,136	$0.00	$36,276,700	$277,678	$36,554,378	0.605	$22,116,000
18	2041	168	422,136	$0.00	$37,365,001	$286,009	$37,651,010	0.587	$22,116,000
19	2042	168	422,136	$0.00	$38,485,951	$294,589	$38,780,540	0.570	$22,116,000
20	2043	168	422,136	$0.00	$39,640,529	$303,427	$39,943,956	0.554	$22,116,000

Evaluation Metrics/Indicators:

	TP Load Removed: lbs	Capital Cost	Annual Operation Cost	Annual Land Use Payment	Total:	Discount Factor	Annual Discounted Total Costs
Net Present Value, (NPV @ 3.0%)	8,442,718	$72,464,069	$439,618,440	$3,360,000	$515,442,509		$404,862,509
Estimated Cost per lb dual nutrients (TP and TN):		$9	$52	$0	$61		
Percent Breakdown: Est. cost / lb.:		14.1%	85.3%	0.7%	100.0%		

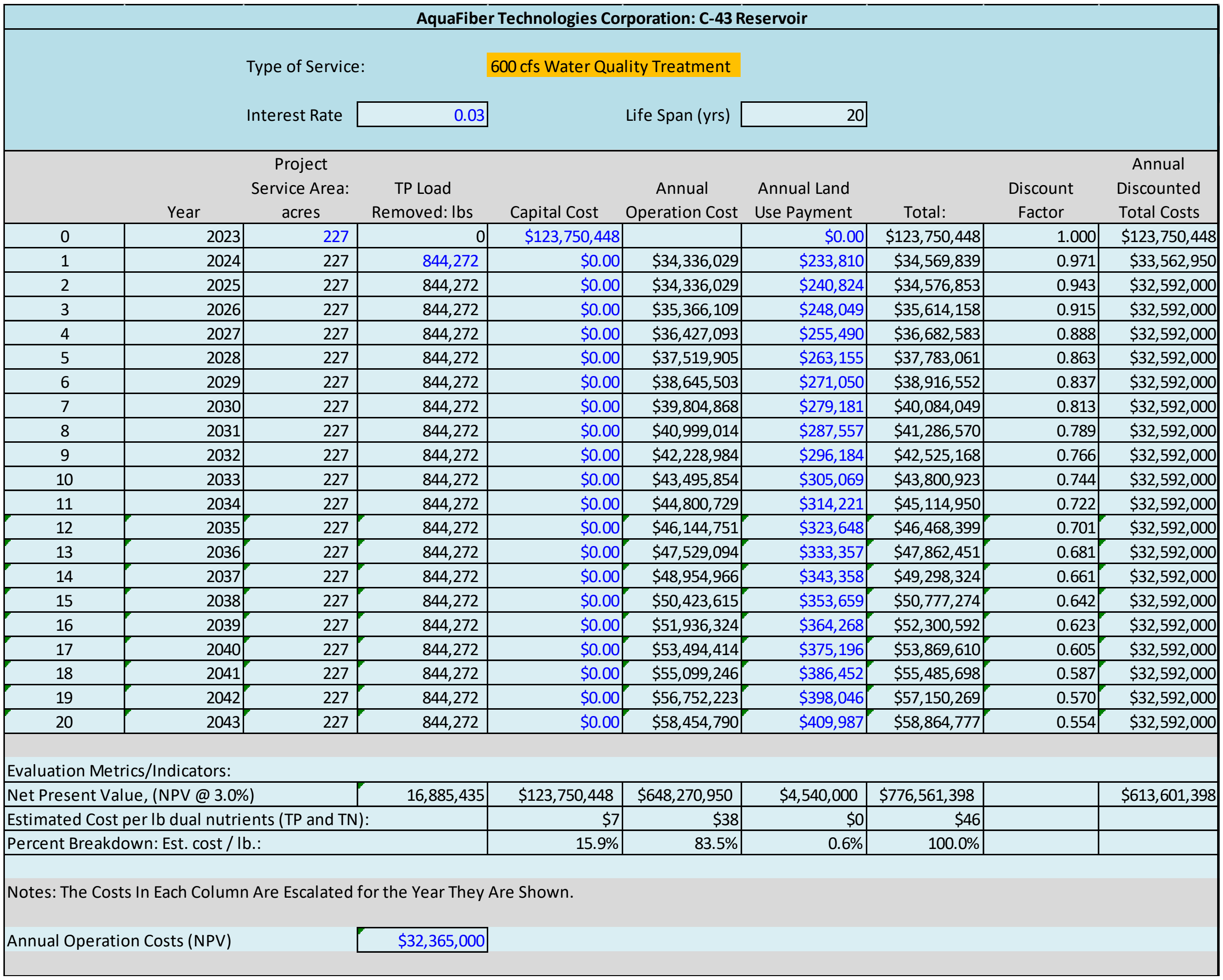
Notes: The Costs In Each Column Are Escalated for the Year They Are Shown.

Annual Operation Costs (NPV) $21,948,000

Table 7: AquaLutions NPV O&M for C-43 at 457 cfs

AquaFiber Technologies Corporation: C-43 Reservoir									
		Type of Service:		457 cfs Water Quality Treatment					
		Interest Rate	0.03		Life Span (yrs)	20			
	Year	Project Service Area: acres	TP Load Removed: lbs	Capital Cost	Annual Operation Cost	Annual Land Use Payment	Total:	Discount Factor	Annual Discounted Total Costs
0	2023	188	0	$97,966,878		$0.00	$97,966,878	1.000	$97,966,878
1	2024	188	641,908	$0.00	$28,906,342	$193,640	$29,099,982	0.971	$28,252,410
2	2025	188	641,908	$0.00	$28,906,342	$199,449	$29,105,792	0.943	$27,435,000
3	2026	188	641,908	$0.00	$29,773,533	$205,433	$29,978,965	0.915	$27,435,000
4	2027	188	641,908	$0.00	$30,666,739	$211,596	$30,878,334	0.888	$27,435,000
5	2028	188	641,908	$0.00	$31,586,741	$217,944	$31,804,684	0.863	$27,435,000
6	2029	188	641,908	$0.00	$32,534,343	$224,482	$32,758,825	0.837	$27,435,000
7	2030	188	641,908	$0.00	$33,510,373	$231,216	$33,741,589	0.813	$27,435,000
8	2031	188	641,908	$0.00	$34,515,684	$238,153	$34,753,837	0.789	$27,435,000
9	2032	188	641,908	$0.00	$35,551,155	$245,297	$35,796,452	0.766	$27,435,000
10	2033	188	641,908	$0.00	$36,617,690	$252,656	$36,870,346	0.744	$27,435,000
11	2034	188	641,908	$0.00	$37,716,220	$260,236	$37,976,456	0.722	$27,435,000
12	2035	188	641,908	$0.00	$38,847,707	$268,043	$39,115,750	0.701	$27,435,000
13	2036	188	641,908	$0.00	$40,013,138	$276,084	$40,289,222	0.681	$27,435,000
14	2037	188	641,908	$0.00	$41,213,532	$284,367	$41,497,899	0.661	$27,435,000
15	2038	188	641,908	$0.00	$42,449,938	$292,898	$42,742,836	0.642	$27,435,000
16	2039	188	641,908	$0.00	$43,723,436	$301,685	$44,025,121	0.623	$27,435,000
17	2040	188	641,908	$0.00	$45,035,139	$310,735	$45,345,875	0.605	$27,435,000
18	2041	188	641,908	$0.00	$46,386,194	$320,057	$46,706,251	0.587	$27,435,000
19	2042	188	641,908	$0.00	$47,777,779	$329,659	$48,107,439	0.570	$27,435,000
20	2043	188	641,908	$0.00	$49,211,113	$339,549	$49,550,662	0.554	$27,435,000
Evaluation Metrics/Indicators:									
Net Present Value, (NPV @ 3.0%)			12,838,153	$97,966,878	$545,757,410	$3,760,000	$647,484,288		$510,309,288
Estimated Cost per lb dual nutrients (TP and TN):				$8	$43	$0	$50		
Percent Breakdown: Est. cost / lb.:				15.1%	84.3%	0.6%	100.0%		
Notes: The Costs In Each Column Are Escalated for the Year They Are Shown.									
Annual Operation Costs (NPV)			$27,247,000						

Table 8: AquaLutions NPV O&M for C-43 at 600 cfs



AquaFiber Technologies Corporation: C-43 Reservoir

Type of Service: 600 cfs Water Quality Treatment

Interest Rate 0.03 Life Span (yrs) 20

	Year	Project Service Area: acres	TP Load Removed: lbs	Capital Cost	Annual Operation Cost	Annual Land Use Payment	Total:	Discount Factor	Annual Discounted Total Costs
0	2023	227	0	$123,750,448		$0.00	$123,750,448	1.000	$123,750,448
1	2024	227	844,272	$0.00	$34,336,029	$233,810	$34,569,839	0.971	$33,562,950
2	2025	227	844,272	$0.00	$34,336,029	$240,824	$34,576,853	0.943	$32,592,000
3	2026	227	844,272	$0.00	$35,366,109	$248,049	$35,614,158	0.915	$32,592,000
4	2027	227	844,272	$0.00	$36,427,093	$255,490	$36,682,583	0.888	$32,592,000
5	2028	227	844,272	$0.00	$37,519,905	$263,155	$37,783,061	0.863	$32,592,000
6	2029	227	844,272	$0.00	$38,645,503	$271,050	$38,916,552	0.837	$32,592,000
7	2030	227	844,272	$0.00	$39,804,868	$279,181	$40,084,049	0.813	$32,592,000
8	2031	227	844,272	$0.00	$40,999,014	$287,557	$41,286,570	0.789	$32,592,000
9	2032	227	844,272	$0.00	$42,228,984	$296,184	$42,525,168	0.766	$32,592,000
10	2033	227	844,272	$0.00	$43,495,854	$305,069	$43,800,923	0.744	$32,592,000
11	2034	227	844,272	$0.00	$44,800,729	$314,221	$45,114,950	0.722	$32,592,000
12	2035	227	844,272	$0.00	$46,144,751	$323,648	$46,468,399	0.701	$32,592,000
13	2036	227	844,272	$0.00	$47,529,094	$333,357	$47,862,451	0.681	$32,592,000
14	2037	227	844,272	$0.00	$48,954,966	$343,358	$49,298,324	0.661	$32,592,000
15	2038	227	844,272	$0.00	$50,423,615	$353,659	$50,777,274	0.642	$32,592,000
16	2039	227	844,272	$0.00	$51,936,324	$364,268	$52,300,592	0.623	$32,592,000
17	2040	227	844,272	$0.00	$53,494,414	$375,196	$53,869,610	0.605	$32,592,000
18	2041	227	844,272	$0.00	$55,099,246	$386,452	$55,485,698	0.587	$32,592,000
19	2042	227	844,272	$0.00	$56,752,223	$398,046	$57,150,269	0.570	$32,592,000
20	2043	227	844,272	$0.00	$58,454,790	$409,987	$58,864,777	0.554	$32,592,000
Evaluation Metrics/Indicators:									
Net Present Value, (NPV @ 3.0%)			16,885,435	$123,750,448	$648,270,950	$4,540,000	$776,561,398		$613,601,398
Estimated Cost per lb dual nutrients (TP and TN):				$7	$38	$0	$46		
Percent Breakdown: Est. cost / lb.:				15.9%	83.5%	0.6%	100.0%		

Notes: The Costs In Each Column Are Escalated for the Year They Are Shown.

Annual Operation Costs (NPV) $32,365,000

A. Labor

Please see **Tables 6, 7, and 8**

B. Materials

Please see **Tables 6, 7, and 8**

1. Acquisition
2. Management
3. Disposal

C. Residuals

Please see **Tables 6, 7, and 8**

D. Power

Please see **Tables 6, 7, and 8**

E. Fuel

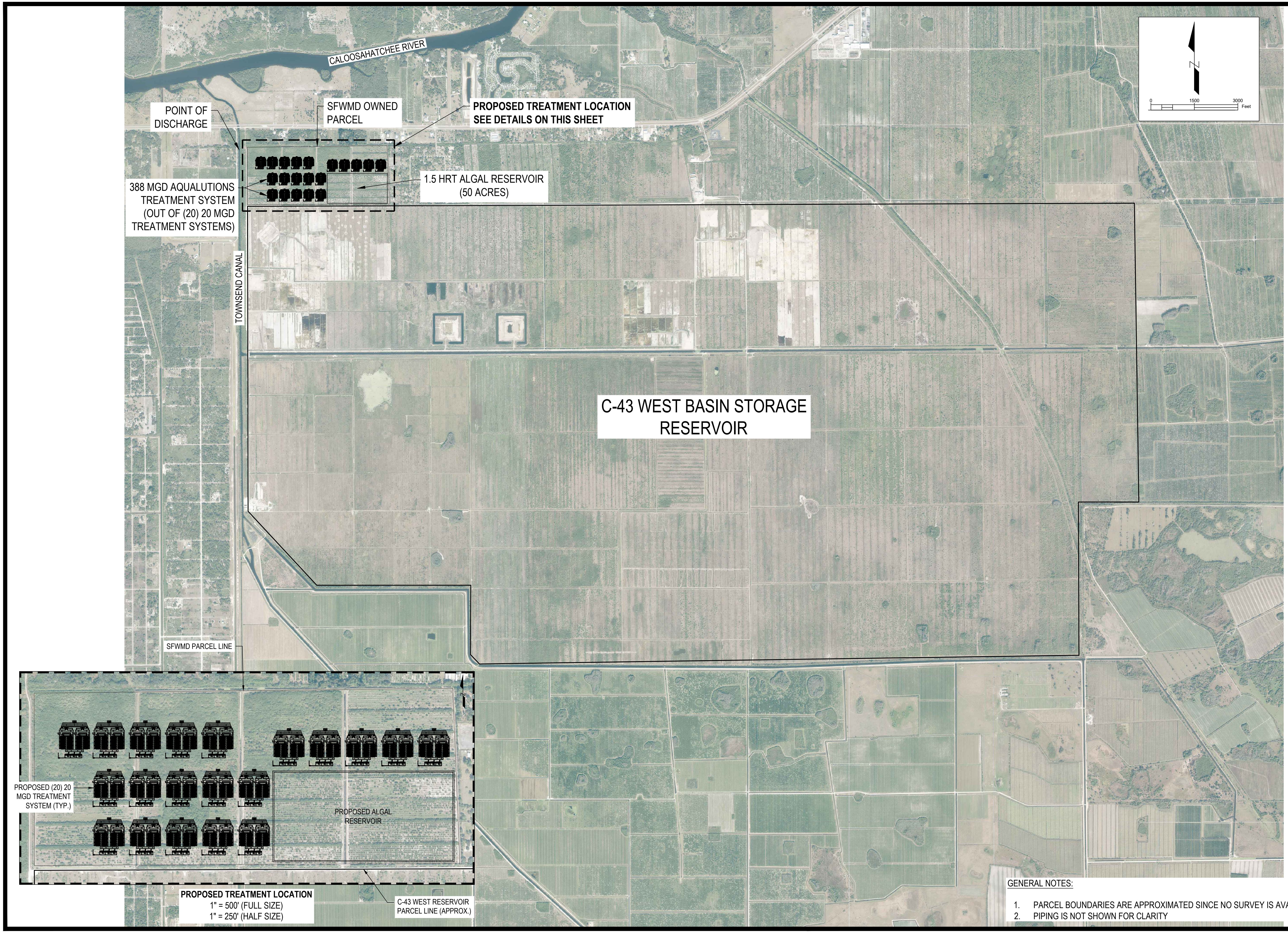
Please see **Tables 6, 7, and 8**

F. Monitoring or Other

Please see **Tables 6, 7, and 8**

Attachment A

Conceptual Plan



PROPOSED TREATMENT LOCATION
1" = 500' (FULL SIZE)
1" = 250' (HALF SIZE)

GENERAL NOTES:

1. PARCEL BOUNDARIES ARE APPROXIMATED SINCE NO SURVEY IS AVAILABLE.
2. PIPING IS NOT SHOWN FOR CLARITY

NO.	BY	DATE	DESCRIPTION

REVISIONS

DESIGNED BY: HJ
DRAWN BY: HJ
DATE: 4/28/2020
CHECKED BY: AHS
APPROVED BY: MJF
JOB NO.: 1720011

NOT FOR CONSTRUCTION

600 CFS TREATMENT FACILITY CONCEPT

AQUAFIBER TECHNOLOGIES
C-43 WEST WATER QUALITY
FEASIBILITY STUDY COST ANALYSIS

WATERMARK ENGINEERING GROUP, INC.
3868 SUN CITY CENTER BLVD., SUN CITY CENTER, FL. 33573
TEL: (813) 641-1200 OR (813) 633-2100
CERTIFICATE OF AUTHORIZATION 25990

3

Attachment B

AquaFiber – Lake Jesup Report

AquaFiber
TECHNOLOGIES CORPORATION

Dual-Nutrient (Total Phosphorus and Total Nitrogen) Remediation of Surface Water Quality at Lake Jesup, FL, a Hypereutrophic Nutrient-Impaired Lake.

Category: Environmental and Chemical Sciences

Title: Dual-Nutrient (Total Phosphorus and Total Nitrogen) Remediation of Surface Water Quality at Lake Jesup, FL, a Hypereutrophic Nutrient-Impaired Lake.

Authors& Affiliation

William A. Eggers[1], Duane E. De Freese[1], Kirby Green[1], Rebecca Burnett[1], William Fagan[1] and Ronald Allen[1]

(1) AquaFiber Technologies Corporation, 1150 Louisiana Avenue, Winter Park, FL 32789. (407) 671-2782. info@aquafiber.com. www.aquafiber.com.

Corresponding Author

William A. Eggers[1] bill.eggers@aquafiber.com

Running Head

AquaFiber Technologies Corporation demonstrated a dual-nutrient remediation process for Florida surface waters at Lake Jesup that targeted high-nutrient legacy loads and turbid tributary sources to achieve Florida's Numeric Nutrient Criteria for both total phosphorus and total nitrogen and achieved high water clarity in post-treatment discharge waters.

Abstract

AquaFiber Technologies Corporation (AquaFiber) conducted a echnology demonstration project at Lake Jesup, FL from 2009-2014. The project goal was to demonstrate the effectiveness of AquaFiber's proprietary, dual-nutrient (TP and TN) removal technology (AquaLutions®™) to help reduce nutrients in a hypereutrophic lake as an effective and efficient component of a whole-waterbody restoration strategy. During the 5-year contract period, AquaFiber treated and returned a mean of 13.8 million liters per day (21,657,880,703 L total) of post-treatment water to Lake Jesup. These data show the capacity and efficiency of AquaLutions®™ to reduce in-lake legacy loads of TP, TN and TSS. Total TP removed was 2,879 kg. Total TN removed was 41,023 kg. Total TSS removed was over 641,795 kg. AquaFiber achieved mean, post-treatment effluent concentrations of 0.033 mg/L TP and 1.64 mg/L TN during the 5-year contract period administered by the St. Johns River Water Management District (SJRWMD). Mean, post-treatment TSS during that same period was

10.22 mg/L. On average, AquaFiber exceeded Florida Department of Environmental Protection (FDEP) Numeric Nutrient Criteria (NNC) for TP in colored lakes (0.050 mg/L) and achieved TN concentrations within the FDEP range for colored lakes (1.27 mg/L - 2.23 mg/L). The post-treatment water also often met or exceeded drinking water clarity (9th quarter effluent TSS was 4.54 mg/L). These data also show that AquaLutions®™ is an important water quality management option that is effective, efficient, environmentally safe and cost-competitive. The AquaFiber process represents a new tool for surface water managers and regulated stakeholders interested in Basin Management Action Plan compliance; Total Maximum Daily Loads (TMDL) and NNC compliance; nutrient legacy load reductions; and whole-waterbody restoration.

Key Words: AquaFiber, AquaLutions®™, AquaKnight®™, BMAP, dual nutrient, eutrophic, Florida, hypereutrophic, in-lake, innovative, legacy, load, Numeric Nutrient Criteria, nutrients, restoration, surface water, TMDL, TN, TP, TSS, technology, water quality, water remediation

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1.0 Introduction

Surface water quality restoration in nutrient impaired freshwater, estuarine and coastal marine ecosystems requires total nitrogen (TN) and total phosphorus (TP) concentration reductions in source inputs and *in situ* legacy loads (Havens & Frazer, 2012; Hudnell, 2010; Conley, et al., 2009; Paerl, 2009; Camargo & Alonso, 2006; and Boesch, 2002). While some scientists continue to debate the efficacy of traditional, single-nutrient (TP or TN) reduction versus dual-nutrient (TP and TN) reduction, growing evidence suggests that dual-nutrient reductions are essential to restore water column ecological integrity and healthy freshwater-estuarine-ocean ecosystem connections (Lapointe, Herren, Debortoli, & Vogel, 2015 in press; Havens, 2013; Havens & Frazer, 2012; Paerl, Hall, & Calandrino, 2011; Hudnell, 2010; Conley, et al., 2009).

To address the growing crisis of nutrient pollution in surface waters, the United States Environmental Protection Agency (EPA) through the Federal Water Pollution Control Act of 1972 (Clean Water Act, 33 U.S.C. Ch. 26) recommended development of NNC for both TP and TN as an effective strategy to address eutrophication and return impaired surface waters to their intended uses. As the result of a lawsuit filed by the Florida Wildlife Federation and others in 2008, followed by a Consent Decree in 2009, the State of Florida and the EPA worked to establish NNC for Florida surface waters (FDEP, 2009). Ensuing Florida legislation and rule-making by the FDEP established NNC for Florida’s lakes, rivers, streams, springs and more than 6,276 of the state’s estimated 6,904 km of coastal estuaries. These new statewide NNC rules included biological response criteria. In 2010, the EPA estimated that the total, annual incremental cost to implement the NNC in Florida could be between $135.5 M - $206.1 M with only $28.1 M in predicted benefits (US EPA Office of Water, 2010), while a competing study commissioned by the Florida Water Quality Coalition estimated that the same incremental costs could be between $3.1 B and $8.4 B, and that even using a narrative approach those costs are still $1.0 B - $3.2 B (CardnoEntrix, 2010). Attainment of both NNC nutrient concentrations and biological response criteria will challenge civic leaders, water managers and regulated stakeholders to comply with the new standards, track water quality status and trends, and implement meaningful surface water restoration.

In addition to regulatory changes, scientists and water managers in Florida now realize that 20 years of stormwater regulations and projects that focused on nutrient reductions associated with stormwater source control have not substantially improved water quality conditions (Hudnell, 2010). For Lake Jesup, simulation models of stormwater loading to the lake demonstrated that even if all available lands were converted to stormwater Best Management Practices (BMPs), the pollution reduction to Lake Jesup would be insufficient to restore the lake (Brandt-Williams, 2010). Reduction of *in situ* nutrient legacy loads is essential to achieve long-term water quality restoration goals for Lake Jesup and most of Florida's surface waters with high *in-situ* nutrient loads and organic muck deposit accumulation.

In 2007, AquaFiber entered into a contract with the SJRWMD (Contract $^{\#}$SK473AA) to demonstrate the effectiveness of its proprietary technology/process (AquaLutions®™). The contract's stated goal,

"…is to clearly demonstrate that nutrient treatment technologies, alone or in combination, can sustainably, substantially and cost-effectively remove TP from Lake Jesup on a long term basis and potentially restore lake water quality to state standards."

The water treatment facility was funded and built by AquaFiber using private funds. AquaFiber supplied 100% of the facility construction costs and research and development (R&D) costs. AquaFiber was reimbursed by the SJRWMD per pound of TP removed from the lake once the harvested biomass and its associated TP were documented quantitatively, verified by SJRWMD, and transported for proper disposal outside of the Lake Jesup sub-basin (contract specified disposal in a landfill). AquaFiber's project goal was to demonstrate and quantify the efficacy of its surface water treatment technology and obtain independent public-sector verification of process performance from relevant state agencies (i.e., SJRWMD, FDEP).

2.0 Materials and Methods

2.1 General: The AquaFiber facility is located on the southern shores of Lake Jesup, FL in Sections 25 and 26, Township 20 South, and Range 31 East, Seminole County (**Figure 1**). The property is ten (10) acres in size. It is owned by the SJRWMD and leased by AquaFiber. In order to demonstrate the technology's compact design, less than one (1) acre or 7% of the site is employed for the AquaLutions®™ treatment process. The remainder of the land is used for: water pre- and post-treatment (10%); biomass dewatering and storage (16%); stormwater ponds (22%); and gravel roads, support infrastructure (e.g., admin trailers) and open space (45%).

The AquaLutions®™ technology and associated processes were developed based on a modified and patented dissolved air floatation (DAF) system with a suite of technology hardware, software and process components all of which are protected by AquaFiber as intellectual property (IP) or trade secrets. AquaFiber's trade secrets represent proprietary, corporate information and are not discussed herein.

AquaFiber conducted this commercial-scale, pilot project at Lake Jesup from April 18, 2009 - April 18, 2014. AquaFiber was responsible for all costs associated with facility. (i.e., O&M, construction mitigation, permitting and transport/disposal costs of biomass).

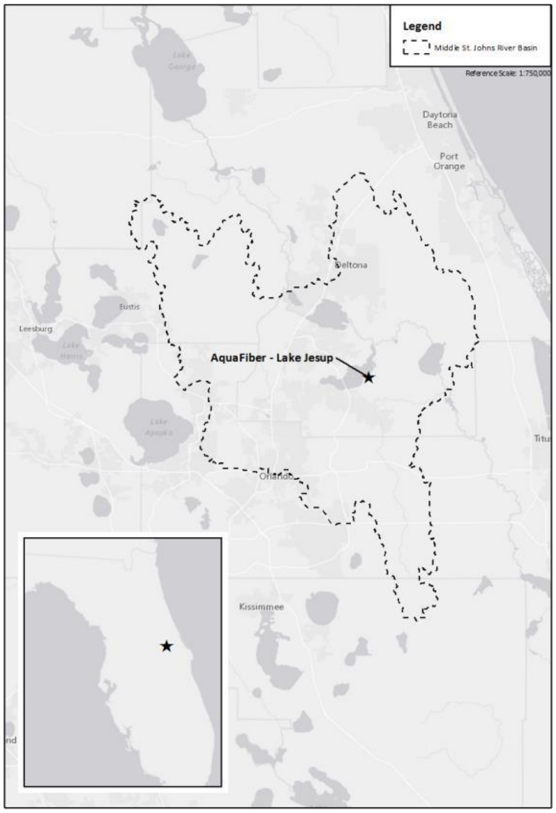

Figure 1: Location Map (Map depicting the AquaFiber Lake Jesup facility location in Florida and the Middle St. Johns River Basin)

AquaFiber used the pilot water treatment facility as an R&D platform to expand the water remediation value of the project to test the efficacy of AquaLutions®™ to address emerging water remediation needs and clean technology sector opportunities in Florida. These included verification of AquaLutions®™ as a:

1. Dual-nutrient (TP and TN) reduction technology.
2. Process that could meet or exceed the new Florida NNC.
3. Process that delivered other water column or ecosystem benefits that were routine requirements in most Florida Basin Management Action Plans (BMAP).
4. Delivery system to generate biomass feedstock that could be processed for beneficial and sustainable uses.
5. Research and development platform for emerging clean-tech industry opportunities for water technologies, biomass conversion technologies and beneficial biomass applications (i.e. bioenergy, novel biochemicals and bio-based fertilizers).

Water was pumped from Lake Jesup through high-density polyethylene (HDPE) intake pipes that extended approximately 671 m into Lake Jesup. A specially designed intake “header” was used to lower intake velocity and minimize organism entrapment. The intake was positioned in the mid-water column. The intake pipe was anchored to the lake bottom and adjusted vertically in response to changing lake water levels.

2.2 AquaLutions®™ Performance: Influent water flow was measured continuously using Seametrics EX101 Magnetic Insertion Meters. Both intake pipes had a separate meter inserted and both meters were connected to a FT420W Flow Computer and DL 76 Data Logger. Post-treatment effluent water flow was measured continuously at a weir using a HACH SC200 Ultrasonic Flow Sensor connected to an SC200 Controller. TSS was measured every six (6) seconds for both influent and post-treatment effluent streams beginning in the 8th operational quarter using HACH SOLITAX TSS probes. Flow and TSS data were collected, organized and archived daily by Microsoft SQL in relational databases.

Composite water samples were collected by AquaFiber from influent (lake) and effluent (post treatment) water streams using HACH Sigma SD 900 refrigerated composite water samplers. Lake influent samples were collected from a side stream sample line connected to the influent pipes. Post-treatment effluent samples were collected from a vault located at the end of the treatment train, just before the water was returned to the lake. Post-treatment water traveled from the post-treatment effluent water sampling site through a final receiving pond and discharge weir structure that dispersed effluent water as a shallow, overland sheet flow through Lake Jesup’s lacustrine fringe wetlands.

During treatment operations, 200 ml aliquots of influent lake water and effluent post-treatment water were collected by each sampler every hour and composited in refrigerated, 5 L vessels. AquaFiber collected weekly samples from each 5 L vessel manually at 0900 on Wednesday using 50 ml bottles with an H_2SO_4 fixative. Influent and post-treatment effluent water samples were transported to an independent, NELAC/NELAP-accredited laboratory for analysis (Flowers Chemical Laboratories, Inc., Altamonte Springs, FL and TestAmerica Laboratories, Inc., Orlando, FL). Back-up samples were also collected from each 5 L vessel using the same methodology and archived in refrigeration.

The laboratory examined both influent and effluent water samples for TP concentration as required by the SJRWMD contract. However, AquaFiber recognized from the beginning that regulation of TN was likely at both federal and state levels in the near future. In response to this emerging regulatory interest in dual-nutrient remediation, AquaFiber instructed the laboratory to analyze each water sample for TN (TKN and NO_2/NO_3).

Because this was a technology demonstration project, the SJRWMD and the FDEP exerted a high level of oversight on system performance. SJRWMD conducted independent regular water quality testing and verification as well as mass-balance nutrient estimates from the harvested biomass. AquaFiber presented Quarterly performance reports to the SJRWMD staff for technical review and comments. FDEP evaluated results of routine whole effluent toxicity (WET) tests. FDEP also conducted an independent, random WET test in September and October of 2011.

2.3 Environmental Safety: Whole Effluent Toxicity (WET) testing is an important component of the EPA's integrated approach for detecting and addressing toxicity in surface waters. Once the facility initiated pumping water (April 18, 2009) and achieved stable water flow and treatment (October, 2009), AquaFiber conducted regular WET tests on both lake influent and post-treatment effluent water. Initial testing was scheduled monthly for the first 4 months and quarterly thereafter. A total of 16 routine WET tests were completed over the project duration. All analyses were performed by Marinco Bioassay Laboratory Inc., Sarasota, Florida. Marinco Bioassay Laboratory is NELAP accredited (#E84191) by the Florida Department of Health and its aquaculture facility is certified by the Florida Department of Agriculture & Consumer Services, Aquaculture Certificate #AQ0668007. Marinco conducted both acute and chronic WET tests on AquaFiber water samples using the fathead minnow (*Pimephales promelas*) and the daphnid (*Ceriodaphnia dubia*). Cyanotoxin testing and algal speciation was conducted by GreenWater Laboratories in Palatka, FL.

2.4 Biomass Handling and Disposal: Nutrient-laden biomass was collected as a byproduct from the AquaLutions®™ process. As a requirement of the SJRWMD contract, this biomass was required to be transported out of the Lake Jesup sub-basin, in a verifiable way. Freshly collected biomass was sampled monthly during the first year of operations for tissue composition analysis. The first stage of biomass dewatering was conducted on the Lake Jesup facility site in 30.5 m geotextile tubes. When it had dewatered sufficiently, the biomass was transported to the second-stage drying site outside of the

Lake Jesup sub-basin where it was stored in a lined pond and allowed to dry further and await an end user.

As part of the verification process and in conjunction with support from SJRWMD technical staff, the total amount of TP contained in it was estimated using mass balance calculations. Biomass mass-balance calculations were used as a quality control comparison to wet chemistry nutrient reduction measurements. Each load of biomass removed from a geotube and transported offsite by truck was weighed. Composite, 500 ml biomass samples were collected from each geotube at three locations. Samples were sent to ABC Research Labs in Gainesville, FL to be analyzed for moisture content and TP concentration. Composite 50 ml samples of the entrained or leachate water were sent to Flowers Chemical Laboratories, Inc. in Altamonte Springs to be analyzed for TP concentration. Together, these data allowed the water volume to be separated from the dry biomass and each assigned a TP load for that geotube. An evaporation factor of 3.3% and 5% was applied pursuant to SJRWMD staff directives to estimate nutrients remaining from any evaporated water.

2.5 Sustainability: One of the project performance criteria considered by the SJRWMD contract was sustainability. Although the contract called for disposal of biomass in a landfill, AquaFiber pursued numerous avenues to identify sustainable and beneficial uses of the biomass waste stream. AquaFiber sought strategic partners within the biomass sector proactively. The company fulfilled many requests for biomass samples from academic institutions, research labs and clean-tech industry representatives. AquaFiber also conducted Resource Conservation and Recovery Act (RCRA-8 metals) and tissue analysis tests on the biomass to insure it did not contain large concentrations of metals or other harmful components. These tests were small in number and conducted for regulatory purposes. Due to the small number of samples, the results of those tests are not discussed in detail. Biomass handling methodologies were varied based on end-user needs and are not detailed in this paper. General comments about sustainable biomass applications are included in the discussion.

3.0 Results

The Lake Jesup facility was fully operational for a majority of the 5-year contract period. Sufficient influent water was available during the entire contract period, but operational downtime was required for routine maintenance and unscheduled events (e.g., power outages, equipment failures, weather events, etc.). The results include all data collected from the operational period.

3.1 Scalable Water Treatment: AquaFiber treated and returned a mean of 13.8 million liters per day of Lake Jesup surface water. The total amount of water flowed was 21,657,880,703 L. AquaFiber adjusted the facility average daily water flow rate from a high of 28,890,249 L/day to a low of 32,706 L/day to test capacity (system scalability) and efficacy characteristics of the AquaLutions®™ process (**Figure 2**). These water treatment data demonstrated that the process was scalable and effective treating a wide range of water volumes and influent nutrient concentrations and TSS loads.

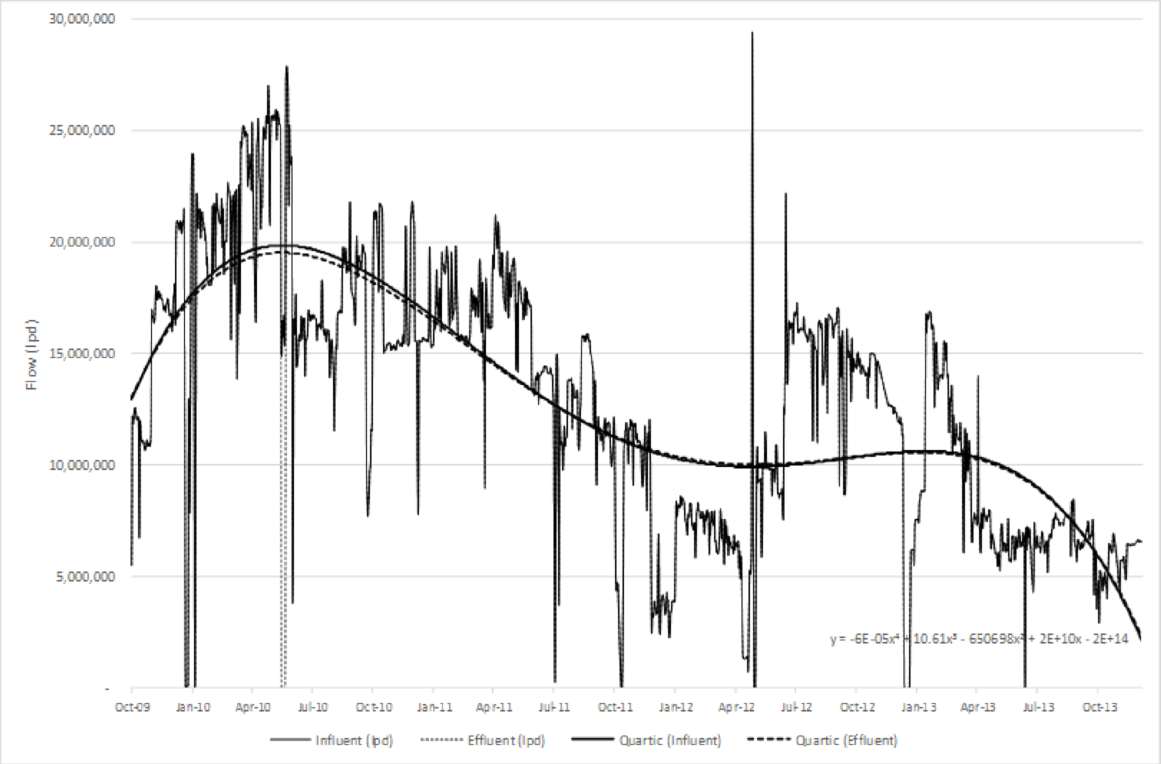

Figure 2: Daily Average Flow v. Time (Influent and effluent flow measurements collected every six seconds and averaged daily over the entire 5-year contract period, downtime included. The quartic trend line (4th-order polynomial) indicates the rate of change when the rate isn't constant)

3.2 Effective and Efficient Nutrient Reductions and Water Clarity Improvements: These data show the efficiency of the AquaLutions®™ technology to remove large quantities of TP and TN, and improve water clarity through TSS removal. Total TP removed was 2,879 kg (based on 228 quantified composite weekly samples). Total TN removed was 41,023 kg (based on 224 quantified composite weekly samples). Total TSS removed was over 641,795 kg or (based on 125 quantified composite weekly samples for operational quarters Q8-Q20 plus estimated TSS removal for Q1-Q7 based on the Q8-Q20 TSS removal average). Post-treatment water had high clarity (low TSS) after the biomass/nutrient separation process was complete. These data show AquaLutions®™ ability to maintain high TP, TN and TSS removal efficiencies over long periods of time and in response to wide swings in both weather and lake water quality conditions. Lake Jesup TP concentrations ranged from 0.03 – 0.62 mg/L (**Figure 3**). The mean weekly TP removal efficiency was 76.87% ± 18.36 SD (n=228 weekly composite samples) with a demonstrated maximum TP removal capacity during an operational quarter = 93.7%.

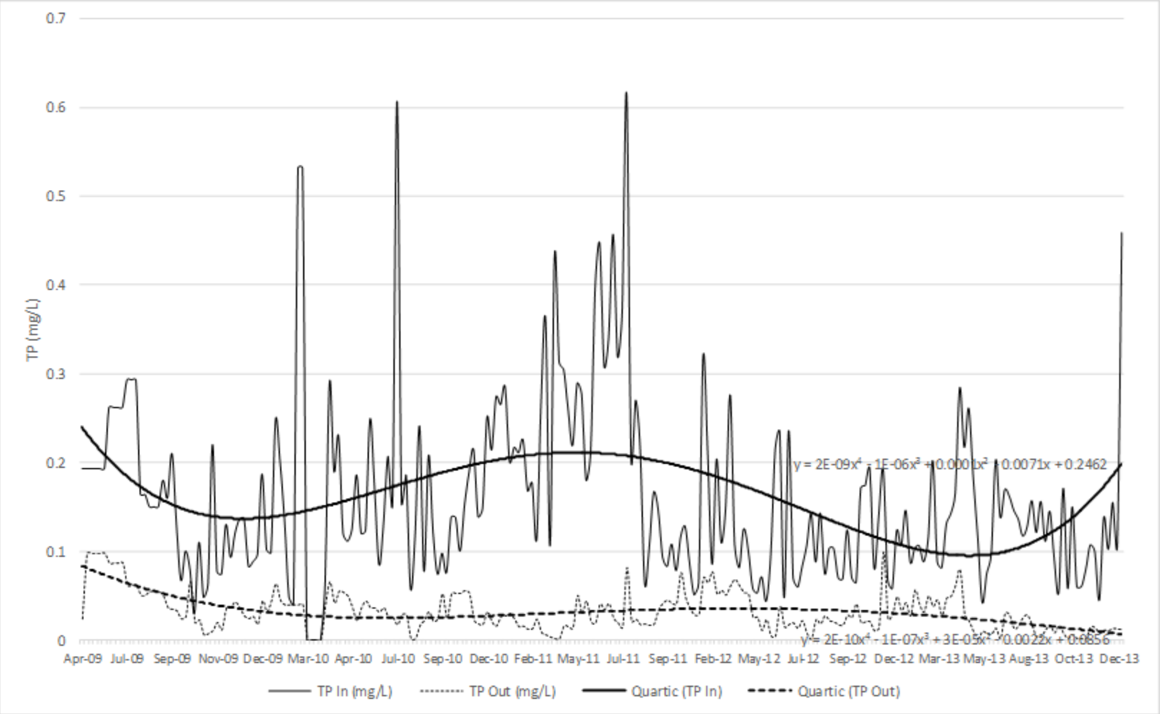

Figure 3: Weekly Composite Influent TP Concentration v Weekly Composite Effluent TP Concentration (Influent and effluent flow measurements collected every six seconds and averaged daily over the entire 5-year contract period, downtime included. The quartic trend line (4th-order polynomial) indicates the rate of change when the rate isn't constant.)

Lake Jesup TN concentrations ranged from 1.26 – 9.92 mg/L (**Figure 4**). The mean weekly TN removal efficiency was 52.03% ± 17.07 SD (n=224 weekly composite samples) with a demonstrated maximum TN removal capacity during an operational quarter of 65.4%.

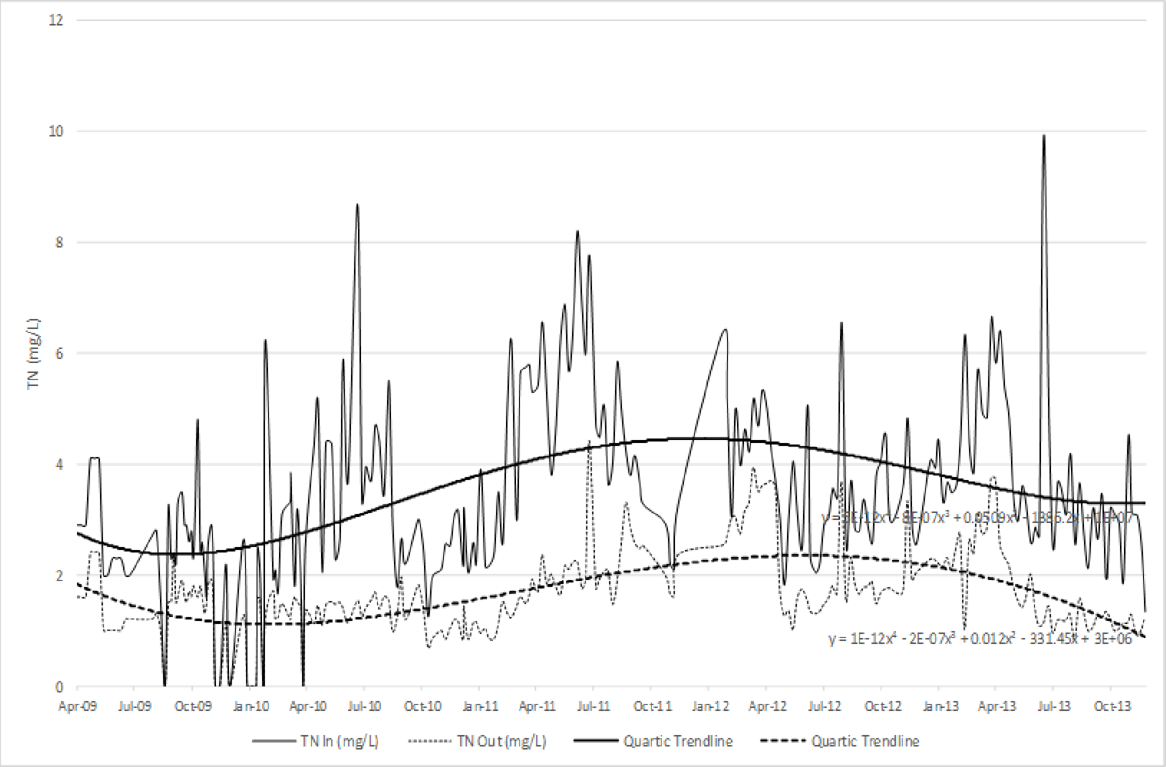

Figure 4: Weekly Composite Influent TN Concentration v. Weekly Composite Effluent TN Concentration (Influent and effluent TN concentrations collected every hour, composited and tested weekly over the entire 5-year contract period, downtime excluded. The quartic trend line (4th order polynomial) indicates the rate of change when the rate isn't constant.)

Lake Jesup TSS concentrations ranged from 4.05 – 199.97 mg/L (**Figure 5**). During high wind events, lake TSS concentrations exceeded the 200 mg/L limit of the HACH sensors. The mean, weekly TSS removal efficiency was 72.5% ± 21.4 SD (n=125 weekly composite samples) with a demonstrated maximum TSS removal capacity during an operational quarter = 90.2%. During the TSS sampling period from 04/18/2011 through 01/18/2014 (Operational Quarters 8-20), the mean water column TSS measured from waters collected from Lake Jesup was 46.14 mg/L. The mean post-treatment discharge water returned to the lake was 9.33 mg/L.

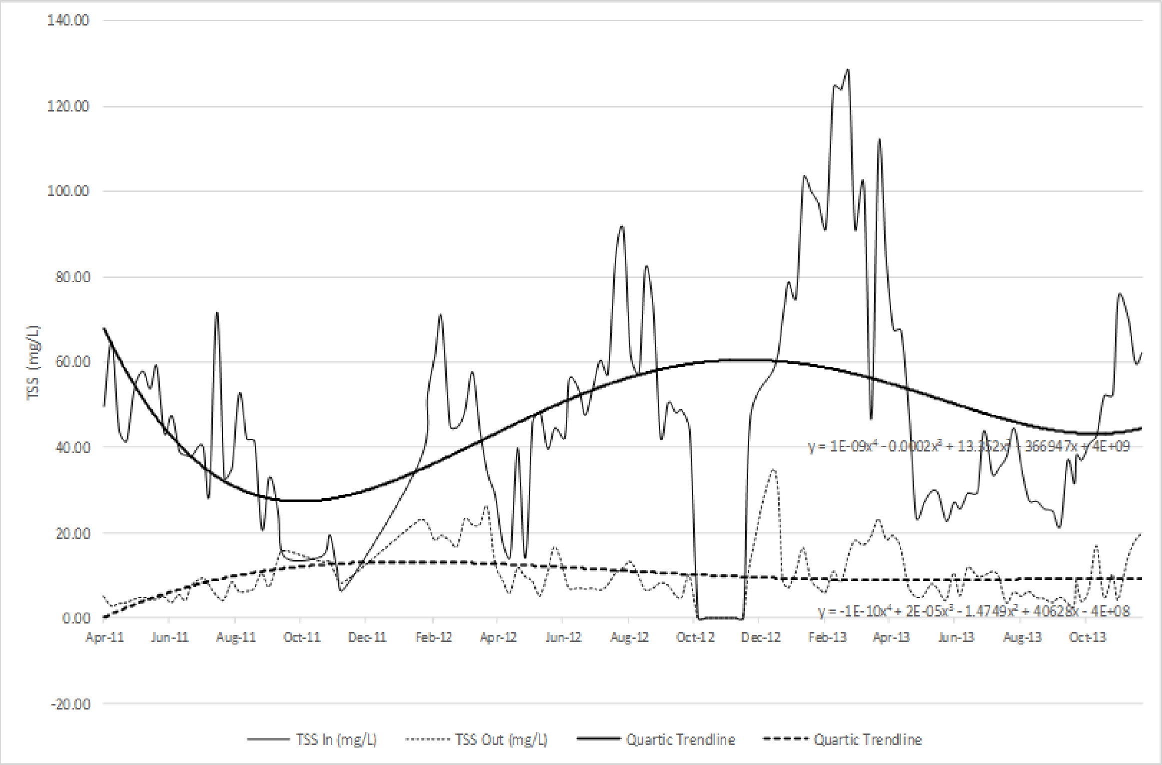

Figure 5: Daily Average Influent TSS Concentration v. Daily Average Effluent TSS Concentration (Influent and effluent TSS concentrations collected every six seconds and averaged weekly over the entire 5-year contract period, downtime excluded. The quartic trend line (4th order polynomial) indicates the rate of change when the rate isn't constant.)

Comparisons of composite influent TP, TN and TSS removal efficiencies versus corresponding lake concentrations showed that TP removal efficiencies were 60 – 90% throughout a range of influent TP concentrations of 0.05 – 0.6 mg/L TP (**Figure 6**).

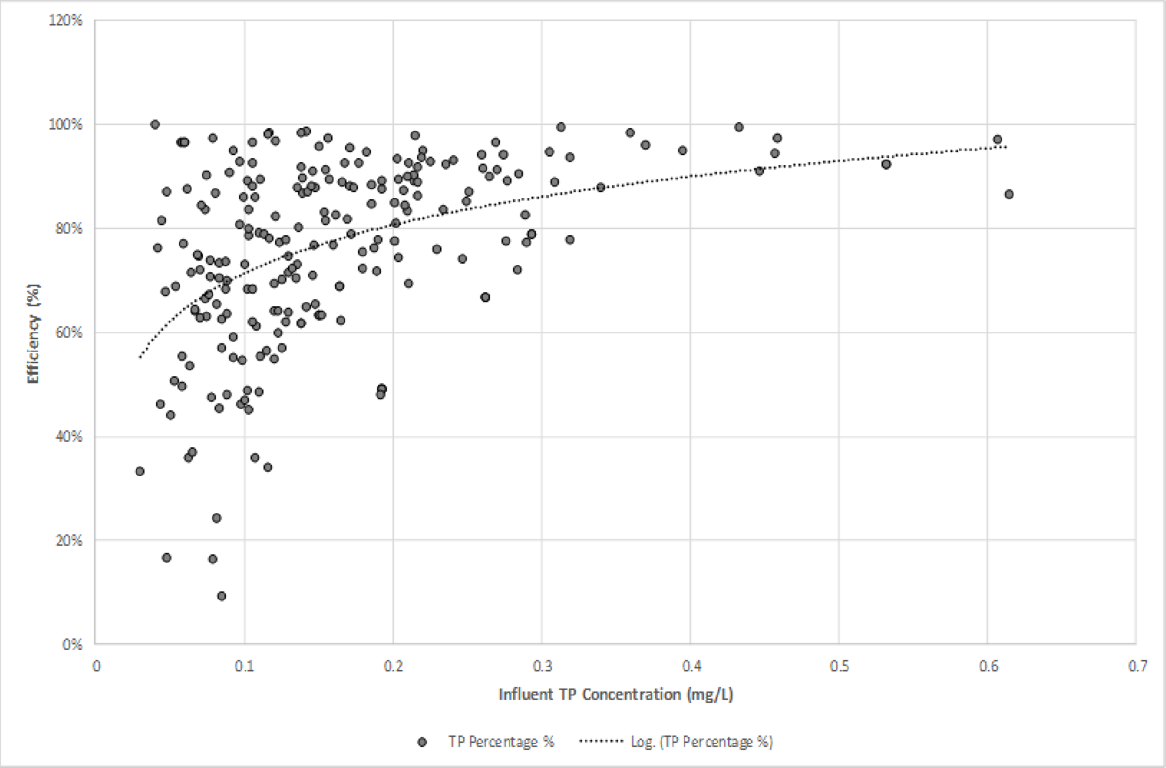

Figure 6: TP Removal Efficiency (TP removal efficiency on a logarithmic scale over the 5-year contract period for all weekly effluent TP composite sampling results.)

TN removal efficiencies were generally lower and highly variable with a narrow range of removal efficiency (45-55%) throughout a TN concentration range of 1.0 – 8.0 mg/L TN (**Figure 7**).

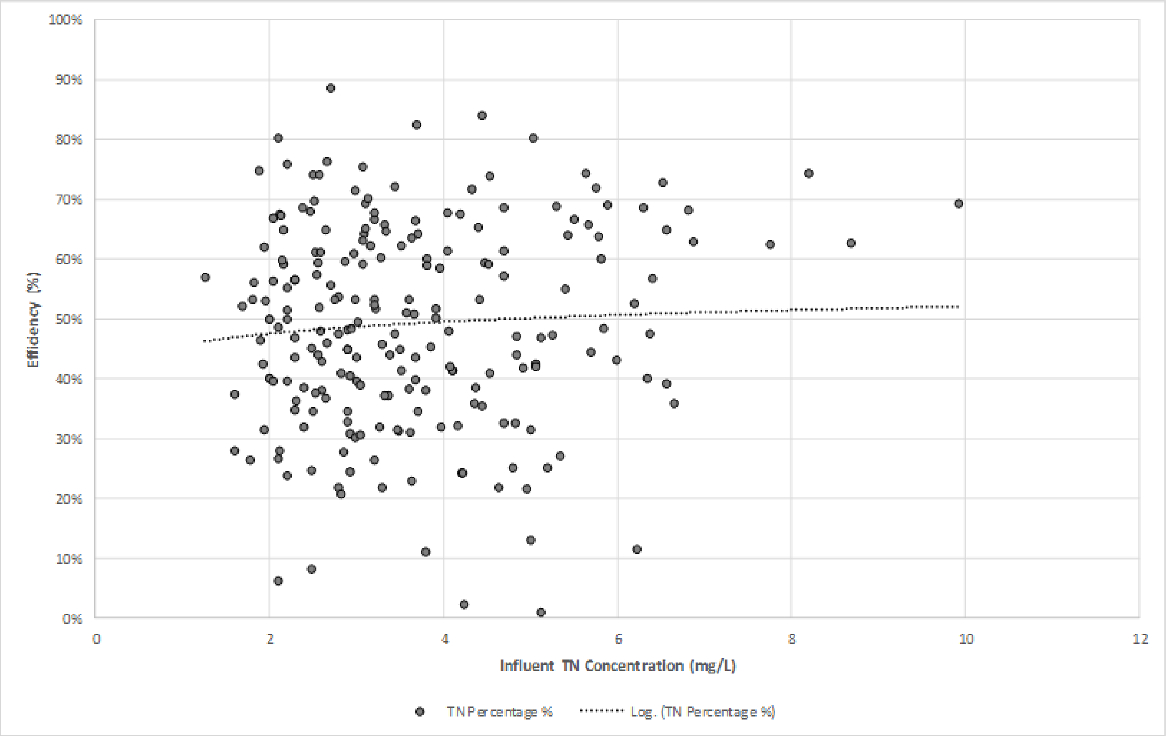

Figure 7: TN Removal Efficiency (TN removal efficiency on a logarithmic scale over the 5-year contract period for all weekly effluent TN composite sampling results.)

TSS removal efficiencies were 40 – 90% throughout a range of influent TSS concentrations of 20 - 120 mg/L TSS (**Figure 8**).

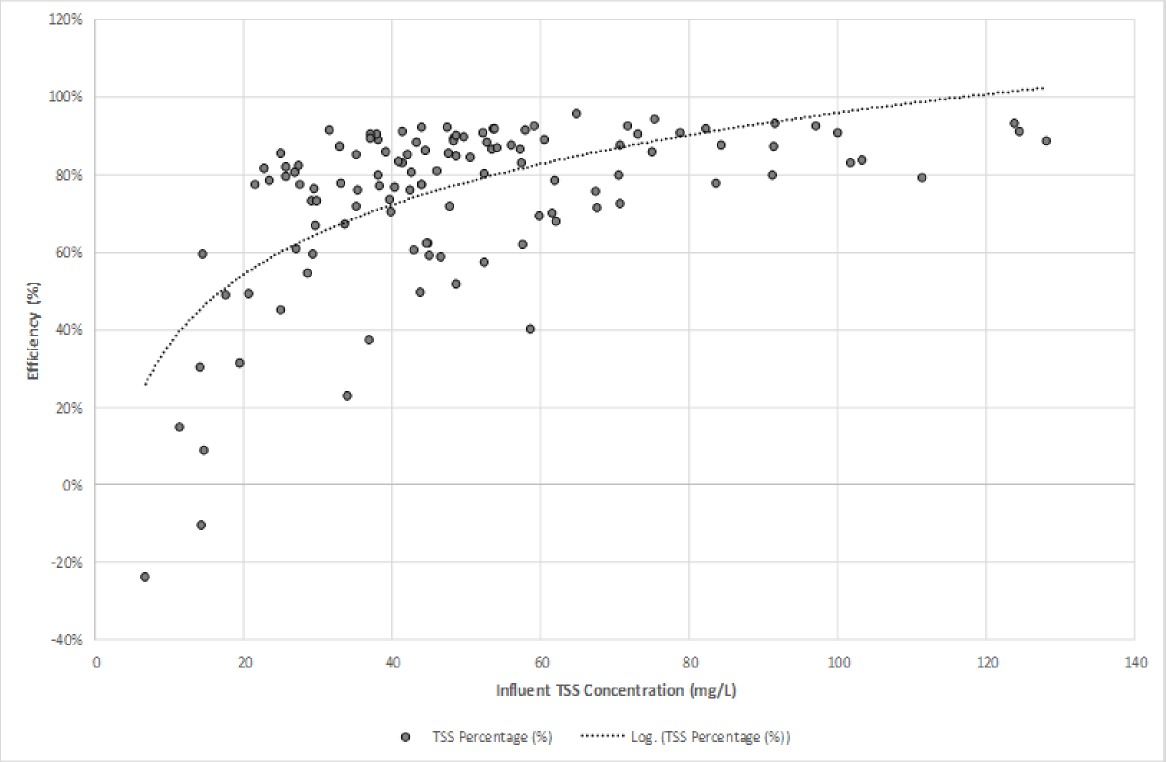

Figure 8: TSS Removal Efficiency (TSS removal efficiency on a logarithmic scale over the 5-year contract period for all average weekly effluent TSS sampling results.)

Pursuant to SJRWMD contract requirements, these data show AquaFiber's ability to remove > 1 Metric Ton of TP/Year during Year-2 Operations (April 18, 2010 – April 18, 2011) with removal of 1,122.2 kg of TP with a mean water flow and treatment rate of 17.4 million L, and a corresponding mean TP removal efficiency of 82.5%. In addition, these data show AquaLutions'®™ capacity to reduce nutrient concentrations of TP and TN to levels that meet or exceed Florida's NNC. The system's best performance period was in the 8th quarter (January 18, 2011 to April 18, 2011) of operations (1,447,821,534 L treated) when TP reduction exceeded 93% efficiency and TN reduction exceeded 65% efficiency. During this period, the average influent TP concentration was 0.248 mg/L (s.d. 0.0987) and the average effluent TP concentration was 0.0122 mg/L (s.d. 0.0158) for a total mass removal of 327.00 kg TP. The average influent TN concentration during the 8th quarter was 4.11 mg/L (s.d. 1.558) while the average effluent TN concentration was 1.30 mg/L (s.d. 0.332) with a total mass removal of 4,014.29 kg TN. AquaFiber achieved mean, post-treatment effluent concentrations of 0.033 mg/L TP and 1.73 mg/L TN over the 5year operational period of the facility. On average, AquaFiber exceeded the targeted NNC established by FDEP for TP for colored lakes (0.050 mg/L) and achieved TN concentrations within the FDEP range for colored lakes (1.27 mg/L - 2.23 mg/L).

Although not mandated by the NNC specifically, AquaFiber's TSS removal capabilities are also impressive. The Lake Jesup system's best performing TSS removal period was the 9th quarter (April 18, 2011 to July 18, 2011) when 1,490,056,183 L of water flowed and TSS removal efficiency exceeded 90%. During this optimal quarter, influent TSS concentrations averaged 48.57 mg/L (s.d. 8.651) while effluent concentrations averaged 4.54 mg/L (s.d. 1.29) for a total mass removal of 324,694.62 kg TSS.

3.3 Environmental Safety: In 11 of 16 WET tests (68.8%), the post-treated water showed a moderate to high decrease in toxicity compared to influent Lake Jesup water. In 2 of 16 WET tests (12.5%), there was no toxicity in either the lake influent or post-treatment effluent waters resulting in no change. In 3 of 16 WET tests (18.7%), there were variable results with IC25 results that Marinco Lab reports indicate had possible pathogen interference. All Marinco Bioassay Laboratory WET test results were provided to the FDEP. There were no non-compliance events throughout all 5 years of operation and WET testing.

Preliminary test results on a Lake Jesup water and post-treatment biomass for cyanobacteria and cyanotoxin (n=1) confirmed the presence and abundance of cyanobacteria species in Lake Jesup. Two species dominated the samples (*Microcystis* spp. and *Cylindrospermopsis* spp.). Both are known to be cyanotoxin producers. microcystin and cylindrospermopsin toxins were detected in Lake Jesup water samples (0.4 µg/L for both toxins). Fresh biomass had microcystin levels of 24.8 µg/L. Aged, air-dried biomass had microcystin levels that ranged from 0.2-1.3 µg/L. No anatoxin-a or saxitoxins were detected.

3.4 Sustainability and Waste Biomass Handling: Freshly collected biomass was sampled monthly for the first year of operations after stable water flow and treatment were achieved. Biomass was also sampled during each offsite transport event and mass balance calculations were applied to estimate the TP and TN contained within it (**Table 1**). Total biomass transported offsite was 6,079,310 kg. Based on 3.3% and 5.5% rates of evaporation estimates, the total TP contained in this biomass was between 2,932 kg and 3,683 kg, respectively. Most of the biomass transported offsite was transported as wet biomass with an average solids content of 8% total mass. This was determined to be a minimum solids content for safe truck transport. For regulatory purposes, a RCRA-8 metals test (n=1) was conducted on the biomass by Flowers Chemical Laboratories, Inc. to determine whether it was safe to spread on the ground. The results showed that the biomass did not contain RCRA-8 metals or did not contain them in concentrations that exceeded regulatory thresholds.

Table 1: Biomass - Physical and Chemical Summary (Physical and chemical summary of all biomass harvested by AquaLutions®™ and used for mass-balance calculations.)

Total Mass	Avg. Moisture	Avg. Biomass [TP]	TP Mass	TP Mass in Entrained Water (3.3%)	TP Mass in Entrained Water (5.0%)	Total TP at 3.3% Evaporation	Total TP at 5.0% Evaporation
kg	%	mg/kg	kg	kg	kg	kg	kg
6,079,310	**92**	**3,078**	**1,473**	**1,459**	**2,210**	**2,932**	**3,683**

The majority of the wet biomass produced and transported offsite was converted to bio-based mulch by Oldcastle Lawn and Garden, Inc., Polk County, FL. A small, but significant volume was used to test a slow-release, low phosphorus fertilizer pellet process developed by VitAg Corporation, Orange County, FL (http://www.vitagcorp.com/). During the contract, AquaFiber accommodated numerous requests for biomass samples for use in a wide range of academic research, industry and government R&D projects (i.e. hydrogen gas production, waste-to-energy via gasification and anaerobic digestion, biofuels production, building materials, novel biochemical prospecting, and feedstock for black soldier fly to protein meal conversion). In 2009-2010, AquaFiber transported approximately 112,279 L of wet biomass for biomass-to-energy research as a subcontractor to Science Applications International Corporation (SAIC, http://www.saic.com/) who secured contracts from the Defense Advanced Research Projects Agency (DARPA) to develop affordable alternatives to petroleum-derived jet fuel (JP-8) from agricultural and aquacultural feedstock materials (DARPA Algal Biofuels Program BAA08-07). Approximately 8,271 kg were produced by AquaFiber as a dry pulverized biomass powder for SAIC energy conversion process development. Certified JP-8 jet fuel was successfully produced from Lake Jesup biomass by SAIC and its partners. These results show that a beneficial use for the biomass can be found throughout a range of treatment options and scale.

4.0 Discussion

4.1 Nutrient Removal Performance: The project results demonstrated that AquaLutions®™ was an effective, efficient, scalable and environmentally safe TP remediation technology for Florida surface waters. The project also demonstrated and verified a number of additional water restoration benefits that were not part of the contract performance criteria. These benefits included: 1) reduction of TN concentrations to meet Florida NNC; 2) reduction of other pollutant loads sequestered in the biomass harvest (including RCRA-8 metals); 3) reduction of in-lake water toxicity; and 4) reduction of water column turbidity. Due to the high flow rate that discharged large volumes of clean, oxygenated water back to Lake Jesup, the project provided qualitative evidence that dissolved oxygen levels and water flow in discharge waters were enhanced. In addition, cyanobacteria and potential cyanotoxins were removed, and wetland habitat and quality improvements were documented. Scientific evidence suggests that oxygen depletion can promote the release of pollutants from sediments (e.g. methylation of mercury, manganese, or release of dissolved phosphorus) that can stimulate freshwater harmful algal/cyanobacterial blooms (FHAB's) and potential cyanotoxin production (Hudnell, 2010). Regional-scale facilities that are sited and scaled strategically could be designed to improve oxygen concentrations in eutrophic and hypereutrophic systems where low oxygen levels often have these other deleterious effects. Strategic siting of facilities with targeted clean water discharge points could be used to advance nearshore water quality improvements and enhanced coverage of submerged aquatic vegetation.

AquaLutions®™ was designed specifically for water bodies with high nutrient loads and high turbidity due to algal/cyano blooms, and thick legacy sediments caused by muck accumulation. Although not presented here, AquaFiber demonstrated the effectiveness of the AquaLutions®™ process using its mobile treatment unit (AquaKnight®™) on other lakes (Lake Apopka, Lake Thonotosassa, Lake Hancock and Lake Trafford), flowing waters (Caloosahatchee River and St. Lucie River), stormwater ponds (Isleworth County Club) and coastal estuaries (Indian River Lagoon). AquaLutions®™ does not represent a "standalone" water restoration solution. Rather, it complements a broad range of source-control technologies, watershed restoration projects, and legacy-load reduction initiatives that can be combined to form a strategic whole-waterbody restoration initiative.

4.2 Need for Nutrient Legacy Load Reductions

For the past three decades, Florida water managers and regulators focused on stormwater management practices and TMDLs to achieve the individual BMAP regulatory targets.

Regulated stakeholders were assigned TMDL targets for source control projects, but few BMAPs recognized the importance of legacy load reductions, nor did they award nutrient removal credits for legacy load reductions. Reduction of this legacy load is important because phosphorus accumulation can be remobilized or recycled to act as a continuous source to waterbodies and downstream waters for years, decades or centuries (Sharpley, et al., 2014). In support of the performance results of this project, FDEP provided two letters to AquaFiber (dated August 31, 2011 and February 7, 2014 respectively) that recognized project success, confirmed process environmental safety, and authorized BMAP credits for both phosphorus and nitrogen on a 1:1 basis ("*…one pound of BMAP reduction credit available for each pound of nitrogen or phosphorus removed from the basin*"). To our knowledge, this is the first issuance of both TP and TN credits for lakes in Florida. Florida's first and only water quality credit trading program was initiated as a pilot project for the Lower St. Johns River in 2008 (s. 403.067, F.S. and Ch. 62-306, F.A.C.). A report to the Florida Governor and Legislature was issued in 2010 with a recommendation that other areas of the state would likely benefit from trading (FDEP, 2010). In August 2014, FDEP began hosting public workshops to discuss expanding Water Quality Credit Trading Programs statewide. Prior to the submission of this paper (2015), nutrient credit trading had not been initiated statewide.

4.3 Scalable: The ability to scale technology to address whole lake restoration goals represents a significant restoration and process challenge. Based on the data collected and observations made at the Lake Jesup pilot facility, AquaFiber modeled, conceptualized and confirmed its ability to build regional-scale facilities on Lake Jesup or other water bodies of the state. The AquaLutions®™ treatment technology is not limited by scale. AquaFiber successfully operated a mobile treatment unit (AquaKnight®™) at flow rates of 37,854 – 45,425 L (10,000 - 12,000 gpd). AquaKnight®™ was operated as a multi-purpose laboratory platform that served three purposes: 1) Experimental platform for new technology testing; 2) Working water treatment laboratory for preliminary nutrient reduction field trials; and 3) A small volume test platform to generate composite water quality data to evaluate facility site locations, facility size and cost-estimate modeling for regional-scale water remediation facilities. The AquaKnight®™ and AquaFiber's comprehensive and iterative process are shown in **Figure 9**.

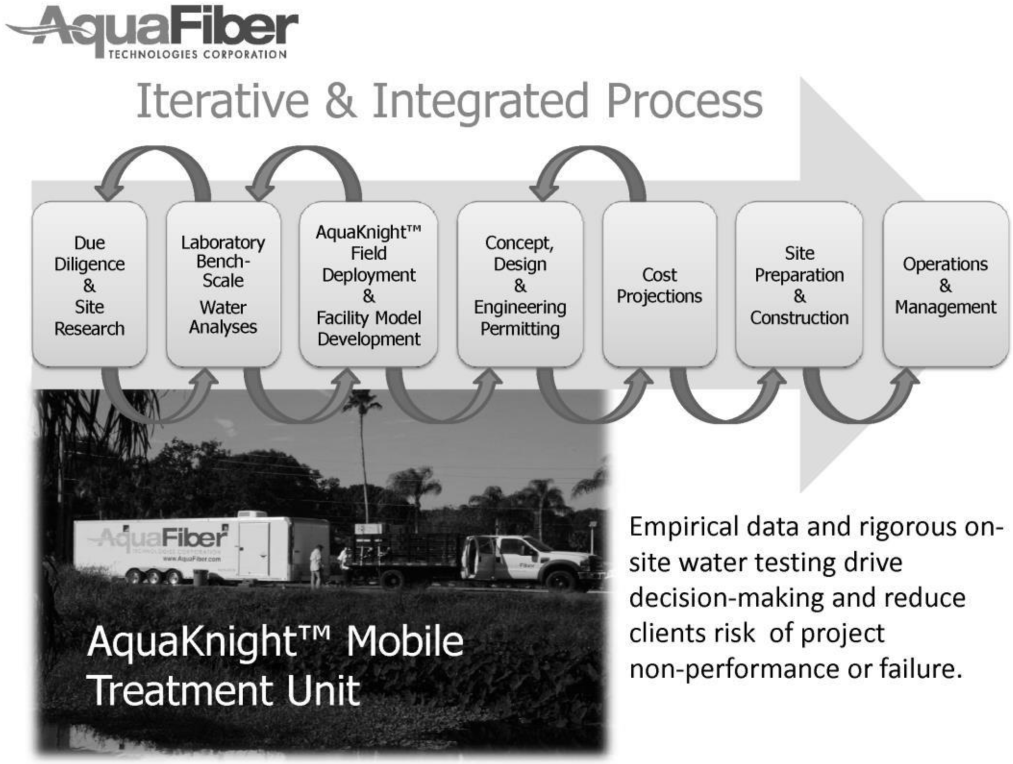

Figure 9: AquaFiber's Iterative Process (Diagram showing AquaFiber's iterative sampling, testing and deployment process)

4.4 <u>Sustainable</u>: Four cornerstones of sustainability are essential considerations for regional- and ecosystem-scale surface water nutrient remediation projects:

1. Nutrient & Pollutant Sequestration: Removal of excess nutrients and other pollutants from the watershed and nearby surface waters is the only way to address long-term nutrient reduction goals. Most surface water nutrient removal projects in Florida that couple hybrid wetlands and chemical treatment with alum consider the biomass a liability and dispose of it as waste. The biomass from these projects is spread typically on the land at the treatment site or at an approved disposal site within the same watershed. Natural wetland remediation sequesters nutrients within the wetland biomass temporarily, but these nutrient sinks can shift to nutrient sources under a variety of conditions and contribute to the problem rather than remediate it. In addition, natural wetland uptake of nutrients do not retain high nutrient uptake efficiencies over diverse spatial or long temporal scales. The preferred method is to find efficient and effective treatment systems that incorporate beneficial uses to keep the nutrients from being

returned to the source water. The AquaFiber process removed all biomass residuals, nutrients and other pollutants within that biomass permanently from the Lake Jesup watershed sub-basin and found a beneficial use for it as a renewable energy feedstock or soil amendment primarily.

2. Reliability and Adaptability: The data show high levels of nutrient reduction efficiency throughout a broad range of weather, seasonal and lake conditions. Over the 5-year contract period, the facility operated 24 hours a day and 7 days each week. Facility operations were terminated from time to time to respond to power outages, equipment maintenance and/or replacement, safety inspections, routine maintenance, technology improvements, holidays and contract transitions. Lake Jesup is impacted by high variability in both weather and water conditions (i.e. lake water levels, nutrient levels, water chemistry, turbidity, salinity impacts from the St. Johns River, and extreme weather/wind events). The data show the ability of AquaLutions®™ to perform effectively and efficiently throughout a wide range of working conditions.
3. Environmental Safety: "Do no harm" is the foundation for sustainable and ethical water technology applications. Results from 16 routine whole effluent toxicity (WET) tests conducted over 5 years on a routine basis support the environmental safety of the process.
4. Biomass Handling and Sustainability: The SJRWMD contract called for residual biomass to be disposed of in a landfill. However, AquaFiber determined that this method was not economically viable, environmentally friendly, nor sustainable. Therefore, several beneficial end-use applications were developed that sequestered and removed the nutrients from the watershed permanently. AquaFiber developed a number of strategic relationships with companies and scientific research institutions that represent the emerging clean technology industry cluster for Florida and the United States. Examples included:
    a. Certified JP-8 aviation jet fuel as part of a DARPA contract with SAIC
    b. A hydrogen-based welding gas in partnership with MagneGas Corporation, Pinellas County, FL (http://magnegas.com/)
    c. Gasification to produce clean electricity with MaxWest Environmental Systems, Inc., Seminole County, FL (http://maxwestenergy.com/)
    d. Anaerobic digestion to produce clean electricity with Harvest Power, Inc., Orange County, FL (http://www.harvestpower.com/florida/)
    e. Bio-based fertilizer mix Oldcastle Lawn and Garden, Inc., Polk County, FL

f. Low phosphorus slow release bio-fertilizer pellets through a process developed by VitAg Corporation, Orange County, FL

In addition, considerable national attention is focused on biomass research for novel industry applications. AquaFiber delivered biomass to a wide range of interested scientific research groups looking at a multitude of applications from renewable energy to novel biochemicals and pharmaceuticals. This level of interest in cyanobacteria and biomass represent a secondary, unforeseen benefit of the AquaFiber Lake Jesup facility as an incubator for clean-tech expansion in Florida.

4.5 Challenges Ahead: Lake Jesup has been described as, "*hypereutrophic and nearly devoid of submerged aquatic vegetation*" (SJRWMD, 2002). The lake has been characterized as unhealthy with excessive phosphorus and nitrogen concentrations, extensive muck deposits, and declining fish populations. These conditions are typical of many lakes throughout Florida. Lake Jesup was an appropriate site for water technology testing because it is considered, "…*the most polluted lake directly connected to the St. Johns River*" (SJRWMD, 2008). After almost 20 years of stormwater regulations and remediation projects, the Lake's ecological condition has not improved dramatically. **Figure 10**, **Figure 11** and **Figure 12** show the SJRWMD's latest 10-year TP, TN and Trophic State Index (TSI) water quality data and trends, respectively for Lake Jesup, as published on the Seminole County Water Atlas (http://www.seminole.wateratlas.usf.edu). All three parameters are well above the NNC or other indicators of a healthy lacustrine ecosystem, and show little change over time. A simulation of stormwater loading to Lake Jesup by the SJRWMD demonstrated that even if all available land in the basin were converted to stormwater Best Management Practices, the pollution reduction to Lake Jesup would be insufficient to restore the lake (Brandt-Williams, 2010).

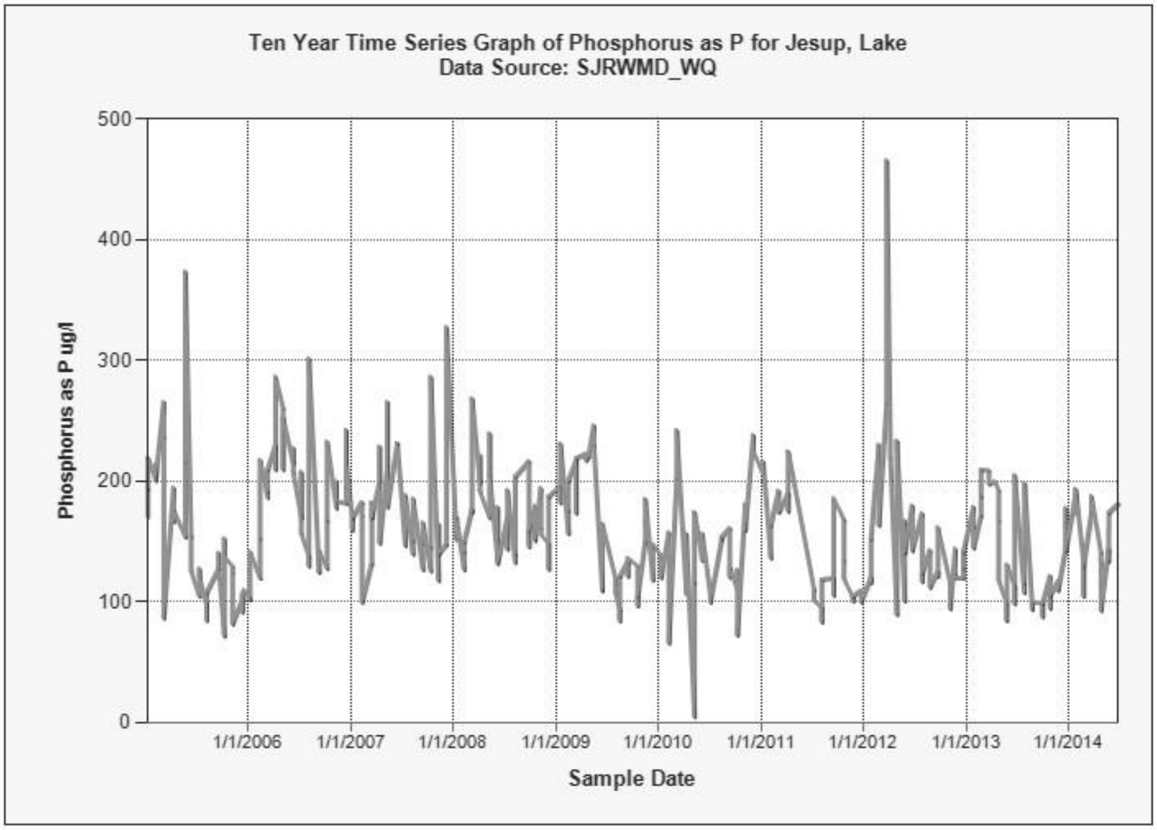

Figure 10: 10-Year TP Trend for Lake Jesup (TP concentrations in Lake Jesup over the last ten years as shown by SJRWMD water quality data on the Seminole County Water Atlas.)

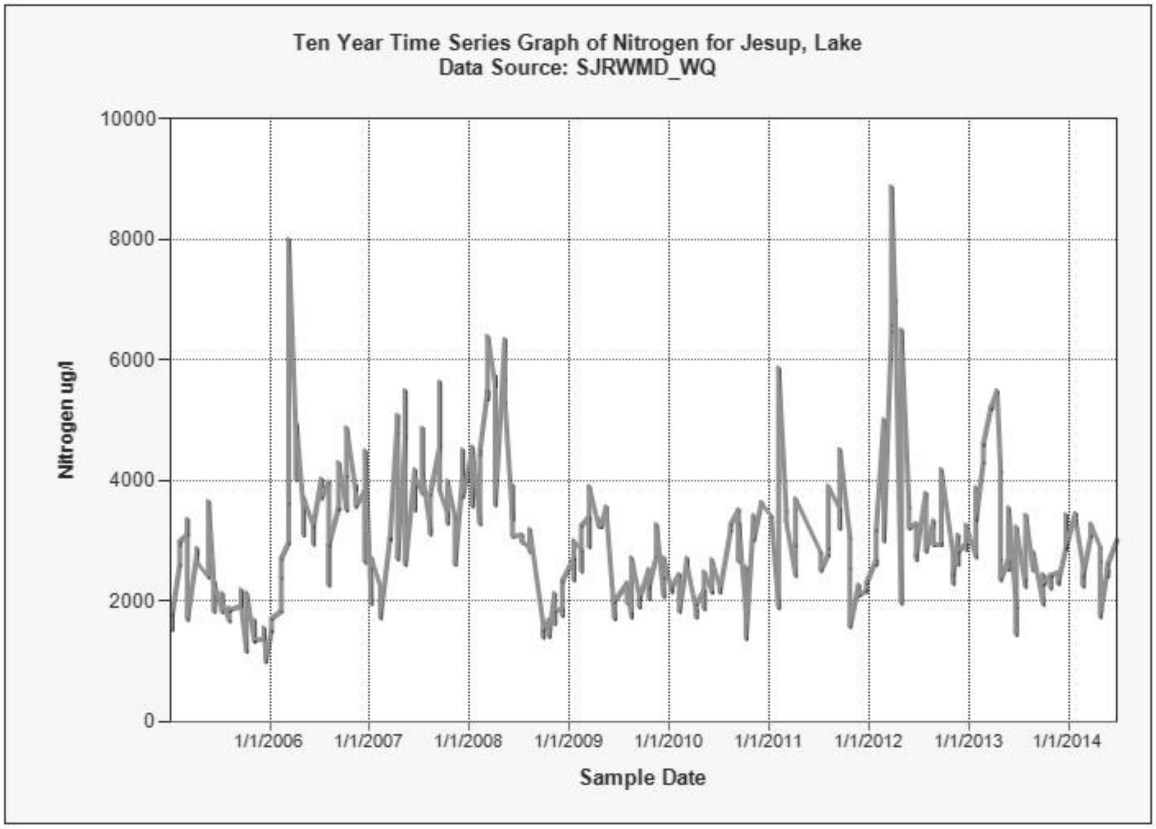

Figure 11: 10-Year TN Trend for Lake Jesup (TN concentrations in Lake Jesup over the last ten years as shown by SJRWMD water quality data on the Seminole County Water Atlas.)

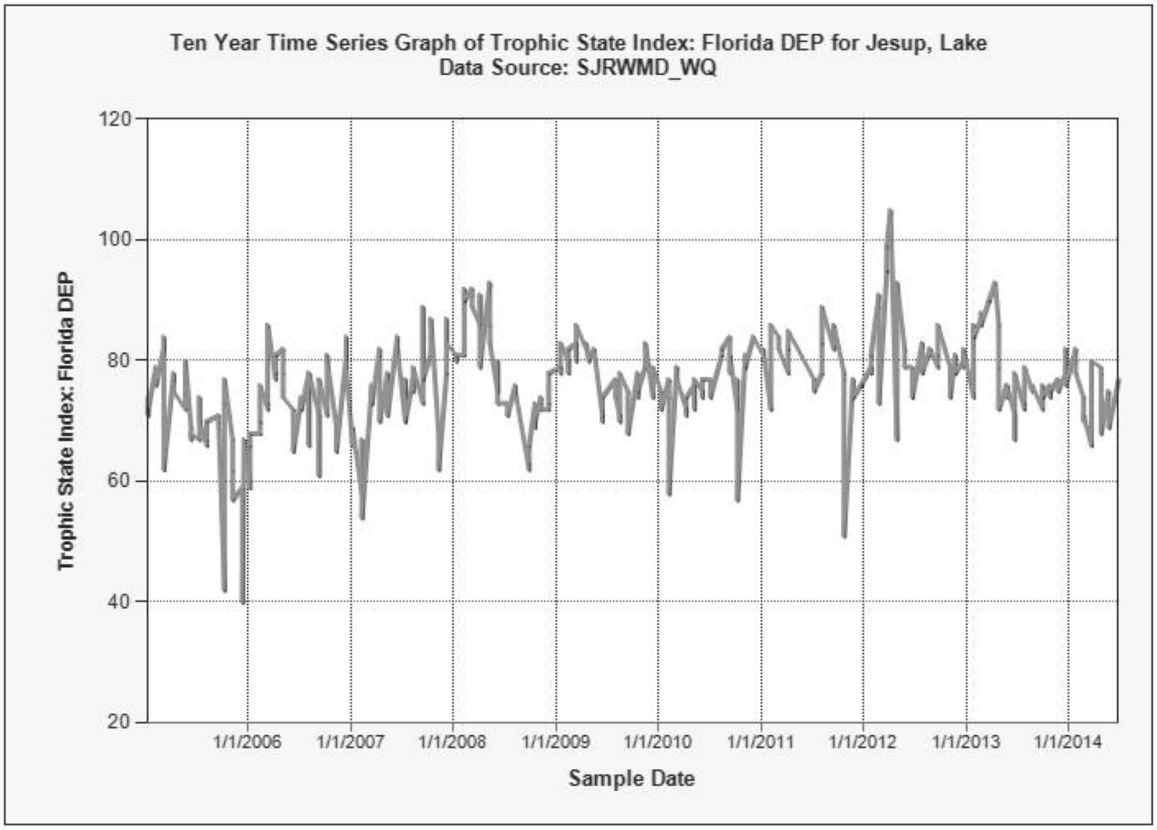

Figure 12: 10-Year TSI Trend for Lake Jesup (TSI values in Lake Jesup over the last ten years as shown by SJRWMD water quality data on the Seminole County Water Atlas.)

This assessment confirms the need for advanced water quality treatment approaches and new technologies to reduce nutrient source inputs and in-lake legacy loads to achieve whole waterbody restoration goals. Past lake management strategies, regulatory compliance actions and BMAPs have focused solely on reduction of TP at Lake Jesup (and most freshwater lakes in Florida). It is our opinion, that a single nutrient reduction strategy is no longer scientifically defensible for Lake Jesup. Lake Jesup is connected to the Middle St. Johns River Basin (MSJRB) with upstream connections to Lake Harney and downstream connections to Lake Monroe, the Lower St. Johns River Basin (LSJRB) and ultimately the Atlantic Ocean (**Figure 13**).

Figure 13: St. Johns River Basin Map (Map depicting the major basin boundaries along the St. Johns River)

The MSJRB nutrient reduction targets are 76,341 kg TP/yr and 2,688203 kg TN/yr. The Lake Jesup BMAP calls for a TP reduction of 8,504 kg only. There is no requirement for TN regulation or reduction in the Lake Jesup BMAP. In contrast, the Lake Monroe and Lake Harney BMAP’s call for a total reduction of Lake Jesup nutrient loads into the MSJRB of 5,715 kg of TP and 124,738 kg of TN. This lack of regulatory consistency and downstream alignment of nutrient reduction goals suggests that there is a clear need for BMAP re-evaluation, consistency analysis and modification. In addition, most BMAPs and stakeholder TMDLs rely heavily on presumptive models and static land-use patterns to estimate nutrient loads. Without quantification and independent verification of measured nutrient reductions by BMAP projects, it becomes difficult for regulatory agencies to document actual nutrient removal, evaluate BMAP compliance and initiate enforcement actions as necessary. The result is that most BMAPs have not documented water quality improvements nor achieved their intended water body remediation goals.

In many Florida lakes, a key symptom of hypereutrophic conditions is cyanobacteria dominance and blooms. This cyanobacteria dominance is a key characteristic of Lake Jesup (Coveney, et al., 2011). Some cyanobacteria such as *Microcystis* can survive and even adapt genetically to the shifting, low N_2 or low P conditions of temperate freshwaters with high levels of dissolved organic matter like Lake Jesup (Harke & Gobler, 2013). Therefore, P-only reduction strategies are likely to fail in lakes dominated by these hardy, or non-N_2 fixing cyanobacteria species (Conley, et al., 2009). Furthermore, these waterbodies are interconnected and ultimately flow to the ocean. Holistic, dual-nutrient reduction policies are necessary, so these downstream waters are also protected. Conley, 2009 and his coauthors state:

> "*It is prudent, and in most cases essential, to implement a dual-nutrient reduction strategy when developing measures to control eutrophication. A focus on only P or N reduction should not be considered unless there is clear evidence or strong reasoning that a focus on only one nutrient is justified in that ecosystem and will not harm downstream ecosystems*."

This emerging focus on dual-nutrient reduction strategies has been supported by a growing number of peer-reviewed scientific publications (Lewis, Wurtsbaugh, & Paerl, 2011; Moss, Jeppesen, Sondergaard, Lauridsen, & Liu, 2013; Paerl, 2009; US EPA Office of Water, 2012). In addition, a recent study on the Indian River Lagoon demonstrated that nutrient limitation may vary on both spatial and temporal scales within a single waterbody (Lapointe, Herren, Debortoli, & Vogel, 2015 in press). This provides further support for nutrient remediation strategies that can address dual nutrient reduction.

The great challenge for Florida water managers will be to integrate and align regulatory mandates with broader water quality restoration strategies to address both source inputs and legacy loads with a long-term commitment to identify and track appropriate biological response criteria. This comprehensive, long-term perspective is essential to evaluate restoration efficacy with full consideration and understanding of complex spatial and temporal variability with Florida ecosystems.

There is an urgent need for the state to adopt standardized methodologies for economic and project cost analyses. The complex nature and diversity of restoration approaches presents a continuing challenge for regulated stakeholders, policy makers and clean-tech industry partners. Over the past 5 years, AquaFiber was confronted with a wide range of opinions and values regarding the cost to remediate phosphorus in Florida surface waters. A review of the published literature and extensive discussions with local municipalities and the SJRWMD confirmed that there was no standard methodology to analyze project costs. In addition, these projects only sequestered the nutrients *in situ* for re-introduction to the water column at a later date (e.g., marsh flowway, alum treatment) unlike AquaLutions®™ that permanently removes the nutrients and exports them out of the watershed. To address this issue, AquaFiber conducted a comprehensive review of existing and proposed cost estimates of a number of existing and proposed nutrient remediation projects to guide development of a business model for full commercialization of AquaLutions®™. AquaFiber discovered that:

1. Most project costs did not identify and consider all capital and O&M costs associated with the project.
2. Most project costs were based on proposed projects and presumptive cost estimates rather than actual project cost analyses.
3. Most project costs did not consider the additional values and ecosystem benefits provided by AquaLutions®™ such as TN and TSS reduction, improved water clarity, reduced toxicity and legacy load reduction.
4. There was no standardized methodology used to amortize the capital cost of construction.
5. There was no standardized methodology used to address site-specific conditions.
6. Water quality variability and post-treatment water quality targets were highly variable and those performance expectations have a direct influence on project costs.
7. There was no standardized application of permit and performance requirements for projects.
8. There was limited or no scientific documentation of system performance, system monitoring for environmental safety, waste stream handling, transport and disposal. This variable application of regulatory oversight, results in regulatory and financial inequities among projects confounding fair and accurate cost comparisons.

5.0 Conclusion

This project demonstrated that advanced DAF treatment technologies coupled with other water treatment applications can remove TP, TN, TSS and water pollutants effectively, efficiently and safely. As the State of Florida begins to address comprehensive water policy during the 2015 Legislative Session, this 5-year nutrient removal demonstration project provided three important insights into potential roadblocks that must be considered by Florida water managers, policy makers and citizens if long-term restoration goals are to be realized:

1. There is an important role for private-sector investment in surface water quality technology development and deployment that can help address Florida water quality restoration needs and drive job creation in the clean-tech industry cluster.
2. To encourage private sector investment and participation in public-private partnerships, Florida must clarify roles and responsibilities of stakeholders within BMAPs, understand total nutrient loads (source and legacy) impacting the system, recognize the role of dual-nutrient reduction, and quantify load reductions with independent verification and enforcement.
3. The State of Florida must reinforce that water quality protection and restoration is a legislative mandate and recognize the potential to take a national leadership role in this market. It must develop and apply models that attribute all excess nutrient loading to a stakeholder and create fair cost-comparison methods It must also consider water quality benefits over the lifetime of a project when considering it for funding.

6.0 Acknowledgements

The authors would like to thank the following: AquaFiber Technologies Corporation investors for their substantial financial support of AquaFiber and the Lake Jesup project. AquaFiber Executive Team - Ronald Edwards and Melanie Reed. AquaFiber Lake Jesup Facility Operations Team - Clinton Simmons, Jody Cline, Michael Wilson, Nicholas Coggon and Franklin Acosta. Special thanks to Dr. Sherry Brandt-Williams, Project Manager for the SJRWMD. AquaFiber extends a broad thank you to all staff from the SJRWMD, FDEP and other Florida state agencies for their input and support during this project. The project was supported financially by AquaFiber shareholders and a SJRWMD Contract (# SK473AA). AquaFiber also received partial funding as a sub-contractor to SAIC for biomass collection, processing and conversion to bio-fuel as part of a DARPA project to develop affordable alternatives to petroleum-derived jet fuel (JP-8) from agricultural and aquacultural feedstock materials (DARPA Algal Biofuels Program BAA08-07).

Glossary

AquaKnight®™	AquaFiber’s mobile, trailer mounted version of AquaLutions®™
AquaLutions®™	AquaFiber’s patented, trade-secret process to remediate water bodies.
Basin Management Action Plan - BMAP	A regulatory document describing how stakeholders will implement restoration projects to meet the TMDL.
Biomass	The combined organic and inorganic material harvested as part of the AquaLutions™ process.
Cyanobacteria	A phylum of bacteria that use photosynthesis to obtain their energy. Also known as blue-green algae.
Dissolved air flotation – DAF	A water treatment process that dissolves air in the water under pressure and then releases that pressure in a flotation tank to create tiny air bubbles that adhere to the suspended matter and cause it to float.
Dual-nutrient	A water remediation term that combines both total phosphorus and total nitrogen into one.
Eutrophic	The ecosystem state that occurs following the addition of artificial or natural substances, mainly phosphates, through detergents, fertilizers, or sewage, to an aquatic system. It is characterized by the "bloom" or great increase of phytoplankton in a water body as a response to increased levels of nutrients.
Hypereutrophic	The ecosystem state of very nutrient-rich water bodies characterized by frequent and severe nuisance algal blooms and low transparency.
Legacy load	The sediment underlying a water body that contributes to internal nutrient cycling. This sediment layer is usually attributed to loadings from anthropogenic sources prior to present-day source control.

Mass balance	An application of conservation of mass to the analysis of physical systems. The total mass entering and leaving a system is used to create budget calculations. In water remediation, it is used to reconcile the mass removed as shown by water chemistry sampling.
Numeric Nutrient Criteria – NNC	Water quality standards established in state and federal rules as the goals for the protection of aquatic ecosystems, safe recreation and fishing, and provision of water supplies, or the designated uses of surface waters.
Sustainability	The ability to sustain or capacity to endure changes in the environment, economy and society; often thought of as the three pillars of sustainability.
Total Maximum Daily Loads – TMDL	A baseline of current pollutant loadings and reductions required to allow a water body to meet its NNC and return to its designated use.
Whole Effluent Toxicity – WET	Acute and chronic water toxicity test that exposes living aquatic organisms to samples of product water to determine survival and fecundity rates.
Whole-waterbody restoration	Restoration method that focuses on restoring the ecosystem functions of a entire lake, not just the water quality.

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Attachment C

Anuvia Plant Nutrients Technology

The Anuvia Ammonium Mix (“AM”) Technology

The Anuvia Ammonium Mix (“*AM*”) process converts dewatered organic materials such as biosolids, digested food-waste and concentrated algae into a safe, pathogen-free USEPA Exceptional Quality (EQ) fertilizer product which meets or exceeds the requirements of local, state or federal regulations. The resultant slow-release dry granular fertilizer fits directly into the regional and national agricultural marketplace. The Anuvia *AM* Process is a sophisticated production of organic ammonium sulfate fertilizer utilizing municipal organics that are in a microbial form, reacted with concentrated acids, and an ammonia source.

The Anuvia manufacturing plant receives the organic material in a dewatered form preferably in the range of 20% to 30% solids. If the solids are out of this preferred range, then additional technology can be applied to bring the organics into the proper percent solids. After receipt, the dewatered organics are conveyed to storage silos in the Anuvia plant. From the storage silos, the dewatered organics enter the conditioning step and process steps as depicted.

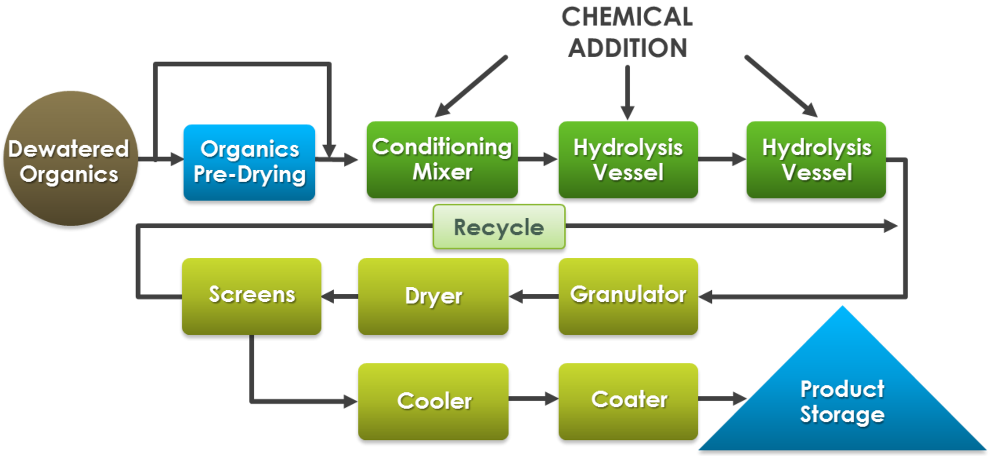


Figure 1 – Primary Components and Sequence of the Anuvia Process

The Anuvia *AM* Process:

- Creates a value-added product unsurpassed in commercial value by utilizing organics derived from multiple natural, municipal and industrial sources.

- Creates a dry granular fertilizer product that meets all U.S. Environmental Protection Agency Exceptional Quality (”EQ”) and environmental quality standards if and when biosolids are used.

- Is operated to exceed USEPA and State pathogen reduction standards by both sterilizing the organic material as well as inactivating/hydrolyzing bioactive compounds present in the input organics.

- Creates a dry (98.5% solids) granular inorganic-organic containing fertilizer product which will compete in the turf, specialty and commodity fertilizer markets with traditional fertilizers such as urea, ammonium sulfate, and diammonium phosphate. Anuvia presently manufactures three brands, Greentrx, for turf and golf course applications; and, Symtrx (20S and 10S) for agricultural applications, and ANUGREEN for retail lawn sale.

The Anuvia process incorporates ammonium salts with conditioned digested organics to create a granular, organic ammonium sulfate slow-release fertilizer from organic materials.

The important steps in this *AM* manufacturing process are an initial exposure of the organics to one or more concentrated acids such that the pH of the mix is reduced to an extremely low value of less than pH 0.1. Because these concentrated acids are introduced into what is basically an aqueous environment, significant heat (greater than 225F) is created by heat of hydration. In addition to liquification, this heated acid treatment of the organics causes macromolecules such as proteins to be hydrolyzed into peptides and monomeric amino acids. Following exposure to this extreme pH heated environment the acidified mix is then sequentially treated with gaseous anhydrous ammonia to both create a high nitrogen multi-nutrient fertilizer mix containing an organic matrix imparting a slow-release characteristic to about 30% of the inorganics present. This reaction with anhydrous ammonia creates a temperature greater than 330F and a pressure greater than 32 PSI. In addition, the basic anhydrous ammonia is used to ultimately neutralize the fertilizer mix pH to physiological levels. Further advantages of this process are that the reaction conditions, such as temperature and pressure, can be controlled, and that all microorganisms are destroyed. An additional finding was that when Florida lake algae were used as the organic input a significant level of algal toxin, e.g., microcystin, was present in the algal concentrate. The Anuvia treatment stresses described above destroyed this toxin by over 99%. Another way of explaining this reaction sequence is to consider that the acidification process principally degrades the input organics preparing them for a build-up in the ammoniation vessel into an organic matrix comprised of amphoteric organics complexed with oppositely charged nutrients such as the ammonium ion and the sulfate ion.

This inorganic-organic matrix causes the “docked” nutrient ions and be gradually released throughout the growth cycle of the target crops thereby imparting the slow-release or Enhanced Efficiency characteristic to the Anuvia fertilizer.

Attachment D

FDEP Verification Letters

FLORIDA DEPARTMENT OF
ENVIRONMENTAL PROTECTION
BOB MARTINEZ CENTER
2600 BLAIRSTONE ROAD
TALLAHASSEE, FLORIDA 32399-2400

RICK SCOTT
GOVERNOR

CARLOS LOPEZ-CANTERA
LT. GOVERNOR

HERSCHEL T. VINYARD JR.
SECRETARY

February 7, 2014

Kirby B. Green, President
AquaFiber Technologies Corporation
1150 Louisiana Avenue, Suite 1
Winter Park, Florida 32789

Dear Mr. Green:

The Department has reviewed the available information on the pilot AquaLutions Project in Lake Jesup. Based on our understanding of the principle of operation of the treatment process in question, as well as measurements performed by our lab on samples collected during our study at Lake Jessup, we believe that the AquaLutions process is demonstrating success in removing phosphorus and nitrogen from the lake. Additionally, toxicity tests of treated and untreated lake water have demonstrated that the treatment is not harmful to the lake. The Department views the project as in-lake nutrient abatement, not source removal or reduction and therefore would be eligible for annual Basin Management Action Plan (BMAP) credits for as long as the practice is operational and effective.

As a result, the Department is allowing BMAP credit for the phosphorous and nitrogen reductions resulting from the project on a 1:1 basis (one pound of BMAP reduction credit available for each pound of phosphorus and nitrogen removed from the basin). Annually, local stakeholders would receive credit against their BMAP obligation for each pound removed as a result of the project.

Should the project be discontinued at any time in the future, local stakeholders who have received credits from the project will need to replace the annual phosphorous and nitrogen reduction credits previously obtained through this project with other activities. As you know, the TMDL and BMAP will continue to be revisited as more information is gained. Future revisions could recognize the effects the AquaLutions Project has on the lake's response to nutrient inputs.

Allowing BMAP credits for the AquaLutions Project in no way alleviates or diminishes the requirement for obtaining permits for continuation or expansion of this project pursuant to State law.

Sincerely,

Thomas M. Frick, Director
Division of Environmental Assessment and Restoration

www.dep.state.fl.us

Florida Department of
Environmental Protection
Bob Martinez Center
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Rick Scott
Governor

Jennifer Carroll
Lt. Governor

Herschel T. Vinyard Jr.
Secretary

August 31, 2011

Mr. Thomas Bland, Jr.
AquaFiber Technologies Corporation
4750 New Broad Street
Orlando FL 32814

Dear Mr. Bland:

The Department has reviewed the available information on the pilot AquaLutions Project in Lake Jesup. Based on this information, the project does not appear to have any harmful effects to the lake and is demonstrating success in removing phosphorous from the lake. The Department views the project as in-lake nutrient abatement, not source removal or reduction and therefore would be eligible for annual Basin Management Action Plan (BMAP) credits for as long as the practice is operational and effective.

As a result, the Department is allowing BMAP credit for the phosphorous reductions resulting from the project on a 1:1 basis (one pound of BMAP reduction credit available for each pound of phosphorus removed from the basin). Annually, local stakeholders would receive credit against their BMAP obligation for each pound removed as a result of the project.

Should the project be discontinued at any time in the future, local stakeholders who have received credits from the project will need to replace the annual phosphorous reduction credits previously obtained through this project with other activities. As you know, the TMDL and BMAP will continue to be revisited as more information is gained. Future revisions could recognize the effects the AquaLutions Project has on the lake's response to nutrient inputs.

Allowing BMAP credits for the AquaLutions Project in no way alleviates or diminishes the requirement for obtaining permits for continuation or expansion of this project pursuant to State law.

Respectfully,

Andrew Bartlett, Director
Division of Environmental Assessment and Restoration

AB/ab/h

cc: Vivian Garfein, Director, DEP Central District
Kirby Green, Executive Director, St. John's River Water Management District
Samantha Budd, DEP Basin Coordinator

www.dep.state.fl.us

From:	Bill Eggers <bill.eggers@aquafiber.com>
Sent:	Wednesday, May 20, 2020 1:22 PM
To:	Bays, Jim/TPA
Cc:	becca.burnett@aquafiber.com; Rocha, Andrea/TPA
Subject:	[EXTERNAL] Re: SUSPICIOUS EMAIL AQUALUTIONS CHECK.xlsx
Attachments:	C 43 npv 457 cfs.xlsx

Jim,

Thanks for your analysis. I hate to say it, but we are having trouble understanding how you came up with some of the numbers in your spreadsheet. I have attached one of our worksheets showing our work and how we calculated the NPV and load reduction for the 457 cfs model. The cost per pound is calculated as if we are being paid for TP only, or TP and TN together.

One difference we can discern is that we don't break out the cost to operate by TP, TN, and TSS. With the work AquaFiber does, all three of those constituents come out at the same time. So, in a case where TP is the target there is no extra work done to extract the TN or TSS. We will spend the same amount of money regardless of whether we are only measuring TP or all three. They all come out at once with the algae.

Note also that we are proposing to remove 75% of the TP and used 300 working days instead of 270. The working days is based on some additional info from Pieter on April 29 where he indicated 10 months of working time (4 months loading, 6 months discharge). If we need to change it, let me know.

If this doesn't help, we might want to schedule a call to discuss more.

Bill

On Wed, May 20, 2020 at 9:52 AM Bays, Jim/TPA <Jim.Bays@jacobs.com> wrote:

> Hi Bill and Becca,
>
> I'm in the midst of summarizing and comparing the different technology submittals for the C-43 West Basin Storage Reservoir Project. I really appreciate the level of detail and interesting information you've provided. However, I'm not sure I'm following the logic or calculations for the treatment performance and cost-effectiveness net present worth calculation.
>
> In the attached spreadsheet, I've utilized the expected removals and your cost projections. The unit costs are greater than what you've summarized in your submittal, and before I go much further, I'd like to make sure we have the same basic understanding.

Can you please review this, and 1) correct me or 2) question me for clarification.

Thanks,
Jim

Jim Bays | Jacobs | Technology Fellow | Natural Treatment Systems | + 01.813.281.7705 | + 01.813.765.9286 mobile | + 01.813.874.3056 fax

Jim.Bays@jacobs.com | www.jacobs.com

--

Bill Eggers, CEP, CWB, PWS
VP Science & Technology
AquaFiber Technologies Corporation
bill.eggers@aquafiber.com
321-277-6500

THIS IS A PROVISIONAL WORKSHEET - SUBJECT TO CHANGE

AquaFiber Technologies Corporation: C-43 Reservoir

Type of Service: 457 cfs Water Quality Treatment

Interest Rate 0.03

Life Span (yrs) 20

	Year	Project Service Area: acres	TP Load Removed: lbs	Capital Cost	Annual Operation Cost	Annual Land Use Payment	Total:	Discount Factor	Annual Discounted Total Costs
0	2023	#REF!	0	$97,966,878		$0.00	$97,966,878	1.000	$97,966,878
1	2024	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.971	#REF!
2	2025	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.943	#REF!
3	2026	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.915	#REF!
4	2027	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.888	#REF!
5	2028	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.863	#REF!
6	2029	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.837	#REF!
7	2030	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.813	#REF!
8	2031	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.789	#REF!
9	2032	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.766	#REF!
10	2033	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.744	#REF!
11	2034	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.722	#REF!
12	2035	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.701	#REF!
13	2036	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.681	#REF!
14	2037	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.661	#REF!
15	2038	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.642	#REF!
16	2039	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.623	#REF!
17	2040	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.605	#REF!
18	2041	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.587	#REF!
19	2042	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.570	#REF!
20	2043	#REF!	641,908	$0.00	#REF!	#REF!	#REF!	0.554	#REF!
Evaluation Metrics/Indicators:									
Net Present Value, (NPV @ 3.0%)			12,838,153	$97,966,878	#REF!	#REF!	#REF!		#REF!

Estimated Cost per lb dual nutrients (TP and TN):	$8	#REF!	#REF!	#REF!		
Percent Breakdown: Est. cost / lb.:	#REF!	#REF!	#REF!	#REF!		

Notes: The Costs In Each Column Are Escalated for the Year They Are Shown.

Annual Operation Costs (NPV)	#REF!

THIS IS A PROVISIONAL WORKSHEET - SUBJECT TO CHANGE

AquaFiber Technologies Corporation: C-43 Reservoir

Type of Service: 457 cfs Water Quality Treatment

Interest Rate 0.03

Life Span (yrs) 20

	Year	Project Service Area: acres	TP Load Removed: lbs	Capital Cost	Annual Operation Cost	Annual Land Use Payment	Total:	Discount Factor	Annual Discounted Total Costs
0	2023	#REF!	0	$97,966,878		$0.00	$97,966,878	1.000	$97,966,878
1	2024	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.971	#REF!
2	2025	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.943	#REF!
3	2026	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.915	#REF!
4	2027	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.888	#REF!
5	2028	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.863	#REF!
6	2029	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.837	#REF!
7	2030	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.813	#REF!
8	2031	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.789	#REF!
9	2032	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.766	#REF!
10	2033	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.744	#REF!
11	2034	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.722	#REF!
12	2035	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.701	#REF!
13	2036	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.681	#REF!
14	2037	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.661	#REF!
15	2038	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.642	#REF!
16	2039	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.623	#REF!
17	2040	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.605	#REF!
18	2041	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.587	#REF!
19	2042	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.570	#REF!
20	2043	#REF!	88,539	$0.00	#REF!	#REF!	#REF!	0.554	#REF!
Evaluation Metrics/Indicators:									
Net Present Value, (NPV @ 3.0%)			1,770,780	$97,966,878	#REF!	#REF!	#REF!		#REF!

Estimated Cost per lb dual nutrients (TP and TN):	$55	#REF!	#REF!	#REF!		
Percent Breakdown: Est. cost / lb.:	#REF!	#REF!	#REF!	#REF!		

Notes: The Costs In Each Column Are Escalated for the Year They Are Shown.

Annual Operation Costs (NPV)	#REF!

Flow (gal. per day)		**295,000,000**
Term of Contract		20
TSS (mgl)		20
TP Avg (ug/L)		160
Operational Days/Year		300
Capital Cost	**$**	**97,966,878**

WATER BODY VARIABLES

Project Flow (gal.)	295,000,000
TSS (mg/l)	20
TSS Removal Efficiency (%)	50%
Biomass/yr. (lb.-dry wt.)	7,378,249
TP avg. (ug/l)	160
TP Removal Efficiency (%)	75%
Total Phosphorous Removed (lb./yr.)	88,539
TN avg. (ug/L)	1,500
TN Removal Efficiency (%)	50%
Total Nitrogen Removed (lb./yr.)	553,369

Annual Sales Price/Pound TP & TN

Annual Flow		88,500,000,000
Annual O&M Cost		**#REF!**
Annual Land Cost	**$**	**188,000**
Annual TP Removal		88,539
Annual TN Removal		553,369
Total Annual TP & TN Removal		641,908

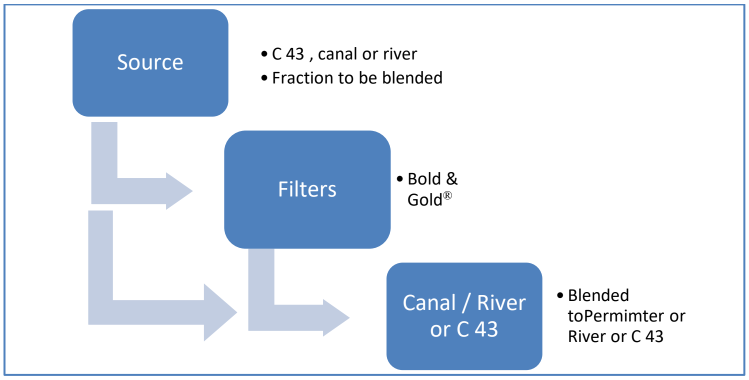
Bold & Gold (B&G)

Environmental Conservation Solutions

Environmental Conservation Solutions (ECS) is pleased to submit this response to the request for information from the C-43 WBSR Water Quality Feasibility Study Working Group. The information provided is compiled from laboratory research conducted by the University of Central Florida along with field data from projects throughout Florida installed since 2003. Dr. Martin Wanielista, Professor Emeritus, University of Central Florida, Dr. Ni-Bin Chang, Professor, University of Central Florida, Dr. Ikiensinma Gogo-Abite, ECS, and RJS Construction contributed to the response. Chris Bogdan is the point of contact from ECS if the Water Quality Feasibility Study Working Group has any questions related to our response or require additional information. We appreciate the opportunity to be involved with this project.

I. **Treatment Process: Bold & Gold® Filtration Media**

A. Process Flow Diagram



At average flow of 457 CFS, 12 filter cells are needed with a blending of source and filtered water.
And (15) filter cells for treatment of the maximum flow of 600 CFS
At minimum flow time, less filter acreage is needed, or greater mass removal is possible.

The media is called Bold & Gold® (B&G) and it removes more pollution than the target levels specified. Thus, there is an opportunity to treat by filtration a fraction of the source water and blend the treated water with the source water before discharge. This also provides an option to not blend when the discharge flow is lower than the average or when influent water quality conditions deteriorate (i.e. mass in the source is in excess of what is expected). A **very flexible** operating rule for treatment results from blending. There are changing source water quality and flow discharge conditions. Blending will permit operation that will allow the targets to be met while achieving a reduced cost from not over building the treatment capacity. A 5-acre filter cell size is recommended to give additional flexibility for meeting source water quality variations and flow discharge to the River. The treatment filtration rate using the media is 5 inches per hour. A 5-acre filter cell will treat 25.2 CFS or [5 (in/hr) x 5 ac x 43,560 (SF/ac) / 12 (in/ft) / 3600 (sec/hr)]. We are proposing to build 15 treatment cells.

Each filter is a mix of graded sand, clay, and recycled tire crumb. The filter mix is called Bold & Gold® CTS. The processes Bold & Gold® CTS media use to attain the desired removal are:

- Removal of particulate species of TN and TP is by physical separation or straining.
- Removal of dissolved species of TP is by chemical means, primarily sorption, and precipitation.
- Removal of dissolved species of TN is by chemical as well as biological means.
  Nitrate removal is by denitrifying organisms and anammox (AMX). AMX functions in an anaerobic environment for the removal of nitrate.

Ammonia is also removed when Ammonia Oxidizing Bacteria (AOB), and Nitrite Oxidizing Bacteria (NOB) are present. Diagram shows bacteria mix on B&G CTS media.

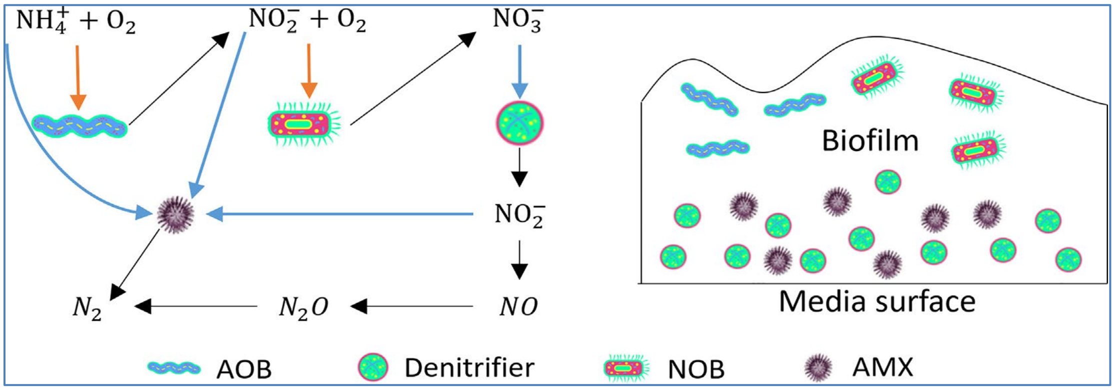


Figure 1 Nitrogen Process Diagram for B&G From: Wen, Chang and Wanielista. Comparative Copper Toxicity impact and enzymatic cascade effects on Biosorption Activated Media. **J. Chemosphere** 2018.09.062 The media in this publication is a form of B&G CTS. Biosorption Activated Media is a term first used by the research team at UCF under a grant from water management districts, Florida DOT and Florida DEP.

B. Flow Equalization - (Temporary detention of water volume or reduction in flow rate required to implement the treatment process using storage tanks, basins, or other means).

A distribution basin is planned so that water can be provided to each cell at the specific treatment rate of 5 inches per hour.

C. Distribution

For the Filter Cell: Water is distributed by pipe and risers onto the surface of the filters. This is common practice with this type of treatment and has been used for infiltration basins.
For the Blending Basin: Values and weirs are used to provide the amount of water that must be mixed from the source as well as from the filters.

D. Pre-Treatment Processes

None, the water quality expected in the reservoir, river or canal has been treated before with the use of a B&G filter and without pre-treatment. We do not expect a need for pre-treatment.

E. Treatment

1. Provide information demonstrating prior pilot/project capability to achieve the project water quality criteria
2. Treatment chemicals and/or media required for the process will be described

Achieve Water Quality Criteria (prior project performance):

B&G has documented performance for nutrient removal from full scale operations. B&G has been used in at least 200 locations around the State of Florida for the reduction of phosphorus and nitrogen species. A partial listing of sites is shown in Appendix “A”. Four sites are operational for over 10 years without media replacement. The removal efficiencies are summarized in Appendix “B” and supported by referred publications. In Appendix “B”, are other references for the use of the materials found in Bold & Gold® and a summary of pollution control effectiveness.
The C 43 filter cells will use B&G CTS mix. CTS refers to a mix with **C**lay, **T**ire Crumb, and **S**and. Based on past monitored and published data on water quality performance, we expect the following average removal percentages and a range (shown in %) with this B&G CTS mix.:

1. Dissolve Organic Nitrogen (DON) 50% (±10%)
2. Dissolved Bio-Available Organic Nitrogen (BON) 50% (±10%)
3. Dissolved Inorganic Nitrogen forms, ammonia and nitrate (NH_3 and NOx) 90% (±10%)
4. Particulate Nitrogen (PN) 90% (±10%)
5. Total Nitrogen (TN) 70% (±10%)
6. Particulate Phosphorus (PP) 95% (±2.5%)
7. Soluble Reactive Phosphorus (SRP) 70% (±5%)
8. Total Phosphorus (TP) 80% (±5%)
9. Total Suspended Solids (TSS) 95% (±2.5%)

Notes: Nitrite is rarely measured above detection levels in the effluent from a B&G filter. Percent removal is based on an understanding of existing Nitrogen and Phosphorus concentrations. The organic nitrogen in the input is assumed to be 50% of TN.

Media Used:

To achieve the above specified removals, the filter uses a Biosorption Activated Media (BAM) called Bold & Gold® (B&G). B&G is a non-degradable media consisting of mineral and recycled materials. BAM is a term first published by the State University System researchers at the University of Central Florida.

The service life is dependent on the removal of SRP and has been economically used to meet design life of Florida Department of Transportation (FDOT) Projects. FDOT specifies a life of at least 30 years for most applications. We are proposing a 50 years life expectancy with lowest cost. See Appendix “A” for a partial listing of locations where the media is used in the State, all with media to match a service life.

The filter media is installed in a treatment cell. A treatment cell contains the media, drainage stone, cover sand and rock, separation fabric, liner, and piping. The B&G mix is composed of sand, clay, and tire crumb. There has been no acute toxicity measured when using B&G (see Appendix “F”). The largest filter built to date is a 3.5-acre stormwater pond in Marion County. A one-acre rapid infiltration basin in DeLand, Florida was built to treat reclaimed water and stormwater. The filters have been used to treat a range of influent nutrient concentrations.

A Material Safety Data Sheet (MSDS) is also available for B&G CTS media. The use of B&G CTS is supported by use over the last 15 years and thus requires a MSDS. One of the first applications was in greenroof technologies (planted areas on roof tops) in Southeast Florida (namely in Bonita Bay in 2003).

Filter Size to Achieve Water Quality Target Concentrations

For TP, the percent SRP is assumed at 58.5 % of the total. This is based on phosphorus species measurements at S -78. Example calculations for phosphorus removal using average TP concentration and 70% removal of SRP are:

Influent TP concentration is 0.16 mg/L
The dissolved concentration **remaining (after treatment)** is 0.16 x .585 x (1-0.70) = 0.028 mg/L
The particulate concentration **after treatment** is 0.16 x (1-.585) x (1.-0.90) = 0.0066 mg/L
The total TP **after treatment** is 0.028 + 0.0066 = 0.0346 mg/L or 22% of input (0.0346/0.16) x 100.

The target TP removal percent is 50%. Based on an input of 0.16 mg/L, this leaves 0.08 mg/L TP discharge. The B&G CTS filter removes 78% (1-22), or 0.125 mg/L removed: leaving a discharge of 0.0346 mg/L. Thus, a unique situation exists that provided great flexibility for operation of the filter. Based on influent conditions, a blending of treated filter effluent with source water is possible to meet the target of 0.08 mg/L. For the treatment level specified in the above calculations and an average discharge of 457 CFS, 292 CFS must be treated by the filter. It is blended with 165 CFS from the source (canal, upstream river or reservoir). The treated fraction is 64% of the total flow. This is based on the following TP mass balance and with details on the calculation, we have:

Mass in the Discharge = Mass from source (reservoir, river or canal) + mass from Filter.
457 x (0.08) = Flow from source (0.16) + Flow from filter (0.0346) and the total flow = 457.
And: 36.56 = S (0.16) + F (0.0346) with S+F=457, where S is source flow (CFS) and F=Filter flow (CFS)
36.56 – 15.81 = (0.16-0.0346)S results in S = 165 CFS, F = 292 CFS.
And: Each filter cell treats 25.2 CFS, thus the number of filter cells is 11.59 (round to 12)

Resiliency: (Reliable Operation) Filter Cells with Blending Achieve Target Level Concentrations for Many Discharge and Source Water Quality Conditions.

It is well known that concentrations in the source water and river discharge change over time. Thus, the number of filter cells used should be large enough to provide treatment for a variety of discharge and source water quality conditions.

For a flow discharge that varies from 300 – 600 CFS, and using the target concentrations and removals, the filter size must be large enough to treat a flow from 192 CFS (7.62 filter cells) to 383 CFS (15.2 filter cells). We are providing 15 cells. The calculations for 600 CFS flow are:

Mass in the Discharge = Mass from source (reservoir, river or canal) + mass from Filter.
600 x (0.08) = Flow from source (0.16) + Flow from filter (0.0346) and the total flow = 600.
And: 48.0 = S (0.16) + F (0.0346) with S+F=600, where S is source flow (CFS) and F=treatment flow (CFS)
48.0 – 20.76 = (0.16-0.0346)S results in S =217 CFS, F = 383 CFS.
And: Each filter cell treats 25.2 CFS, thus the number of filter cells is 15.2 (round to 15)

For a source TP concentration that is 50% higher than assumed (0.24 mg/L) and an average discharge, the number of filter cells needed is 14.28 (call 15). The calculations are:

Mass in the Discharge = Mass from source (reservoir, river or canal) + mass from Filter.
457 x (0.08) = Flow from source (0.24) + Flow from filter (0.0346) and the total flow = 457.
And: 36.56 = S (0.24) + F (0.0346) with S+F=457, where S is source flow (CFS) and F=Filter flow (CFS)
36.56 – 15.81 = (0.24-0.0346)S results in S = 100 CFS, F = 357 CFS.
And: Each filter cell treats 25.2 CFS, thus the number of filter cells is 14.28 (round to 12)

Additional operating rules can be developed and based on monitoring water quality and flow demand. Based on the professional talent of the SFWMD and with the project team, it is expected that the rules will be both in a graphical form as well as a computer-based algorithm that is remotely operational. The rule is used to determine the fraction of flow from the source to the filter and the number of filters used.

TN removed with the Filter Cells to Meet the TN Target Concentration of 1.0 mg/L

TN discharge concentration is also managed. With the filter flow of 292 CFS and blending, will total nitrogen removal exceed the target reduction of 33%? Particulate Nitrogen removal using B&G CTS is about 90% and dissolved Nitrogen removal is about 70%. Some of the particulate fraction is converted to inorganic dissolved forms, so simply adding the removals based on source water measured dissolved and particulate forms will not result in total Nitrogen removal. Based on past monitoring of B&G, we are assuming a low TN removal (conservative) of 60% (70% average – 10% variation). Based on the following with

Influent TN is 1.5 mg/L, Target level discharge is 1.0 mg/L (33% removal)
Filter removal of 60% or **remaining (discharged)** is 0.6 mg/L.

For an average discharge to the river of 457 CFS, if 292 CFS (required by TP target removal) is used, the blended discharge concentration for TN is 0.93 mg/L or (292 x 0.6 + 165 x 1.5)/457). Note 0.93 mg/L is less than the target level of 1.0 mg/L or we have achieved the 33% removal target for TN. TP is the limiting nutrient in terms of meeting discharge concentration levels after blending.

Total Suspended Soils Removal

Total Suspended Soils (TSS) removal typically is equal to or greater than particulate TP removal. TSS target removal is 50%. TP removal is 50%. Thus, it is expected that the control for any blended waters due to suspended soils will be meet provided TP target levels are met.

Additional Water Quality Benefits

Additional benefits from the use of B&G is the removal of algal toxins and Polyfluorinated Alkyl Substances (PFAS). The PFAS removals in the lab were documented using duplicated field water quality conditions. Using the B&G CTS mix initial testing documents 76-85% removal of the most common forms of PFAS (see Appendix “D”). Algal mass removal is more obvious because of its particulate form and B&G removes most (about 95%) particulates. Algal toxin and PFAS removal are added environmental benefit from the use of B&G media.

Effluent from B&G have not exceeded Class III receiving water standards. Anammox and other microbial populations has been identified in B&G and thus a partial reason for BON removal (see Wen, et al. 2020, End of Appendix “B”).

Location and Some Filter Details

The location for the 15 filter cells is an area suitably close to the source water of the river, a canal and the C-43 reservoir. The exact location will depend on the availability and cost of land. The reservoir location with the perimeter canal is shown below. The river is to the north of the reservoir.

There are 15 filter cells treating the water with a flow equalization basin and a blending basin. In addition, there is an access road with a stormwater pond. The surface area of a filter is 5 acres for a total area of 75 acres. Added to the filter area is the cell bank area and an access maintenance area. The total area is about 130 acres. The reservoir holding the water will occupy about 10,500 acres and has a perimeter of about 16 miles. Thus, the relative size of the filter cells is about 1.2% of the reservoir size.

The filter cells do not all have to be located adjacent to the perimeter ditch or within a fixed distance from the reservoir or river. The filter can accept water from the canals and river. The location of the filter may provide for that flexibility.

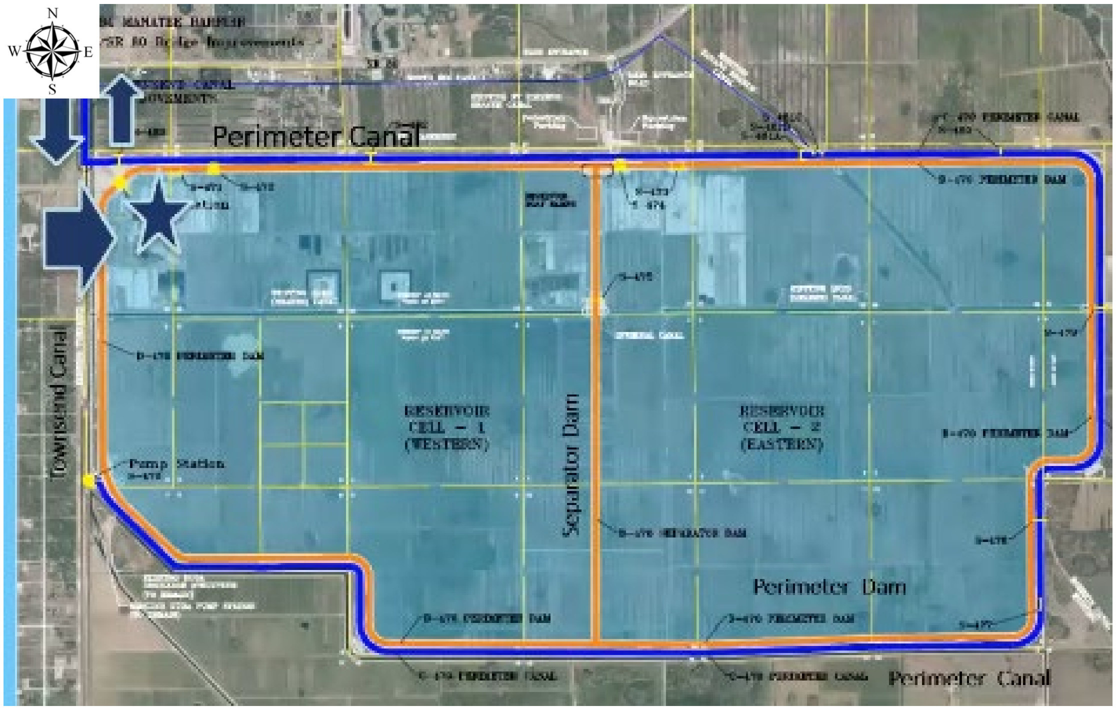


Figure 2 **Site Location Map for C-43 Reservoir**
From: C43 West Storage Reservoir Test Cell Water Quality Summary: Stanley Consultants, 2007

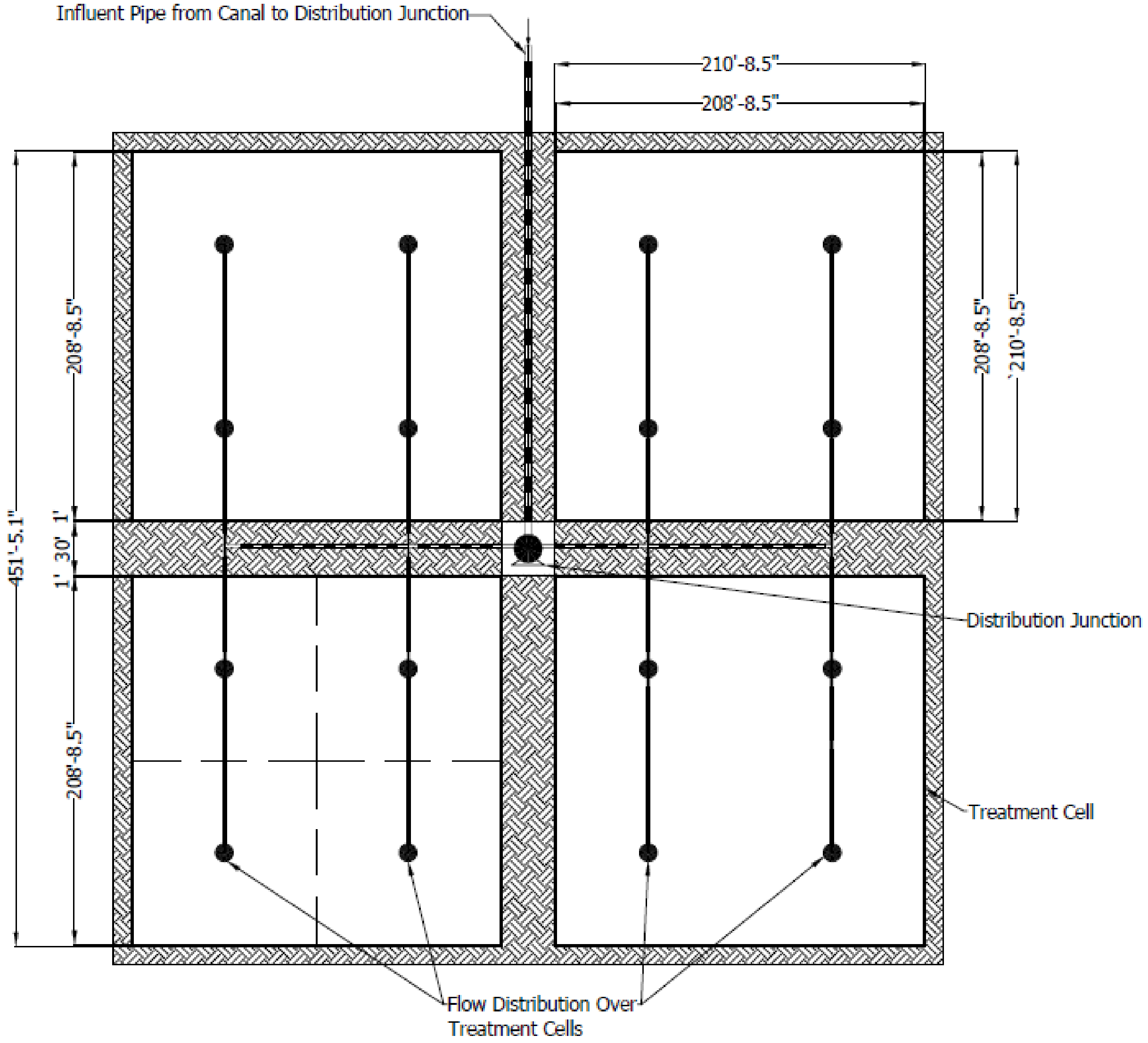


Figure 3 **Plan View of a typical 5-acre filter Cell (total of 15). Other shapes to fit the available land configuration are possible. Raw water from reservoir or canal is available for treatment. A maximum water depth of 24 inches is anticipated above the top of the filter with free board depth of 2 feet. A total depth of 8 feet from bottom of filter to top of bank is used to estimate cost.**

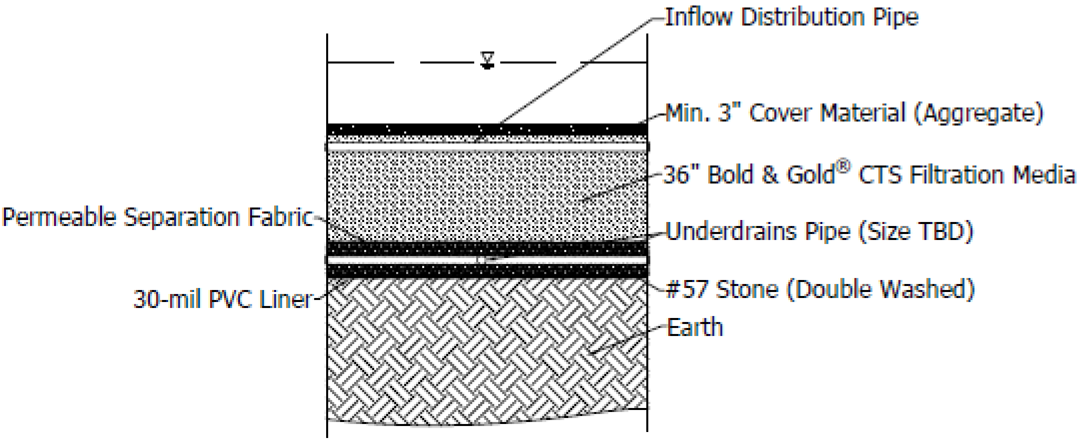


Figure 4 **Bold & Gold® CTS Media Cross Section along Influent Pipe**

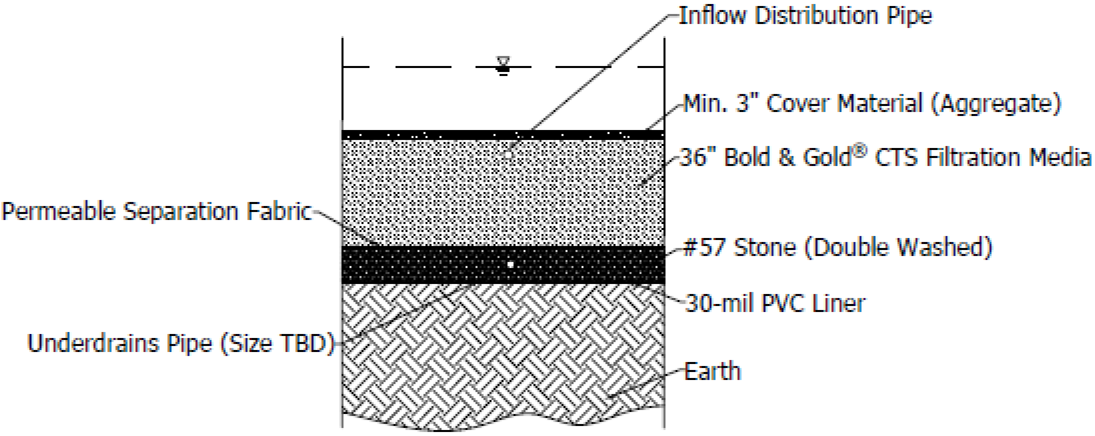


Figure 5 **Bold & Gold® CTS Media Cross Section Perpendicular to the Influent Pipe.**

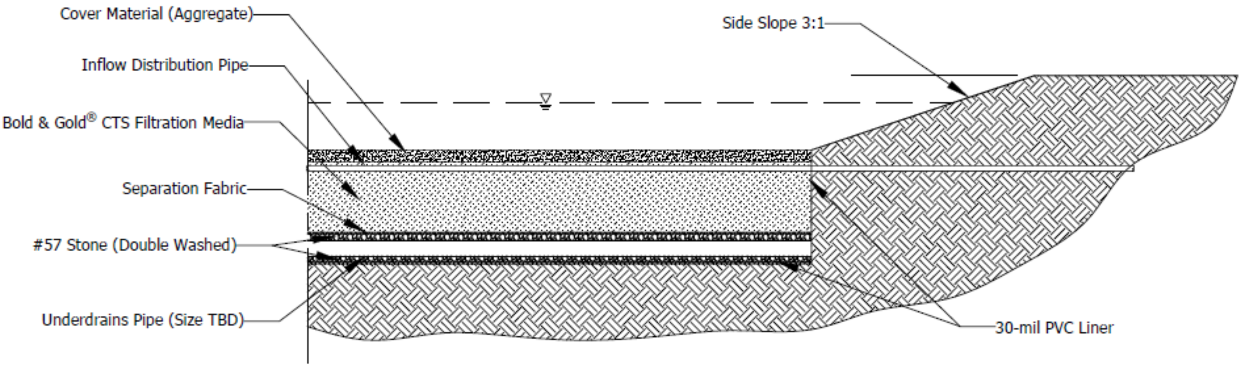


Figure 6 **Bold & Gold® CTS Filtration Media Bank Side Cross Section**

NOTES: 1. ALL DRAWINGS ARE CONCEPTUAL PENDING ENGINEERING DESIGN. 2. EXACT DIMENSIONS SHALL BE DETERMINED AFTER SITE VISIT AND DESIGN BY CONSULTING ENGINEER. 3. DETAILS SHALL BE AS DETERMINED BY CONSULTING ENGINEER IN ACCORDANCE WITH RELEVANT LOCAL REGULATIONS and SFWMD REVIEW. 4. EXACT LOCATIONS OF TREATMENT CELLS TO BE DETERMINED AFTER SITE VISIT.

The proposed location of the treatment filter is shown with preliminary design details. Water entering the B&G filter will be treated and mixed with source water. A flow measuring device for continuous monitoring of discharge flow rate will be used to document performance. Inflow to the filters is distributed by riser pipes, now planned to be at most 6 inches above the top of the cover material. Rip-rap rock will surround the riser pipe to minimize erosion. The treatment rate is based on the filtration rate of the media, which is 5 inches per hour. The daily rate of treatment is about 15 million gallons per day per treatment cell (about 23 CFS). The underdrain pipes minimize water accumulation within the filter and thus the treatment rate is not affected by excess water levels in the filter. Nevertheless, there will be a water level recorder for water depth above the filter and if the water level exceeds 24 inches, the input water will be shut down. A free board is planned at two feet for cost estimating purposes. The exact freeboard to be determined at final design.

F. Post-Treatment Processes

No treatment is expected after the filter; however, a blending of the source and treated water is done.

G. Collection

Water is pumped to the treatment filters and it flows by gravity to a blending tank and then either back to the reservoir, or to the perimeter canals, or to the river.

H. Chemical Supply

No chemicals are used.

II. Residuals Process

A. Collection or Removal

No residuals are expected.

B. Volume Reduction/Dewatering

None required

C. Storage

A blending tank or pond to accommodate a maximum flow of 600 CFS is planned. It will consist of valves and other sensors to adjust flow.

D. Transfer

E. Disposal Process and Location

F. Centrate Management

It is anticipated that professional staff with environmental and hydrological capabilities will be available to collect and monitor water quality and discharge. In addition, field staff to check pipe connections and repair or replace monitoring is needed. It is understood that this capability and understanding now exists within the staff of the District. Nevertheless, the persons who fill the need will be provided with training from the ECS team.

III. Land Area (total)

A. Treatment Facility (including process tanks or basins, chemical storage, electrical system, buildings)

A total of 130 acres is needed. A building for the storage of replacement pipes and other monitoring equipment is desirable.

B. Supporting Facilities (Vehicle Access Roads, Fencing, Security, Equipment Garage, Storage, Parking, and Administration)

The site is assumed to be fenced for cost estimation.

C. Residuals Handling and Solids Storage

D. Stormwater Management

It is expected that the rainfall on the filters and from the bank will be treated in the filter. A stormwater wet pond is added to the access road with the discharge from the pond to one of the 5-acre filter cells.

IV. Power (annual)

A. Process requirements

B. Site requirements

C. Monitoring

We expect water quality and discharge measurements. A monitoring cost of about $80,000 per year based on a vendor lease agreement for a similar filter is anticipated. This monitoring cost however can be offset by District professional staff.

V. Fuel Consumption (annual)

None

A. Chemical Supply, Storage, and Transport

None

B. Site Vehicle Operation

None Expected except for repairs and inspections.

C. Residuals Transport and Disposal

The filter Bold & Gold® media is expected to have a service life of around 50 years. Thus, no residual transport is needed. The filter material is also primarily sand and may even be left on site after 50 years.

VI. Other Beneficial Attributes

A. Additional Vendor Provided Information

ECS is licensed to manufacture Bold & Gold® Filtration media since 2015. During that time, we manufactured over 30,000 tons of Bold & Gold® Filtration media for projects funded by the Florida Department of Transportation, Florida Department of Environmental Protection, St. John's Water Management District, Suwanee River Water Management District, Southwest Florida Water Management District, and private development. A partial list of these projects is available in Appendix "A". Several of these projects were monitored for effectiveness and some of that data is presented in this report.

The production of a consistent product is critical for the nutrient removal effectiveness of any media. Every cubic yard of Bold & Gold® manufactured by ECS meets stringent product specifications. The ECS testing lab was built by Dr. Ikiensinma Gogo-Abite specifically for purpose of manufacturing Bold & Gold® Filtration media. He earned his PhD at the University of Central Florida in geotechnical engineering and worked with Dr. Martin Wanielista while Bold & Gold® was in development. Our lab is used to test the component materials of Bold & Gold® along with the finished product to ensure that the manufactured product meets the patent specifications of the University of Central Florida.

Bold & Gold® Filtration media can be manufactured at our factory and/or at a project site based on economic costs. To keep transportation costs low, we will manufacture the Bold & Gold® CTS Filtration media required for this project at the installation site. Our state-of-the-art blending equipment is portable and has the capacity to produce 300 cubic yards of Bold & Gold® CTS media per hour. The blending equipment uses FDOT certified scales to monitor the input of the component materials in real time during production. The sand required to manufacture the Bold & Gold® CTS media will be sourced in LaBelle. Our engineers have tested the material to ensure it meets our component material specifications.

VII Capital Cost (2020 Dollars)

A. Process Facility (including components described under Items I & II)

The following cost analysis includes typical materials and installation practices associated with constructing a dry detention system to include an underdrain system to discharge the water after treatment. ECS consulted with a contractor certified to work with the South Florida Water Management District to determine construction costs. The costs may not be representative of material costs and labor rates in the geographic area where the Bold & Gold® treatment cells will be constructed since the exact location is unknown.

The proposed cost to construct a five-acre Bold & Gold® treatment cell is $4,500,000.00. This estimate includes the labor, equipment and materials for the following:

1. Excavate the existing soil in the designated five-acre area. Utilize the excavated material to build a berm around the treatment cell. Grade the excavated area to prepare for material installation.
2. Install a 30-mil impermeable PVC liner in the treatment cell. The liner will cover the bottom and embankments of the filtration cell.
3. Install the underdrain system to include HDPE perforated pipe, washed #57 stone and a 6-ounce non-woven filter fabric.
4. Install twenty-four thousand and two hundred (24,200) cubic yards of Bold & Gold® CTS media on the bottom of the treatment cell. The Bold & Gold® media will be installed in a three-foot thick layer.
5. Install four-thousand eight hundred and forty (4,840) cubic yards of clean sand over the Bold & Gold® CTS media. The sand will be free of organics and have a permeability greater than or equal to the Bold & Gold®. The sand will be installed in a six-inch thick layer.
6. Install sod on the embankment of the treatment cell. The bottom of the cell will be left natural with the sand cover.
7. Connect the inflow and outflow conveyance systems to the Bold & Gold® treatment cell. Test the system for performance to include flow, leaks and operation.

Total Cost to Construct Fifteen Five-Acre Bold & Gold® Treatment Cells:	$ 67,500,000.00
MS Level Engineer for Design and Construction Management:	$ 80,000.00
Security Fencing Around 110 Acre Treatment Cells:	$ 105,000.00
Cost to Construct Proposed Onsite Stormwater Treatment Pond:	$ 50,000.00
Monitoring Costs:	$ 80,000.00
Total Proposed Project Cost:	**$ 67,815,000.00**

B. Land (including components under Item III)

No estimate included in the cost. Approximately 130 acres are required.

VIII Operations and Maintenance (Annual)

The service life of the Bold & Gold® Filtration media is determined based on the concentration of influent Soluble Reactive Phosphate (SRP), the volume of influent water, the volume of the filter media, and the flow rate. For the Bold & Gold® CTS Filtration media, the estimation for the life expectancy is based on the rate of removal of SRP, which is 0.2 mg per gram of media. For this project it is estimated be 50 years.

The filter will need weekly inspection. Inspections are to insure there is flow through the filters. Nevertheless, there is a possible need for pipe replacement though infrequent.

It is assumed that the water is delivered to the filter treatment site, thus no operating and maintenance costs is associated with the delivery.

Birds are attracted to the area and if a wildlife viewing station or area is established, there is a need for trash management.

A. Labor

Based on 8 hours per week and $40 per hour for inspections. $16,640 per year

B. Materials

There is no need to replace the media, a design life of 50 years is expected.

i. Acquisition

ii. Management

iii. Disposal

C. Residuals

None to manage, thus no cost

D. Power

No power cost for the filters.

E. Fuel

No fuel cost.

F. Monitoring or Other

Monitoring of the B&G CTS performance has been done in the past. It is anticipated that monitoring of the influent and effluent will be done for this project. Flow rate (treatment rate) was monitored in the past as well. Monitoring points are the point of influent to the filters as well as effluent is typically done, and the cost of the sampling ports have been included in the construction cost.

APPENDIX A

A partial listing of stormwater facilities in Florida that use B&G media

Marion County	Hunters Trace and Rainbow Springs Areas
Escambia County	One Stop Permit Building, Fairfield Ave, Pensacola
Gainesville	CVS Store #5832, NW 13th and 16th
Lakeland	Walgreen Store #5327, 6985 S. Florida Road
Pinellas County	Walgreen Stores (5 in total)
Clermont	Honda Headquarters, Route, 50
BOK Towers	1151 Tower Rd. Lake Wales, Fl
Doral Ben Gamla	3650 Van Buren Rd. Hollywood, Fl
Altamonte Springs Wawa	S.R. 436, Altamonte Springs, Fl
Lake Isis, Avon Park	Hwy 27 and W. Lake Isis Ave.
Tampa Greenroof	2 locations in Tampa
Brickell City	1970 N.W. 129th Ave. Miami, FL
Lake Weir Heights	Marion County, south of Ocala
Retreat at Gainesville	1111 S.W 16th Ave. Gainesville, FL
Cocoa Beach Minuteman Causeway	2 South Orlando Ave. Cocoa Beach, FL
Shands EC	7405 SW Archer Rd. Gainesville, Fl
Ft Meyers Cypress Grove Greenroof	10200 Cypress Cove Dr. Fort Meyers, FL
Seminole County	Lake Jessup Feeder Facilities
Winter Garden,	Lake Clarice Pond
DeLand Bent Oaks RIB	New Hampshire Ave. DeLand, FL
Naples Central Avenue	1 Tamiami Trail. Naples, FL
Ocala Silver Shores #55	9000 SE 58th Ave. Ocala, Fl 34480
Ocala Rainbow Springs Replat	Rainbow Springs 5th Replat Ocala, FL
Rainbow Springs Replat two	Rainbow Springs 5th Replat Ocala, FL
Gainesville	Beville Creek, Land shore Enterprise
Brevard County Rd & Bridge	Johnson Middle Sch
Homestead.	Southern Blossom
Suwannee River spring shed	SRWMD Fanning Springs
Oakland	Town of Oakland
Miami Visual Scape	Miami Central OB
Silver Springs Shores Area 7	Silver Springs Shores Area 7
Alachua Co.-EC Shands# 2	Archer Fl 32608
Orlando	Home2Suite

Traders cove Riviera Bella East	Fort Florida Rd. Debary, FL 32771
Orlando	4301 Urbana Dr. Orlando, FL 32837
Silver Springs Shores Area 7	Pine Rd. & Midway Ter. Ocala, FL
Oviedo Salt Creek Stream Restoration	2650 Packard Ave. Oviedo, FL 32765
Sarasota Wilde Lexus	5157 Shangri-La Rd. Sarasota, 34233
Lakeland Old Dominion	5620 N. Combee Rd. Lakeland, FL 33805
Maitland	E2 Homes, 250 Northwind Rd. Maitland, 32751
Rainbow Springs CP72	9850 SW 196th Cir. Dunnellon, FL 34432
Clearwater Bainbridge Bayside	19321 US Hwy 19 Clearwater, FL 33764
LRMC Lakeland REG MED #15-764	1324 Lakeland Hills Blvd. Lakeland, FL 33805
Ocala FDOT E5U92	1751 SW 110th Ave. Ocala, FL 34481
Dunnellon Rainbow Springs CP 67	9850 SW 196th Cir. Dunnellon, FL 34432
Hillsborough County Sports Complex	9300 East Columbus Drive, Tampa, FL 33619
Dunnellon Rainbow Springs CP 72	9850 SW 196th Cir. Dunnellon, FL 34432
Green Cove Springs FDOT T2686-	1010 Leonard C Pkwy. Green Cove Springs, FL 32043
Marion County CP 71	19030 SW 98th Loop Dunnellon, FL 34432
Marion County CP 76 DRA 7219 pond C	21 Pine Ct Dr Ocala Fl
Marion County - CP76	21 Pine Court Dr, Ocala Fl
Englewood Colorado	8051 S Jordan, Englewood CO
Brandon Florida	1716 Silver Way, Brandon Fl
Lakeland LRMC #15-764	1324 Lakeland Hills Blvd. Lakeland FL
Rockledge	Gus Hipp Blvd Canal
Sanford HCME Headquarters	800 Martin Luther King Blvd Sanford Fl
Eustis	Harbco, W Hwy 44S & Hwy 19, Eustis Fl
ST Cloud 7-11	1780 Nolte Rd, St Cloud Fl 32722

Note: Small facilities using less than 6 cubic yards are not listed.

APPENDIX B
PERFORMANCE DATA

Sorption Media	Composition	DON	TN Removal		Nitrate Removal	NOx	Ammonia Removal	TP Removal	Reference
B&G CTS	• 85.0% sand (volume) • 10.0% tire crumb (volume) • 5.0% clay (volume) (Fixed-bed column and field studies)	45%-81% (stormwater)	42-51% 52-85% (groundwater) 62-70% 48%-73% (stormwater)		45% - 83%	72% 49%-69% (stormwater) 83% (reclaimed)	14% 22%-61% (stormwater)	66% (reclaimed) 4%-92% (stormwater) (-165%) -54%	Chang et al. (2018a) Hood et al. (2013) Wen et al. (2018) Wen et al. (2020) Valencia et al. (2020) Chang (2018c)
	• 75.0% expanded clay (volume) • 25.0% tire crumb (volume) (Test bed roadside Swale study)		-	-	-	-	-	71%	Hood et al. (2013)
	• 59.0% sand (volume) • 14.0% tire crumb (volume) • 26.0% clay (volume) (Stormwater dry ponds)		69%	-	34.6%-96.9%	-	65.7%	-	O'Reilly, et al. (2012)
IFGEM 1	• 96.2% sand (volume) • 3.8% iron filing(volume) (Fixed-bed column study)	86%-97% (stormwater)	85% - 94% 85%-93% (stormwater)	-	85%-90% 91%-95%	98%-99% (stormwater)	(-61%)-63%	45%-80% 60%-92% 54% - 83% 60%-91% (stormwater)	Chang et al. (2018a) Valencia et al. (2020)

Sorption Media	Composition	DON	TN Removal		Nitrate Removal	NOx	Ammonia Removal	TP Removal	Reference
IFGEM 2	• 80.0% sand (volume) • 10.0% tire crumb (volume) • 5% clay (volume) • 5.0% iron filing (volume) (Fixed-bed column study)		-	-	61%-92% 88%-94%	-	-	85% 26%-62%	Chang et al. (2018b)
IFGEM 3	• 83.0% sand (volume) • 10.0% tire crumb (volume) • 2% clay (volume) • 5% iron filing (volume) (Fixed-bed column study)	71%-93% (stormwater)	91-94% 81%-97% 80%-96% (stormwater)	-	*42%	98%-99% (stormwater)	95%-98% 29%-91% (stormwater)	84-92% 50%-92% *97% 50%-92% (stormwater)	Valencia et al. (2019) Ordonez et al. (2020b) Valencia et al. (2020)
IFGEM 3	• 83.0% sand (volume) • 10.0% tire crumb (volume) • 2% clay (volume) • 5% iron filing (volume) (Isotherm study)		83%-85%					81-99.95%	Ordonez et al. (2020a)

* Cumulative nutrient removal over prolonged experimental running time

Notes: There are 3 commonly used recipes for B&G. The one we are proposing is Bold & Gold® CTS. IFGEM is also shown in the list because it has promising Laboratory results, however, there are no field applications at this date (May 2020) that document large scale field applications. This is done to illustrate the level of commitment that is being made to develop additional mixes of B&G.

APPENDIX C
References Performance Data

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APPENDIX D

Additional Documentation using materials found in Bold & Gold® to show the depth of published information related to the use of Bold & Gold® media for water pollution control.

Media used	Treated water	Nutrient removal	Limitation	Reference
Phosphate precipitation with $FeCl_3·6H_2O$	Municipal wastewater with 0 – 5 mg/L OP_4-P	63% phosphate removal at 1:1 molar addition of Fe(III) at pH = 4	Excessive addition of $FeCl_3·6H_2O$ is necessary for ideal removal; High maintenance cost	Fytianos et al. (1998)
Iron-aluminum hydroxyl (oxide) coated filter media	Artificial groundwater, tap water, treated wastewater with 0.5 mg/L OP_4-P	Over 90% phosphate removal	Lack of ability for nitrogen species removal; Special pre-treatment of the media is required	Ayoub et al. (2001)
Bioretention system with soil, mulch, and plants	Urban stormwater runoff with 2-4 mg/L TN and 0.6 mg/L TP	> 90% heavy metal; 60 – 80% phosphorus; Moderate TKN	Little nitrate was removed; Nitrate production confirmed	Davis et al. (2001)
Iron packed bed in columns	Groundwater spiked with nitrate solution to 5 mg/L	> 80% nitrate removal	By-products generation of ammonia and metal ions	Westerhoff and James (2003)
Soil, sand, mulch in bioretention system with layer configurations	Synthetic water with 2 – 3 mg/L of nitrate, ammonia and phosphorus	68% ammonia removal; 85% phosphorus removal;	Nitrate export was confirmed	Hsieh et al. (2007b); Hsieh et al. (2007a)
Sand, tire crumb, sawdust, and limestone in different configurations	Stormwater with 0.38 - 2.5 mg/L nitrate, 0.125 – 0.785 mg/L OP_4-P	Over 90% nitrate removal; 50 – 90% orthophosphate removal	Ammonia export was confirmed	Moberg (2008)
Expanded clay, tire crumb, sawdust, and lime stone	Septic tank effluent with 40 – 80 µg/L TN	75.4% TN removal; 94.9% TP removal	; Limited nitrification process	Xuan et al. (2009)
Sand, limestone, sawdust, and tire crumb for stormwater dry ponds	Stormwater with 35 – 54 mg/L TN, 7.5 mg/L TP	65 – 95% nitrate removal; Completely ammonia removal	Certain requirement of media thickness for achieving proper HRT	Hossain et al. (2010)
Fine sand, tire crumb, and sawdust placed in vadose zone	Septic tank effluent with 1.76 mg/L ammonia, 0.352 nitrate, 0.116 nitrite, 1.498 OP_4-P	55% nitrate removal; 89% TP removal	Larger aerobic zone and longer HRT required for complete denitrification	Xuan et al. (2010)
Nanoscale zero valent iron supported on pillared clay	Synthetic solution with 0.806 mmol/L nitrate	Over 90% nitrate removal within 40 min of HRT	End products of ammonium was observed	Zhang et al. (2011)
Fine sand, tire crumb, sawdust, and limestone in various configurations	Stormwater under various temperatures	70 – 90% nitrate removal; 40 – 85% orthophosphate	Lower temperature may inhibit the nutrient removal	Chang et al. (2011)

Media used	Treated water	Nutrient removal	Limitation	Reference
Nanoscale zero valent iron	Synthetic phosphorus solution with 1 – 10 mg/L OP_4-P	96 – 100% removal with ~ 78% phosphorus recovery	Too expensive to conduct economic implication	Almeelbi and Bezbaruah (2012)
Tire crumb, silt, clay, and sand in stormwater infiltration basin	Stormwater with 0.46 – 0.90 mg/L TDP	70% phosphorus removal	Anaerobic needed for denitrification and better removal effects	O'Reilly et al. (2012)
Cement sand, tire crumb, fine expanded clay, and limestone	Stormwater with 0.5 – 1.0 mg/L TDP	Maximum adsorption equilibrium is 0.0151 mg-P/g-absorbent	Lack of nutrients recovery potential	Jones et al. (2015)

APPENDIX E

References for the additional documentation of Bold & Gold® removal.

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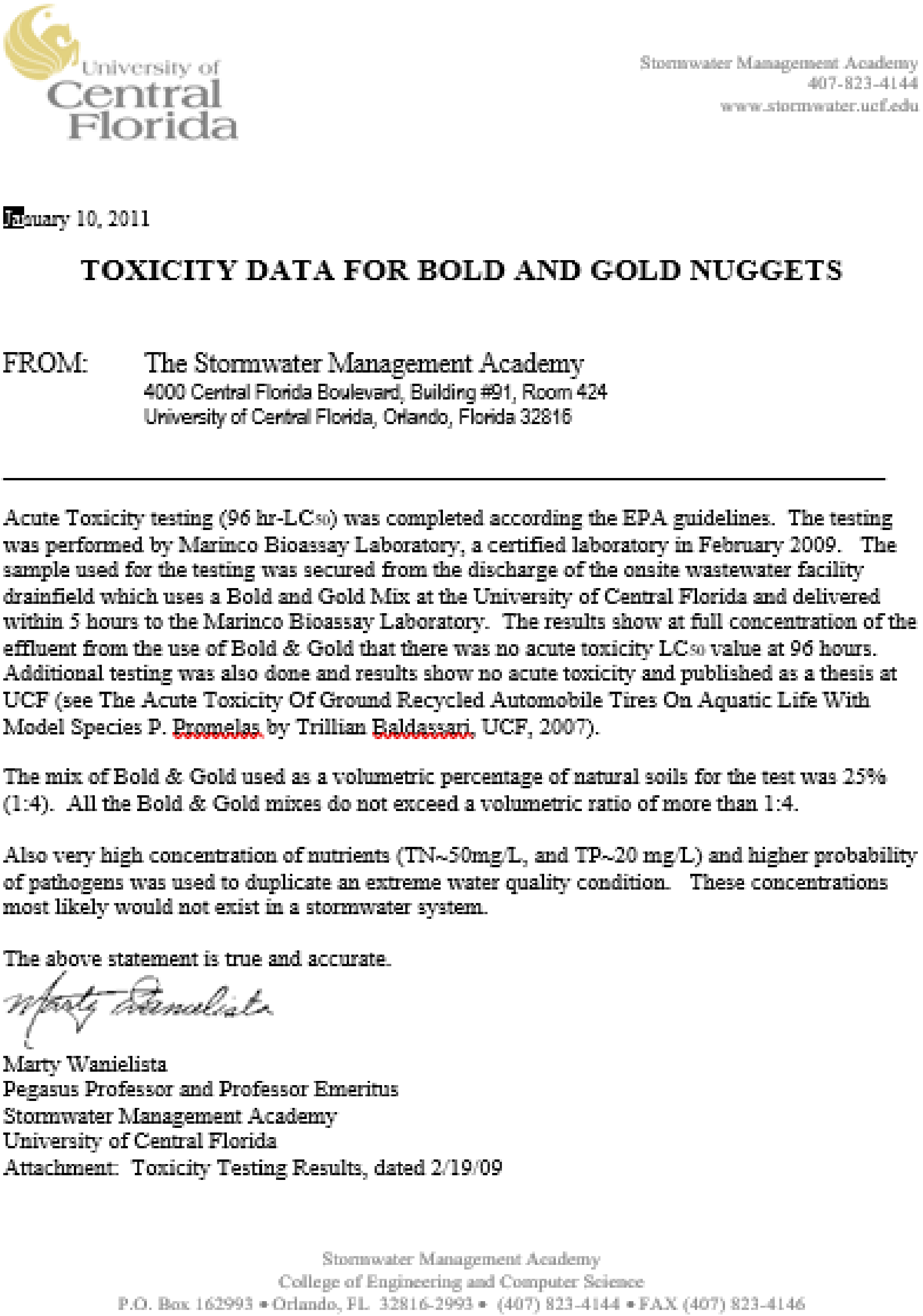
Appendix F
EPA Acute Toxicity Testing



University of Central Florida

Stormwater Management Academy
407-823-4144
www.stormwater.ucf.edu

January 10, 2011

TOXICITY DATA FOR BOLD AND GOLD NUGGETS

FROM: The Stormwater Management Academy
4000 Central Florida Boulevard, Building #91, Room 424
University of Central Florida, Orlando, Florida 32816

Acute Toxicity testing (96 hr-LC_{50}) was completed according the EPA guidelines. The testing was performed by Marinco Bioassay Laboratory, a certified laboratory in February 2009. The sample used for the testing was secured from the discharge of the onsite wastewater facility drainfield which uses a Bold and Gold Mix at the University of Central Florida and delivered within 5 hours to the Marinco Bioassay Laboratory. The results show at full concentration of the effluent from the use of Bold & Gold that there was no acute toxicity LC_{50} value at 96 hours. Additional testing was also done and results show no acute toxicity and published as a thesis at UCF (see The Acute Toxicity Of Ground Recycled Automobile Tires On Aquatic Life With Model Species P. Promelas by Trillian Baldassari, UCF, 2007).

The mix of Bold & Gold used as a volumetric percentage of natural soils for the test was 25% (1:4). All the Bold & Gold mixes do not exceed a volumetric ratio of more than 1:4.

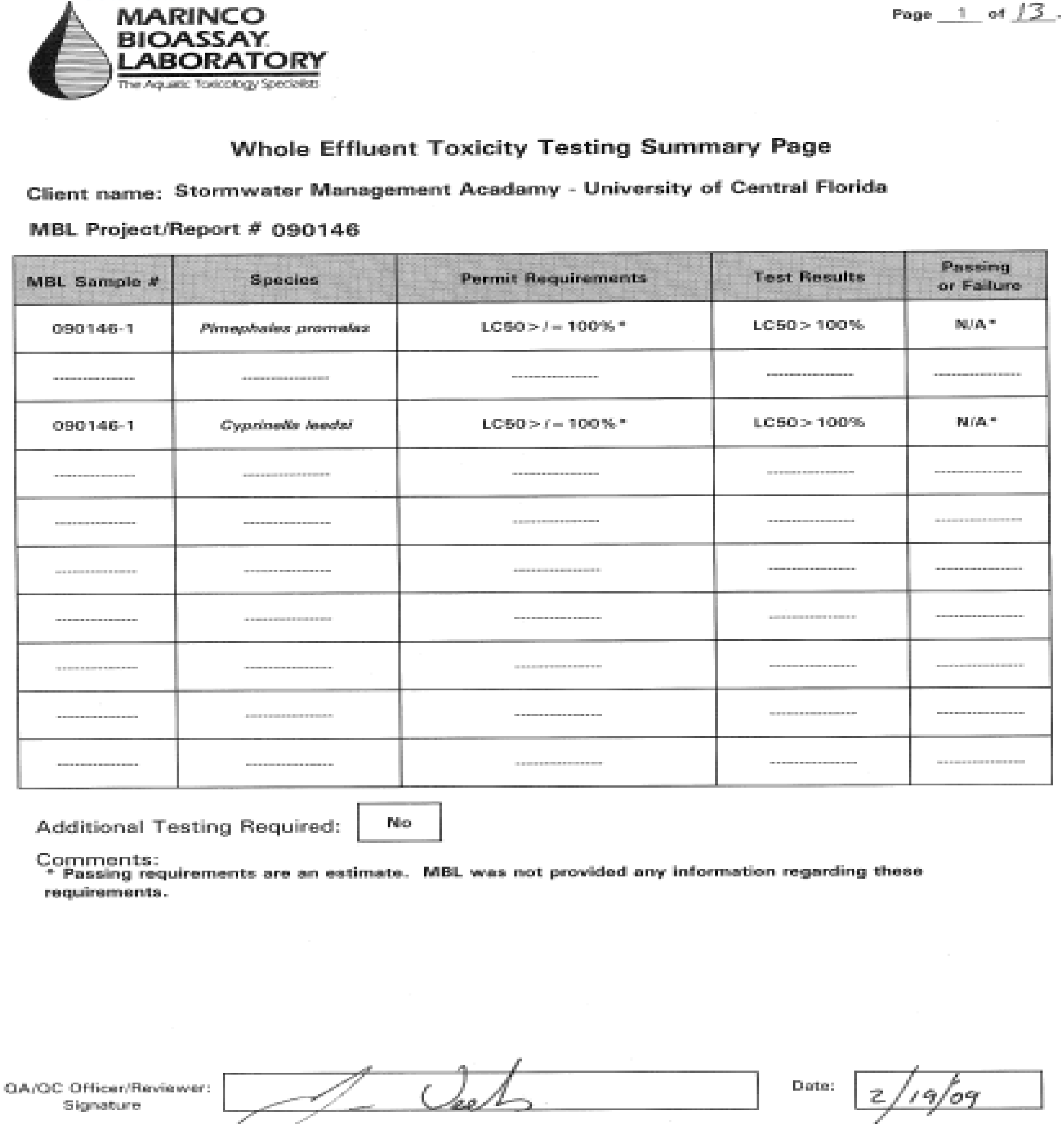
Also very high concentration of nutrients (TN~50mg/L, and TP~20 mg/L) and higher probability of pathogens was used to duplicate an extreme water quality condition. These concentrations most likely would not exist in a stormwater system.

The above statement is true and accurate.

Marty Wanielista
Pegasus Professor and Professor Emeritus
Stormwater Management Academy
University of Central Florida
Attachment: Toxicity Testing Results, dated 2/19/09

Stormwater Management Academy
College of Engineering and Computer Science
P.O. Box 162993 • Orlando, FL 32816-2993 • (407) 823-4144 • FAX (407) 823-4146

NOTE: LC50 refers to the lethal concentration to kill 50% of the organisms in the specific holding time. The lethal concentration of B&GW treated water from an on-site wastewater facility has to have a concentraion of greater than 100% or be concentrated to possibly have an acute toxic effect.



MARINCO BIOASSAY LABORATORY
The Aquatic Toxicology Specialists

Page 1 of 13.

Whole Effluent Toxicity Testing Summary Page

Client name: Stormwater Management Academy - University of Central Florida

MBL Project/Report # 090146

MBL Sample #	Species	Permit Requirements	Test Results	Passing or Failure
090146-1	*Pimephales promelas*	LC50 >/= 100%*	LC50 > 100%	N/A*
-------------	-------------	-------------	-------------	-------------
090146-1	*Cyprinella leedsi*	LC50 >/= 100%*	LC50 > 100%	N/A*
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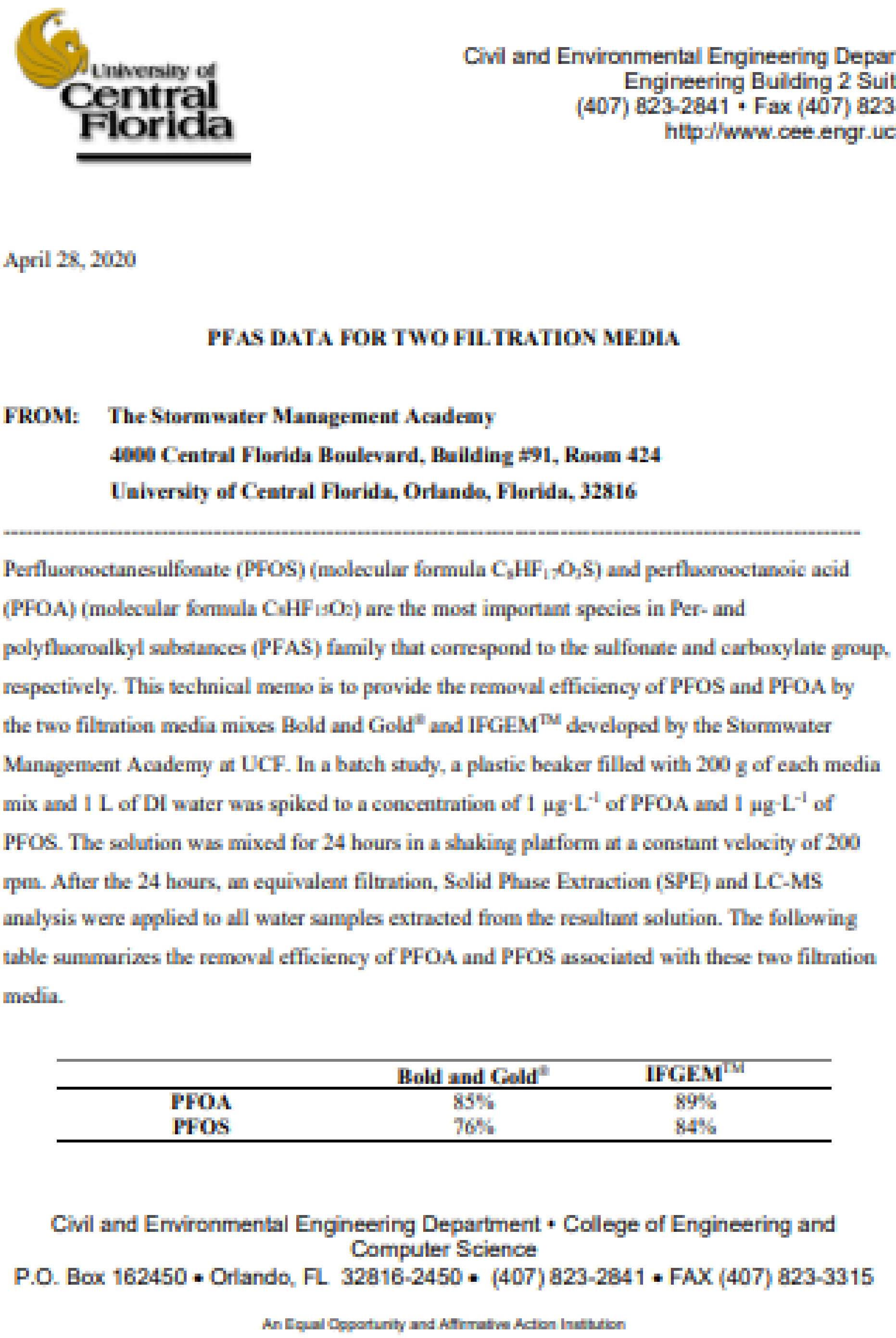
Additional Testing Required: No

Comments:
* Passing requirements are an estimate. MBL was not provided any information regarding these requirements.

QA/QC Officer/Reviewer: Signature

Date: 2/19/09

Appendix G
PFAS Removal Testing



University of Central Florida

Civil and Environmental Engineering Department
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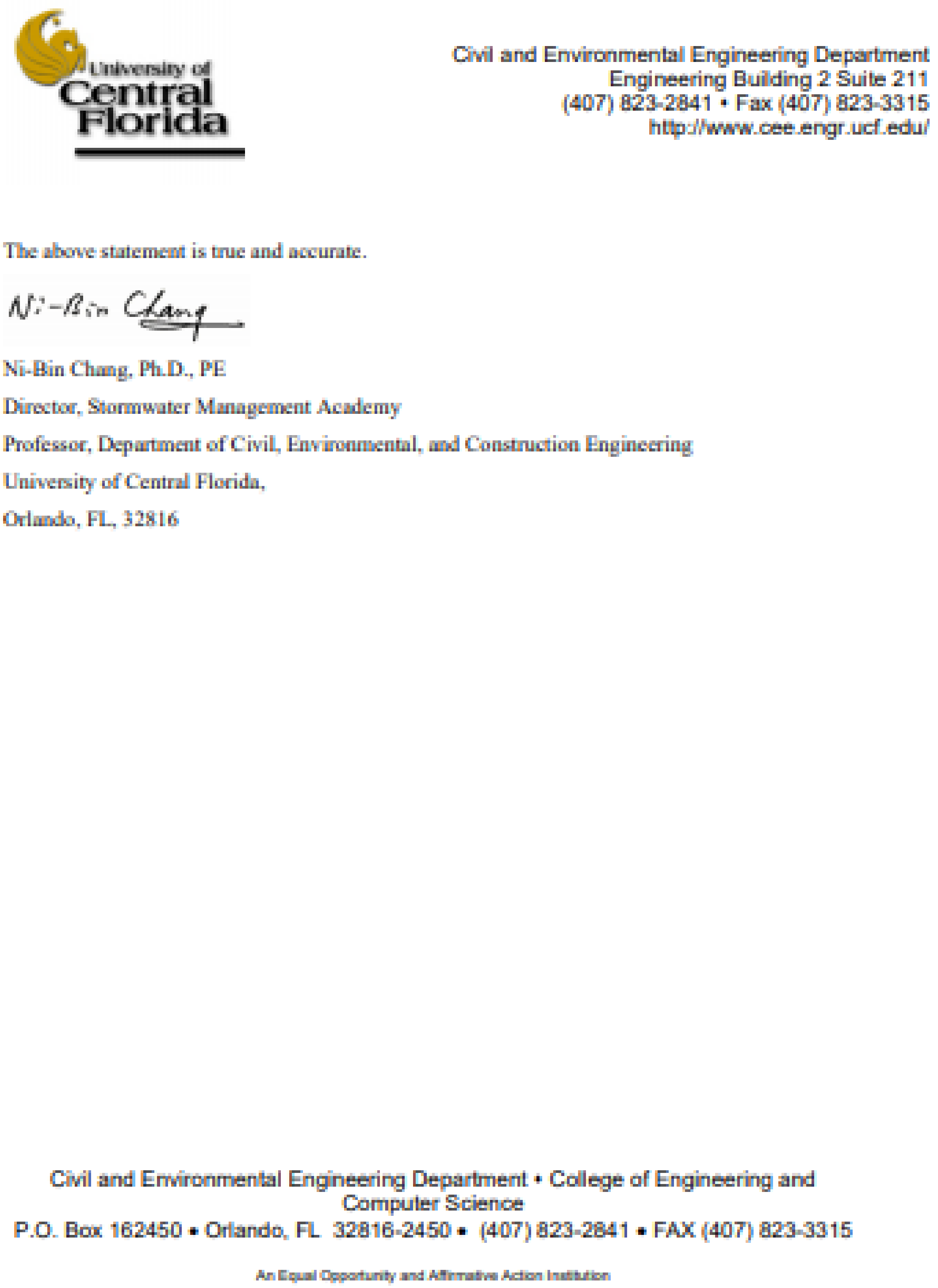
April 28, 2020

PFAS DATA FOR TWO FILTRATION MEDIA

FROM: **The Stormwater Management Academy**
4000 Central Florida Boulevard, Building #91, Room 424
University of Central Florida, Orlando, Florida, 32816

Perfluorooctanesulfonate (PFOS) (molecular formula $C_8HF_{17}O_3S$) and perfluorooctanoic acid (PFOA) (molecular formula $C_8HF_{15}O_2$) are the most important species in Per- and polyfluoroalkyl substances (PFAS) family that correspond to the sulfonate and carboxylate group, respectively. This technical memo is to provide the removal efficiency of PFOS and PFOA by the two filtration media mixes Bold and Gold® and IFGEM™ developed by the Stormwater Management Academy at UCF. In a batch study, a plastic beaker filled with 200 g of each media mix and 1 L of DI water was spiked to a concentration of 1 $\mu g \cdot L^{-1}$ of PFOA and 1 $\mu g \cdot L^{-1}$ of PFOS. The solution was mixed for 24 hours in a shaking platform at a constant velocity of 200 rpm. After the 24 hours, an equivalent filtration, Solid Phase Extraction (SPE) and LC-MS analysis were applied to all water samples extracted from the resultant solution. The following table summarizes the removal efficiency of PFOA and PFOS associated with these two filtration media.

	Bold and Gold®	IFGEM™
PFOA	85%	89%
PFOS	76%	84%



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The above statement is true and accurate.

Ni-Bin Chang

Ni-Bin Chang, Ph.D., PE
Director, Stormwater Management Academy
Professor, Department of Civil, Environmental, and Construction Engineering
University of Central Florida,
Orlando, FL, 32816

Civil and Environmental Engineering Department • College of Engineering and Computer Science
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Environmental Conservation Solutions

C-43 WBSR Water Quality Feasibility Study Group June 26, 2020

Reference: Response to Questions in a "teams" meeting on June 23, 2020

Mr. Jim Bays:

Following is information in response to three discussion topics during the "teams" meeting and sent in an email on the same day, June 23, 2020.

From this meeting, we were instructed to provide a filter system that can treat water at 457 CFS for 365 days per year. We understand that a cost analysis will be used on a 20-year basis. The Bold & Gold® CTS media filter design for a 20-year basis without replacement of media results in 24 five-acre filters (5-foot deep). We also provide a design option using 15 five-acre filters (4-foot deep) with Bold & Gold® IFGEM media. A minimum depth of 2 feet for CTS media and 3 feet for IFGEM media are required to maintain the removal effectiveness based on residency time. However, the additional depth was needed to extend life expectancy of the media.

IFGEM uses the components of the CTS media blend and replaces some of the sand with iron filings. It is offered as another option for filtration. There are in operation at least 166 surface water treatment facilities using iron filings in the State of Minnesota (State Stormwater Manual). As a comparison, there are over 200 CTS facilities in Florida.

For a 20-year time period and constant 457 CFS flow, the number of filters with CTS media is 24 (see Table 1) The number is calculated based on the OP removal in 20 years / filter removal OP capacity per year or (315 x 10^9 mg / 13.1 x 10^9 mg/filter). The required number of five-acre filters with IFGEM media is 15. Fifteen is the minimum number needed for an average daily filter flow of 292 CFS used to produce a blended flow of 457 CFS that meets target water quality conditions.

We also provide referred publications for the removal of Dissolved Organic Nitrogen (DON). Calculations are provided on the cumulative removal of nitrogen species with these referred published data. There are no changes to our original calculations for nitrogen removal using the filters.

We added cost estimates based on a daily flow of 457 CFS. These are compared to our original cost estimate that was based on flows provided when the river discharge was less than the MFL of 457 CFS . Twenty-four (24) five-acre filters with a five-foot layer of Bold & Gold® CTS media are required. Using IFGEM, 15 five-acre filters are required.

Three Discussion Areas:

1. **Adjusting performance basis to 365 days per year**, and what effect this will have on cost and media performance requirements. Also, let us know what the disposal implications and approach might be for replaced media.

a. **Daily operation (365 days per year) at 457 CFS and for a 20-year operational life.** Twenty-four (24) CTS five-acre filters are recommended for a 20-year life expectancy. For IFGEM media filters, 15 filters are recommended for 20 years.

b. **Disposal implications.** If media are exhausted, in-place use is recommended. The media is mostly sand and does support limited vehicular traffic. It can also be used as a soil amendment for vegetated growth. We support media reuse in-place after exhaustion. The land can be reused for other purposes including those that would bear traffic loads.

2. **Developing "scenarios" of filter size and media blend with cost estimates**. This could include different filter cell numbers and different media blends.

Two different scenarios are advanced. One using CTS media cells that are 5 feet deep. The other is using IFGEM media cells 4 feet deep. We have not built a filter deeper than 5 feet so that is the maximum depth of filter used. The calculations for service life follow and include data relative to the direction provided in the "teams" meeting.

Table 1 CTS Media

Calculations are provided for five feet deep five-acre CTS media filters treating a constant flow of 457 CFS every day of the year and for a service life of 20 years. Twenty-four (24) filters are needed. Each filter can provide after blending 40 CFS. Thus, only 11.425 filters (11 filters operating daily and one filter operating 10 hours per day) operate at any one time to provide 457 CFS. This allows a dry period between filtration to provide inspection and maintenance if needed. Again, only 11-12 filters will be in operation daily to provide 457 CFS. Six hundred (600) CFS demand will require 15 filters to operate at one time.

	Description	Committee Numbers	With CTS media	Responses/Comments
1a.	CTS B&G per 5-acre	24,200 cy	40,333 cy	5 feet deep media and each filter is 5-acres
1b.		653,400 ft^3	1,089,000 ft^3	5 feet deep media and each filter is 5-acres
2.	Bulk Density	63 lb/ft^3	95 lb/ft^3	63 pcf is loose minimum density requirement at production. Field density (dry) used to estimate the OP removal rate from actual test sites is 95 pcf. (primarily sand)
3.	# 5-ac units	15	24	Increased number and depth for longer service life
4a.	Total media mass	617,463,000 lb	3,476,088,000 lb	= 24 × 1.4(95 pcf) × 1,089,000 cf. [At full saturation of a media with 40% void, saturated weight is $95 \times [1 + (40/100)] = 133\ pcf$]
4b.		2.80075E+11 g	1,576,725,708,096 g	Conversion rate of 1 pounds ≈ 453.592 grams
5.	Adsorption rate	0.2 mg/g	0.2 mg/g	Agreement, note removal is based saturated conditions and for OP
6a.	Removal (Sorption) Capacity	56,015,008,434 mg	315,345,141,619 mg	= 0.2 mg × 1,576,725,708,096 g and note as OP, **per filter = 13.14 (10^9) mg/filter**
6b.		123,493 lb	695,178 lb	Conversion rate of 1 mg ≈ 2.2045×10^{-6} lb
7a.	Flow	457 CFS	292 CFS from filter blended with 165 CFS of source water for a total output of 457 CFS	Refer to ECS proposal page 4: subheading "**Filter Size to Achieve Water Quality Target Concentrations"** The target TP removal percent is 50%. Based on an input of 0.16 mg/L, this leaves 0.08 mg/L TP discharge. The B&G CTS filter removes about 78% (rounded off) of TP, or 0.1254 mg/L removed: leaving a discharge of 0.0346 mg/L, or less than the target of 0.08 mg/L. Thus, a unique situation exists that provides flexibility for operation of the filter. Based on influent conditions, a blending of treated filter effluent with source water is possible to meet the target of 0.08 mg/L. For the treatment level specified and an average discharge of 457 CFS, 292 CFS must be treated by the filter. It is blended with 165 CFS from the source (canal, upstream river or reservoir). **The treated fraction is 64% (292/457)** of the total flow. This is based on the following TP mass balance: Mass in the Discharge = Mass from source (reservoir) + mass from Filter 457 x (0.08) = Flow from source x (0.16) + Flow from filter x (0.0346)

	Description	Committee Numbers	With CTS media	Responses/Comments
				And: 36.56 = S (0.16) + F (0.0346) with S+F=457, S is source and F=Filter flow 36.56 – 15.81 = (0.16-0.0346)S results in S = 165 CFS, F = **292 CFS.**
7b.		295 MGD	188.7245 MGD	Filter Flow**:** 292 CFS x 0.646317 MGD/CFS
7c.	Flow capture		260,756,025,397 L/yr	Filter Flow for augmentation**: 188.7245** MGD x 3.785 L/gal x 365 D/yr x 1,000,000 g/MG
8.	P in	0.16 mg/L	0.093 mg/L	Removal for **OP** not TP. Influent OP=0.093 mg/L based on a 0.58 fraction OP in TP,
9.	P out	0.08 mg/L	0.032 mg/L	For 66% **OP** removal (appendix B, proposal), 0.061 mg/L of OP is removed (0.66 x 0.093). Thus, **OP** out of filter = 0.093 – 0.061 mg/L= 0.032 mg/L
10a.	Removed (annual removal of OP)		15,751,936,019 mg of OP/yr	OP removed/yr: conc removed × Annual flow capture: i.e. 0.061 mg/L × 260,756,025,397 L/yr and OP removed over **20 years = 20 x 15.75 (10)^9 per year = 315 x $(10)^9$ mg.**
10b		71,941 lb/yr	34,727 lb of OP/yr	Pounds = 15,751,936,091 mg / 453,592 mg/pound
11.	Service Life (years)	1.72 yr	20 years	Removal Capacity divided by annual removal or 695,178 lb / 34,727 lb per year.

The proposed cost to construct one five-acre Bold & Gold® CTS treatment cell is $7,402,902.00. This estimate includes the labor, equipment and materials for the following:

1. Excavate the existing soil in the designated five-acre area. Utilize the excavated material to build a berm around the treatment cell. Grade the excavated area to prepare for material installation.
2. Install a 30-mil impermeable PVC liner in the treatment cell. The liner will cover the bottom and embankments of the filtration cell.
3. Install the underdrain system to include HDPE perforated pipe, washed #57 stone and a 6-ounce non-woven filter fabric.
4. Install forty thousand, three hundred and thirty-three (40,333) cubic yards of Bold & Gold® CTS media on the bottom of the treatment cell. The Bold & Gold® media will be installed in a five-foot thick layer.
5. Install four-thousand eight hundred and forty (4,840) cubic yards of clean sand over the Bold & Gold® CTS media. The sand will be free of organics and have a permeability greater than or equal to the Bold & Gold®. The sand will be installed in a six-inch thick layer.
6. Install sod on the embankment of the treatment cell. The bottom of the cell will be left natural with the sand cover.
7. Connect the inflow and outflow conveyance systems to the Bold & Gold® treatment cell. Test the system for performance to include flow, leaks and operation.

Description	Cost
Materials and Labor to Construct Twenty-Four Bold & Gold® CTS Treatment Cells	$140,655,138
Design, Permitting and Construction Management	$ 1,275,000
Security Fencing Around Treatment Cells	$ 168,000
Cost to Construct Proposed Onsite Stormwater Treatment Pond	$ 75,000
Monitoring Costs	$ 80,000
Total Proposed Project Cost	**$142,253,138**

Table 2 IFGEM Media

Calculations are provided for four feet deep five-acre IFGEM media filters treating for a constant flow of 457 CFS every day of the year and for a service life of 20 years. However, a service life of 50 plus years is possible (see calculations below). Fifteen (15) filters are needed. Each filter can provide 40 CFS after blending. Thus, only 11.425 filters (11 filters operating daily and one Filter operating 10 hours per day) any one time providing the 457 CFS. Six hundred (600) CFS demand will require all 15 filters to operate at one time.

	Description	Committee Numbers	With IFGEM media	Responses/Comments
1a.	IFGEM B&G per 5-acre	24,200 cy	32,267 cy	4 feet deep media and 5 acres
1b.		653,400 ft^3	871,200 ft^3	4 feet deep media and 5 acres
2.	Bulk Density	63 lb/ft^3	98 lb/ft^3	Field density (dry) used to estimate the OP removal rate from actual test sites is 98 pcf. (primarily sand)
3.	# 5-ac units	15	15	Same number of units
4a.	Total media mass	617,463,000 lb	1,792,929,600 lb	= 15 × 1.4 x 98 pcf × 871,200 cf. [At full saturation of a media with 40% void, saturated weight is $98 \times [1 + (40/100)] = 137.2\ pcf$]
4b.		2.80075E+11 g	813,258,523,123 g	Conversion rate of 1 pounds ≈ 453.592 grams
5.	Adsorption rate	0.2 mg/g	1.0 mg/g	Removal based CTS media mix with iron filings at 5% weight.
6a.	Removed (Sorption Capacity)	56,015,008,434 mg	813,258,523,123 mg	= 1.0 mg × 609,943,892,342 g and note as OP
6b.		123,493 lb	1,792,828 lb	Conversion rate of 1 mg ≈ 2.2045×10^{-6} lb
7a.	Flow	457 CFS	292 CFS from filter blended with 165 CFS of source water for a total output of 457 CFS	Refer to ECS proposal page 4: subheading “**Filter Size to Achieve Water Quality Target Concentrations”** The target TP removal percent is 50%. Based on an input of 0.16 mg/L, this leaves 0.08 mg/L TP discharge. The B&G CTS filter removes about 78% (rounded off) of TP, or 0.1254 mg/L removed: leaving a discharge of 0.0346 mg/L, or less than the target of 0.08 mg/L. Thus, a unique situation exists that provides flexibility for operation of the filter. Based on influent conditions, a blending of treated filter effluent with source water is possible to meet the target of 0.08 mg/L. For the treatment level specified and an average discharge of 457 CFS, 292 CFS must be treated by the filter. It is blended with 165 CFS from the source (canal, upstream river or reservoir). **The treated fraction is 64% (292/457)** of the total flow. This is based on the following TP mass balance: Mass in the Discharge = Mass from source (reservoir) + mass from Filter 457 x (0.08) = Flow from source x (0.16) + Flow from filter x (0.0346) And: 36.56 = S (0.16) + F (0.0346) with S+F=457, S is source and F=Filter flow 36.56 – 15.81 = (0.16-0.0346)S results in S = 165 CFS, F = **292 CFS.**

	Description	Committee Numbers	With IFGEM media	Responses/Comments
7b.		295 MGD	188.72 MGD	Filter Flow: 292 CFS x 0.646317 MGD/CFS
7c.	Flow capture		260,756,025,397 L/yr	Filter Flow for augmentation: **188.72** MGD x 3.785 L/gal x 365 D/yr 1,000,000 g/MG
8.	P in	0.16 mg/L	0.093 mg/L	Removal for **OP** not TP. Influent OP=0.093 mg/L based on a 0.58 fraction OP in TP,
9.	P out	0.08 mg/L	0.032 mg/L	For 66% **OP** removal (appendix B, proposal), 0.061 mg/L of OP is removed (0.66 x 0.093). Thus, **OP** out of filter = 0.093 – 0.061 mg/L= 0.032 mg/L
10a	Removed (annual removal of OP)		15,751,936,019 mg of OP/yr	**OP** conc removed × Annual flow capture: i.e. 0.061 mg/L × 260,756,025,397 L/yr
10b		71,941 lb/yr	34,727 lb of OP/yr	Pounds = 15,751,936,019 mg / 453,592 mg/pound
11.	Service Life (years)	1.72 yr	51.63 years	Removal Capacity divided by annual removal or 1,792,808 lb / 34,727 lb per year.

The proposed cost to construct a five-acre Bold & Gold® IFGEM treatment cell is $9,801,680.00. This estimate includes the labor, equipment and materials for the following:

1. Excavate the existing soil in the designated five-acre area. Utilize the excavated material to build a berm around the treatment cell. Grade the excavated area to prepare for material installation.
2. Install a 30-mil impermeable PVC liner in the treatment cell. The liner will cover the bottom and embankments of the filtration cell.
3. Install the underdrain system to include HDPE perforated pipe, washed #57 stone and a 6-ounce non-woven filter fabric.
4. Install thirty-two thousand, two hundred and sixty-seven (32,267) cubic yards of Bold & Gold® IFGEM media on the bottom of the treatment cell. The Bold & Gold® media will be installed in a four-foot thick layer.
5. Install four-thousand eight hundred and forty (4,840) cubic yards of clean sand over the Bold & Gold® CTS media. The sand will be free of organics and have a permeability greater than or equal to the Bold & Gold®. The sand will be installed in a six-inch thick layer.
6. Install sod on the embankment of the treatment cell. The bottom of the cell will be left natural with the sand cover.
7. Connect the inflow and outflow conveyance systems to the Bold & Gold® treatment cell. Test the system for performance to include flow, leaks and operation.

Description	Cost
Materials and Labor to Construct Fifteen Bold & Gold® IFGEM Treatment Cells	$ 147,025,200
Design, Permitting and Construction Management	$ 1,075,000
Security Fencing Around Treatment Cells	$ 105,000
Cost to Construct Proposed Onsite Stormwater Treatment Pond	$ 50,000
Monitoring Costs	$ 80,000
Total Proposed Project Cost	**$ 148,335,200**

3. **Provide papers to bolster the organic nitrogen removal expectations**.

a. **Reference published manuscript**: Chang, Wen, McKenna and Wanielista. 2018. The Impact of Carbon Source as Electronic Donor on Composition and Concentration of Dissolved Organic Nitrogen in Biosorption Activated Media for Stormwater and Groundwater Co-Treatment. Environmental Science and Technology.**52**, 9280-9380.

From Table 3. DON (Higher Dissolved Organic Nitrogen) concentrations with and without carbon

		DON concentration
No Carbon	In	887 ug/L
	Out	418 ug/L
	Removal (%)	53 %
With Carbon	In	883 ug/L
	Out	240 ug/L
	Removal (%)	67 %

In C43 reservoir, there is an assumed DON concentration of 1 mg/L. Carbon concentrations will vary. A removal of 60% ((53+67)/2), is assumed to calculate average DON removal and based on the above data.

b. **Reference published manuscript**: Valencia, Odonez, Wen, McKenna, Chang, and Wanielista. 2020. The Interaction of Dissolved Organic Nitrogen Removal and Microbial Abundance in Iron-Fillings Based Green Environmental Media for Stormwater Treatment. Environmental Research. **188**. 109815.

This publication shows the linkage between DON and microbial populations that affect nutrient reduction. Four media were used, namely a natural soil with about 6% clay by volume, BAM CTS, and two different BAM IFGEM mixes. The BAM IFGEM-3 mix has clay and iron filings in addition to tire crumb and sand. The natural soil was chosen with clay to provide removal of nitrogen and phosphorus. However, with the natural soil, the filtration rate was 10 times slower than BAM, or additional area and costs would be incurred relative to the BAM CTS and IFGEM mixes.

The influent DON was 700 ug/L for three influent conditions and the nitrate and ammonia concentrations were varied. This was done to determine any reduced effects of DON removal due to other microbial competition for nutrients. The results from Figure 5 of the reference publication are shown. Removal of DON using BAM CTS and IFGEM-3 were 67% and 83% respectively.

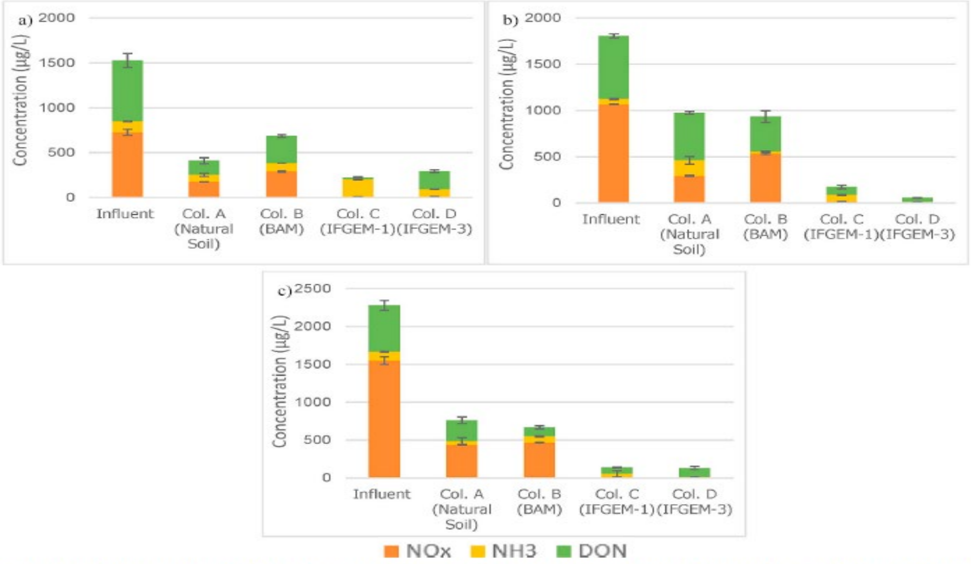

Fig. 5. NOx (nitrate-nitrite), ammonia, and DON (dissolved organic nitrogen) effluent concentrations for (a) influent condition 1 (I1), (b) influent condition 2 (I2), and (c) influent condition 3 (I3).

Concluding Remarks relative to DON

From these publications, when DON is present with other nitrogen species, the microbial populations maintained a reduction in TN. For an influent TN concentration of 1.5 mg/L of which 1.0 mg/L is DON (assumed at the C 43 reservoir), the removal of DON using CTS or IFGEM media is assumed to be at least 60% or an effluent of 0.4 mg/L. For the remaining 0.5 mg/L which is primarily nitrate and ammonia, the effluent is expected to be 0.2 mg/L (60% removal, a conservative estimate). TN in the filter effluent is 0.6 mg/L (0.4 + 0.2). Using a blending ratio of 64% filter effluent to 36% reservoir water produces a filter effluent concentration of 0.92 mg/L (0.64 x 0.6 + 0.36 x 1.5) or less than the target concentration of 1.0 mg/L.

Our previous project budget of $67,815,000 included fifteen 5-acre treatment cells with CTS media at a depth of 3 feet and discharge for an assumed flow schedule that augmented the MFL of 457 CFS. The service life of the Bold & Gold® media in the previous budget is fifty years. We believe 15 five-acre cells is a realistic solution based on historical data. We understand that the estimate may change if a different historical data base on river flow is used. Our previous cost estimate for this project is based on several factors.

1. According to historical discharge data for the Caloosahatchee River and Lake Okeechobee, there are extended periods of time when there are minimal discharges. Flow augmentation is needed during those time periods.
2. Also, there are extended periods of time when there are excessive discharges. Providing addition flow during excessive high flow times is not reasonable in a program for managing flow in the river.
3. Bold & Gold® CTS media provides more nutrient reduction than the target level concentration goals for the C-43 project. Blending filter treated water with untreated water achieves the nutrient discharge concentration goals.
4. The blending of the filter effluent water provides an opportunity for adjustment of the volume of treated water to take into account changes in water quality in the source water. An example is at the point of mixing when water quality of the source water is worse than assumed, thus more filter water (greater volume) can be mixed with a reduced volume of source water.

Environmental Conservation Solutions

Here is the cost summary for our previous submission using fifteen Bold & Gold® CTS cells.

The proposed cost to construct a five-acre Bold & Gold® treatment cell is $4,500,000.00. This estimate includes the labor, equipment and materials for the following:

1. Excavate the existing soil in the designated five-acre area. Utilize the excavated material to build a berm around the treatment cell. Grade the excavated area to prepare for material installation.
2. Install a 30-mil impermeable PVC liner in the treatment cell. The liner will cover the bottom and embankments of the filtration cell.
3. Install the underdrain system to include HDPE perforated pipe, washed #57 stone and a 6-ounce non-woven filter fabric.
4. Install twenty-four thousand and two hundred (24,200) cubic yards of Bold & Gold® CTS media on the bottom of the treatment cell. The Bold & Gold® media will be installed in a three-foot thick layer.
5. Install four-thousand eight hundred and forty (4,840) cubic yards of clean sand over the Bold & Gold® CTS media. The sand will be free of organics and have a permeability greater than or equal to the Bold & Gold®. The sand will be installed in a six-inch thick layer.
6. Install sod on the embankment of the treatment cell. The bottom of the cell will be left natural with the sand cover.
7. Connect the inflow and outflow conveyance systems to the Bold & Gold® treatment cell. Test the system for performance to include flow, leaks and operation.

Description	Cost
Materials and Labor to Construct Fifteen Bold & Gold® CTS Treatment Cells	$ 67,500,000
Design, Permitting and Construction Management	$ 1,075,000
Security Fencing Around Treatment Cells	$ 105,000
Cost to Construct Proposed Onsite Stormwater Treatment Pond	$ 50,000
Monitoring Costs	$ 80,000
Total Proposed Project Cost	**$ 68,810,000**

Thanks for the opportunity to respond to your questions. Please let us know if we can provide any additional information.

Environmental Science & Technology

Article

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The Impact of Carbon Source as Electron Donor on Composition and Concentration of Dissolved Organic Nitrogen in Biosorption-Activated Media for Stormwater and Groundwater Co-Treatment

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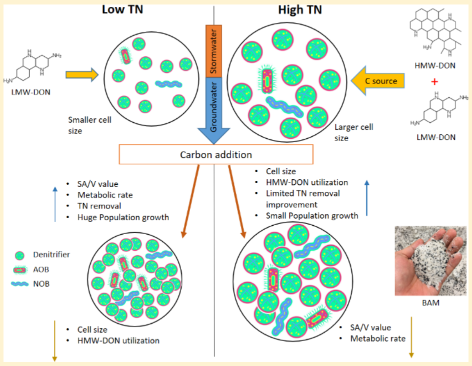
ABSTRACT: Eutrophication has been a long-term issue in aquatic environments, where dissolved organic nitrogen (DON) recalcitrance is important. Bioavailable nitrogen qualification and quantification for effluents from stormwater and wastewater are always a challenge. The information in this study deepens the understanding of the interactions between carbon addition and DON decomposition through linear-ditch best management practices for stormwater and groundwater cotreatment. By running a laboratory-scale column study for nitrogen removal using green sorption media, the variation in composition and concentration of DON can be further linked to the population dynamics of microbial species that dominate the nitrification and denitrification processes. With the varying levels of influent total nitrogen concentration, the efficacy of nitrogen removal via biosorption activated media may be realized at the molecular level with ultrahigh resolution Fourier transform ion cyclotron resonance mass spectrometry.



1. INTRODUCTION

The National Academy of Engineering has indicated that understanding and managing the nitrogen cycle is one of the 14 grand challenges for engineering in the 21st century.[1] Human activities have largely increased nitrogen consumption and distribution.[2−4] Much of the residual nitrogen is normally carried out by stormwater runoff, wastewater effluent, or agricultural discharge.[5−7] Within such an urban nitrogen cycle, dissolved organic nitrogen (DON) is a nonnegligible part since it occupies a large proportion, up to as much as 80%, of total nitrogen (TN) and is an important N source supporting many microbial processes.[8−10] Particularly in stormwater runoff and agricultural discharge, sediment release is the major source of DON, and the uptake of DON through bacterial degradation is the major sink of DON.[11,12] Understanding the processes responsible for DON production, behavior, and characteristics is thus critical for managing nutrient cycling with adequate nutrient control strategies. Previous studies tried to address the ecological significance of DON in various environments such as marine[8,11,13] and freshwater systems.[10,14,15] These studies revealed that DON is a structurally complex mixture of different kinds of organic molecules that are highly variable in chemical structure and composition and thus in bioavailability and ecological functioning. The inherent complexity of DON is a major barrier for understanding how different best management practices (BMPs) can change, modify, and remove DON through innovative stormwater treatment processes.[16−26] One of the promising media types, biosorption activated media (BAM), has been used in various BMPs in varying landscapes for effective nitrogen removal through biological nitrification and denitrification.[21,22,27−34] However, the interaction between BAM and DON remains unclear, especially for the cotreatment of stormwater and groundwater in linear ditch (bioswale) facilities.

Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR-MS) has been applied to analyze complex dissolved organic matter (DOM) for marine organics,[13] surface water,[35] and stormwater.[35−37] The ultrahigh resolving power ($m/\Delta m_{50\%} > 270\,000$ at m/z 400)[38] and mass accuracy (80−200 ppb) of FT-ICR-MS enables the resolution and confident identification of tens of thousands of unique elemental compositions in dissolved organic matter (DOM). This technique is promising for understanding the qualitative molecular interactions between DOM composition, nitrogen-containing compounds, and concentration of nitrogen species in the BAM-based stormwater treatment process. Previous studies have applied FT-ICR-MS to assess the biodegradability of DON from stormwater at the molecular level,[37] but they only evaluated the relative abundance of DON based on the DOM analysis. Moreover, the highly variable natural environment has many influential factors related to bacterial activities for nitrogen removal. One of these factors is a carbon source as part of the total organic carbon in a natural environment, which is a critical element for biomass formation and the electron donor for denitrification processes.[39] This impact on

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denitrification processes can be further realized by using real-time polymerase chain reaction (Real-Time PCR) to quantify the population dynamics of nitrifiers and denitrifiers.

Our objectives in this study were to evaluate the carbon source impact on nitrogen removal for cotreatment of groundwater and stormwater in a column study. By linking the results between real-time PCR and FT-ICR-MS, the novelty of this study was the relationship between the change of DON composition and the response of the microbial community under scenarios with or without carbon addition in a low impact development engineering practice. The cotreatment process is an innovative strategy for treating the groundwater that was extracted and distributed by a solar powered pump during sunny days and the stormwater runoff during storm events. This cotreatment process helps maintain activity of the key bacteria for biological removal of nitrogen species before the water recharges to groundwater. Some scientific questions to be answered may include: (1) What is the effect of a carbon source on the nitrogen removal under various influent conditions? (2) How would the carbon addition affect the microbial species development in terms of population dynamics, metabolic rate, and cell conditions with respect to the changing inlet nutrient concentration? And, (3) can the corresponding microbial community digest the DON concentration and reshape the DON composition efficiently given the available carbon source? We hypothesize that (1) carbon addition would enhance the nitrogen removal and make a difference in DON concentration and composition; (2) there is a cascade effect of the microbial species development in terms of population dynamics when digesting the DON concentration, and (3) there are different trends (changing directions) of DON concentration and composition when comparing the treated water under different influent conditions with untreated counterparts.

2. MATERIALS AND METHODS

2.1. Experiment Setup. The groundwater used in this study was collected from Fanning Spring, Florida (linear ditch site), and the stormwater was collected from a stormwater retention pond on the University of Central Florida (UCF) campus. The linear ditch on a road side in the watershed of Fanning Spring is the locale where the cotreatment of stormwater and groundwater with BAM was examined (Figure 1c and d). To explore the feasibility of nitrogen removal performance as well as the impact on DON concentration and composition, two columns named columns 1 and 2 were set up in a laboratory at UCF for the study of nutrient concentration impacts in the influent; both columns are 15 cm in diameter and 1.2 m in height with three water sample ports at 30 cm intervals on the side (Figure 1a and b). The BAM mixture used in this study contains sand (85%), tire crumb (10%), and clay (5%) by volume. There are two cycles for running the columns: in cycle 1, groundwater was pumped at 10 mL/min for 3 days followed by stormwater at 15 mL/min for 1 day, and in cycle 2 the running method remained the same as cycle 1 except an additional carbon source (40 mg/L COD of glucose) was added to both the groundwater and stormwater reservoir. For both cycles, the inlet was spiked with nitrate to the theoretical concentration of 1.5 mg/L for column 1 and 5 mg/L for column 2 for the study of nutrient concentration impacts due to the highly variable nutrient concentrations in stormwater runoffs (Table 1). Such operational strategies were thus set up to mimic the field conditions for dealing with the stormwater runoff in storm events, as well as for treating pumped groundwater in between two adjacent storm events for nitrogen removal since this area has been heavily polluted by excess nitrogen sources from stormwater runoff and agricultural discharge collectively. Triplicate water samples were collected from inlet, outlet, and each sample port of the column at the end of the running section of stormwater and groundwater.

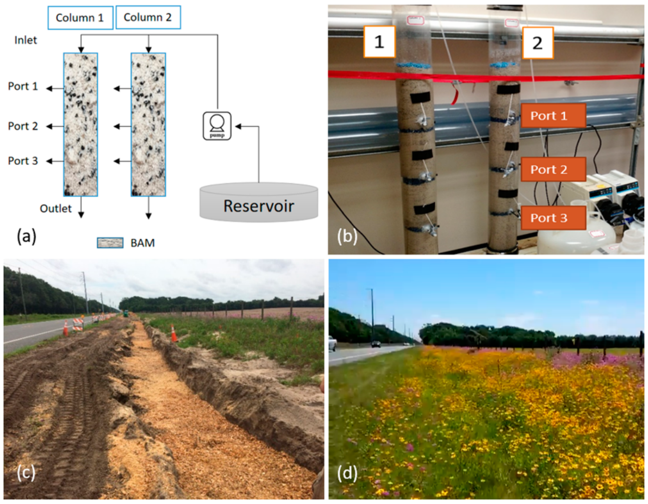

Figure 1. (a) Schematic diagram for column setup. (b) Column study—laboratory view, (c) field construction with BAM deployment, and (d) after construction for cotreatment of groundwater and stormwater.

Water quality parameters of dissolved oxygen (DO) and pH were measured right after the water collection at UCF. Total nitrogen (TN); ammonia, nitrate, and nitrite (NO_x); and alkalinity were determined by an external certificated laboratory, Environmental Research & Design (ERD), and all methods and instruments are listed in Table 2. The corresponding measurement unit is μg/L for TN−N, NO_x−N, and NH_3−N, and the organic nitrogen concentration can be calculated by subtracting NO_x and NH_3 from TN. Water samples were collected only for the inlet and outlet of stormwater sections in each cycle to analyze the DON because stormwater contains the newly washed out DOM. The media samples were collected at the top, port 1, and port 2 from columns 1 and 2 after running the stormwater section in each cycle.

2.2. DON and DOM Analysis. The DON of interest is a part of DOM, and we only focus on the N-bearing organic component as a subset of the DOM analysis. The water sample was first preserved with solid phase extraction (SPE) in the manner described by Dittmar et al.[40] After SPE, all final samples were kept under −20 °C until analysis. Sample analysis for DON was performed at the National High Magnetic Field Laboratory (NHMFL) in Tallahassee, FL. DOM extracts were analyzed with a custom-built FT-ICR-MS[41] equipped with a 9.4 T horizontal 220 mm bore diameter superconducting solenoid magnet operated at room temperature, and a modular ICR data station (Predator)[42] facilitated instrument control, data acquisition, and data analysis. Experimentally measured masses were converted from the International Union of Pure and Applied Chemistry (IUPAC) mass scale to the Kendrick mass scale[43] to identify homologous series for each heteroatom class (i.e., species with the same

Table 1. Inlet Conditions for the Column Study[a]

	cycle 1, no carbon source				cycle 2, with carbon source			
water source	groundwater (3 days)		stormwater (1 day)		groundwater (3 days)		stormwater (1 day)	
pumping rate	10 mL/min		15 mL/min		10 mL/min		15 mL/min	
spiked nitrate concentration	1.5 mg/L	5.0 mg/L	1.5 mg/L	5.0 mg/L	1.5 mg/L	5.0 mg/L	1.5 mg/L	5.0 mg/L
scenario	LGN	HGN	LSN	HSN	LGC	HGC	LSC	HSC

[a] LGN = low TN groundwater inlet with no carbon addition; HSC = high TN stormwater inlet with carbon addition, etc.

Table 2. Methods and Instruments for Water Sample Analysis[a]

parameter	analysis method/instrument
total nitrogen (TN)	SM-21, Sec. 4500 N C
nitrate + Nitrite (NO_x)	SM-21, Sec. 4500-NO3 F
ammonia	SM-21, Sec. 4500-NH3 G
alkalinity	SM-21, Sec. 2320 B
dissolved oxygen (DO)	HACH HQ40D - IntelliCAL LDO101 LDO
pH	Waterproof Double Junction pHTestr 30

[a] SM = Standard Methods for the Examination of Water and Wastewater, 21st Edition, 2005.

$C_cH_hN_nO_oS_s$ content, differing only by their degree of alkylation). For each elemental composition, $C_cH_hN_nO_oS_s$, the heteroatom class, type (double bond equivalents, DBE = number of rings plus double bonds involving carbon), and carbon number, *c*, were tabulated for subsequent generation of heteroatom class relative abundance distributions and graphical abundance-weighted DBE vs carbon number or H/C ratio vs carbon number images or van Krevelen diagram with PetroOrg software [Corilo, Y. E. PetroOrg Software; Florida State University, Omics LLC: Tallahassee, FL, 2014]. The full operation details of FT-ICR-MS can be viewed in an external link.[44]

Due to the immense compositional polydispersity and polyfunctionality, ionization of DOM yields a range of ionization potentials and challenges all mass spectral techniques. Therefore, comparison of nitrogen-containing DOM compounds can be conducted between samples based on relative abundance differences between heteroatom classes.[37] However, it is possible to retrieve the absolute DON concentration of each heteroatom class with the help of the measurement of total DON from the water quality analysis (eq 1). It is also necessary to understand that not all DON components are ionized equally in the ionization process, as oxygen-rich molecules are more efficiently ionized than DON. The absolute concentration of each heteroatom DON class is then calculated based on their relative abundance in DOM. On the basis of the sum of the relative abundance of DON, the relative abundance of each DON species becomes absolute when the whole DON can be divided only among DON species accounting for the total DON (eq 2):

$$C_{\mathrm{T}}^{\mathrm{DON}} = C_{\mathrm{TN}} - C_{\mathrm{NO}_x} - C_{\mathrm{NH}_3} \tag{1}$$

$$C_i^{\mathrm{DON}} = C_{\mathrm{T}}^{\mathrm{DON}}\left[\frac{14N_i}{\mathrm{AMW}_i}\mathrm{RA}_i^{\mathrm{DON}}\right]\left[\sum_m^n \frac{14N_i\cdot\mathrm{RA}_i^{\mathrm{DON}}}{\mathrm{AMW}_i}\right]^{-1} \tag{2}$$

where C_i^{DON} is the absolute DON concentration of species *i*; $C_{\mathrm{T}}^{\mathrm{DON}}$ is the total DON concentration; $\mathrm{RA}_i^{\mathrm{DON}}$ is the relative abundance of N-organic species *i* based on all DOM in the sample; AMW_i is the average molecular weight of N-organic species; N_i is the nitrogen atom number in each N-organic species *i*; and C_{TN}, C_{NOx}, and C_{NH_3} are the concentrations of total nitrogen, nitrate and nitrite, and ammonia.

2.3. Real-Time PCR Analysis. Identifying the gene copy number of corresponding microbial species in relation to nitrogen removal would be helpful in providing one more dimension for understanding the microbial community development in the media samples between ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB), and denitrifiers. Real-time PCR, also known as quantitative polymerase chain reaction (qPCR), is a laboratory technique used in molecular biology for quantifying microbial species. The gene copy number of nitrifiers and denitrifiers was tested with real-time PCR in the Bioenvironmental Research Laboratory at UCF. The collected samples of BAM were stored at −80 °C until gene extraction by using the Mobio PowerMax Soil Kit; the extraction process followed the kit protocol provided by the vendor. All extracted DNA elutes were stored in Tris-EDTA buffer under −20 °C. The real-time PCR was performed with StepOne from Applied Biosystems and PowerUp SYBR Green Master Mix. The primer sets and running methods utilized are shown in Table 3. The PCR assays are of 20 μL reaction volumes with 10 μL of master mix, 0.8 μL of each primer (10 μmole), 4 μL of DNA template, and 5.2 μL of PCR degree water for reactions.

3. RESULTS

3.1. Carbon Impact on Inorganic Nitrogen Removal.

The influent and effluent concentrations of TN, NO_x, and ammonia with the comparison of carbon influences is shown in Figure 2a as well as the N-balance that evaluates the transformation of different N species, which is shown in

Table 3. Primer Sets and Real-Time PCR Running Conditions

target bacteria	primer name	primer sequence	running method	reference
AOB (annealing at 60 °C)	amoA-1F	GGGGTTTCTACTGGTGGT	2 min 50 and 95 °C, 15 s at 95 °C, and 1 min at 60 °C for 45 cycles	Rotthauwe et al.[45]
	amoA-2R	CCCCTKGSAAAGCCTTCTTC		
NOB (annealing at 63.8 °C)	NSR1113f	CCTGCTTTCAGTTGCTACCG	2 min 50 and 95 °C, 15 s at 95 °C, and 1 min at 63.8 °C for 45 cycles	Dionisi et al.[46]
	NSR1264r	GTTTGCAGCGCTTTGTACCG		
denitrifier (annealing at 60 °C)	1960m2f	TAYGTSGGGCAGGARAAACTG	2 min 50 and 95 °C, 15 s at 95 °C, and 1 min at 60 °C for 45 cycles	López-Gutiérrez et al.[47]
	2050m2	CGTAGAAGAAGCTGGTGCTGTT		

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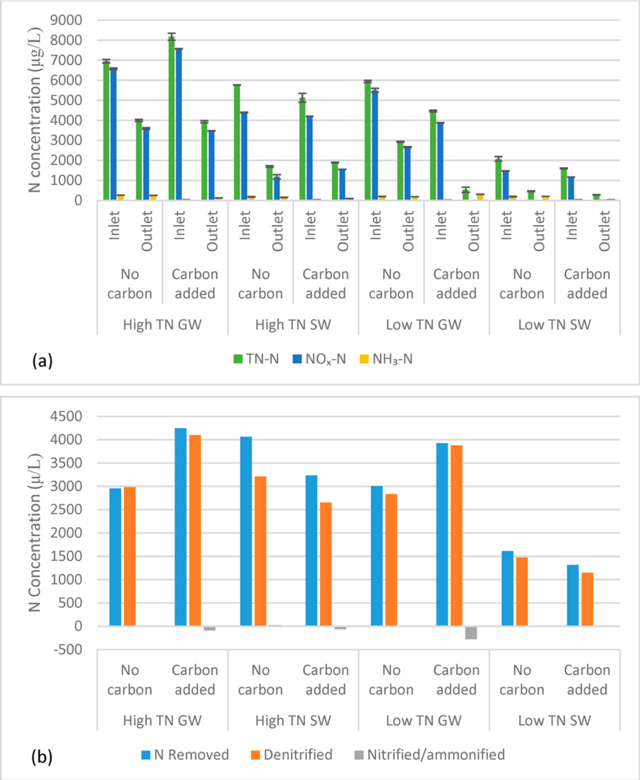

Figure 2. (a) Influent and effluent concentrations of TN, NO_x, and ammonia of BAM before and after the carbon source addition under low TN inlet conditions (column 1) and high inlet conditions (column 2) with groundwater (GW) and stormwater (SW) scenarios. (b) Transformed N species for N-balance calculation based on the average concentration of nutrients from inlet and outlet under each scenario.

Figure 2b. Note that in Figure 2b, gray columns with positive values indicate the removed ammonia (with better nitrification), but those with negative values indicate the increased ammonia (with better ammonification). The inlet TN concentrations are about 7−8 mg/L and 5−6 mg/L for groundwater and stormwater in high TN cases and 4.5−6 mg/L and 1.5−2 mg/L for groundwater and stormwater in low TN cases. Before carbon addition, the TN removals of groundwater and stormwater are 51% and 78%, respectively, for the low TN case, while they were 42% and 70%, respectively, under the high TN case. NO_x removal through denitrification seems to be the dominant removal mechanism, which is also evidenced by the dominant denitrifiers in the next section. After carbon addition, the impact on stormwater TN removal is negligible; however, there is a significant improvement for groundwater as it increased to 88% and 52% for the low and high TN inlet conditions, respectively. Denitrification is still the dominant removal mechanism for all columns, but it was significantly enhanced for treating groundwater. The enhancement of TN removal in groundwater at low TN is largely due to the removal of NO_x through denitrification, in which added carbon was used as an electron donor, but the groundwater with high TN has less improvement of TN removal. This might be a sign of reaching the treatment capability. However, significant ammonia was generated in both stormwater and groundwater after carbon was added due to more complex decomposition of DON, which can be removed by including more clay contents in the green sorption media.

3.2. Real-Time PCR. The gene copy density of AOB, NOB, and denitrifiers for both columns with depths of 0, 30, and 60 cm and the relative abundance of all three species in each layer is shown in Figure 3. Despite carbon addition, the majority of the bacterial population stayed at the top layer for both columns, and denitrifiers were the dominant species in both columns (approximately 88% at top and 99% at 60 cm depth). Before the carbon addition, column 2 had higher bacterial population density than column 1 due to its more nutrient-rich inlet condition; however, the population changes of the two columns are of different magnitudes after the carbon addition. The bacterial population density of the top layer in column 1 increased by 40 times for AOB, 12 times for NOB, and 4.8 times for denitrifiers, while it only increased by 2.5, 1.7, and 1.6 times for the top layer in column 2. However, the bacterial population densities of AOB, NOB, and denitrifiers in the column 1 top layer are 20, 5.2, and 2.4 times larger than those in column 2, respectively, after the carbon addition. Furthermore, the carbon addition had almost no impact on the relative abundance of each type of bacteria in the column 2 top layer, but it enhanced the AOB and NOB percentages in the column 1 top layer.

3.3. DON Compositional Changes. The total DON concentrations from the inlet and outlet are calculated through eq 1 for both low and high TN scenarios before and after the carbon addition, as summarized in Table 4. Some acronyms are used in this paper to represent different scenarios. For instance, LSC represents low TN concentration (spiked 1.5 mg/L nitrate) stormwater with carbon addition while LSN represents low TN concentration (spiked 1.5 mg/L nitrate) stormwater with no carbon addition. Likewise, HSC represents high TN concentration (spiked 5.0 mg/L nitrate) stormwater with carbon addition, while HSN represents high TN concentration (spiked 5.0 mg/L nitrate) stormwater with no carbon addition. With the help of additional carbon, the total DON removal increased from 27% to 42% for stormwater treatment with low inlet TN, and from 52% to 73% for stormwater treatment with high inlet TN. This outcome is part of the reason why the ammonia concentration went up quickly as a result of carbon addition in the case with high inlet TN (Figure 2), because carbon addition may increase the ammonia concentration through the enhancement of ammonification for the treatment of both stormwater and groundwater.[48,49] At that moment, AOB was not abundant enough to decompose those ammonia (Figure 3), although more complex reactions may coexist with ammonification toward ammonia generation.

The corresponding DON classes being removed can be seen through focusing on N-bearing formulas (CHON) in the analysis, and each of the heteroatom classes (e.g., N1O10 indicates the class of molecules containing 1 nitrogen atom and 10 oxygen atoms) can be quantified based on eq 2 (Figure 4). High inlet TN showed generally better total DON removal than the counterpart with low inlet TN. This is indicative that carbon addition has a limited impact on DON removal, which is not as significant as the change of initial TN concentrations at least; it did slightly enhance DON removal when compared to the overlapped DON portion, however, about 25% and 33% of new DON species were found after carbon addition in low and high TN influent scenarios, respectively.

Figure 5 shows the comparative inlet and outlet conditions of all N-bearing formulas found for stormwater treatment associated with either low or high inlet TN before and after carbon addition. In this figure, we further overlaid diagrams

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Figure 3. (a) Gene copy number of AOB, NOB, and denitrifiers from different depths in column 1 and 2 and population percentage of AOB, NOB, and denitrifiers in different depths of (b) column 1 and (c) column 2.

Table 4. Total DON Concentration (μg/L) Changes for Stormwater Treatment Scenarios Associated with Low or High Inlet Total Nitrogen (TN) with or without Carbon Addition

carbon dosage	sample location	low inlet TN	high inlet TN
no carbon	inlet	442	877
	outlet	322	418
carbon added	inlet	398	883
	outlet	226	240

with rectangles to note where important classes of biomolecules are known to fall on a van Krevelen diagram.[37,51] These biomolecules include lipid-, protein-, tannin-, amino sugar-, and lignin- formulas as well as a group of uncharacterized hydrocarbons falling within O/C ratio <0.4 and H/C ratios between 0.5 and 1.75. The scenario of stormwater treatment with low inlet TN shows a similar outlet DON composition pattern before and after carbon addition, which is also consistent with the observations from Figure 4a and Figure 4b. For the counterpart with high inlet TN, the outlet DON composition contains fewer and less dense molecular species than the low TN case, and the carbon addition seems to help remove more DON classes.

4. DISCUSSION

4.1. Carbon Impact on Microbial Community Development and Nutrient Removal. Nitrogen removal within BAM is mainly attributed to a series of biological reactions involving ammonification, nitrification, and denitrification. Given the two inlet TN conditions, the microbial development can be seen in Figure 6, in which the addition of carbon boosted more bacterial growth in nutrient-poor conditions than in nutrient-rich conditions (Figure 3). One reason is that the production of the initiation protein DnaA and other essential components of the replication machinery is proportional to carbon availability for nutrient-poor bacteria,[50] but the DON can be utilized as a carbon source for bacteria in nutrient-rich environments, which makes carbon addition less valuable.[51]

The difference from the inlet TN concentration can also affect the average cell size of bacteria that would substantially keep a certain surface-area-to-volume ratio (SA/V) favorable in response to nutrient availability. Given that column 1 was fed with low TN influent and column 2 with high TN influent, the bacteria cell size in column 1 has to be much smaller than that in column 2 to have a chance to survive. Harris and Theriot[52] used the ratio of SA/V as a key indicator of the cell size because cells modify their size in order to achieve and maintain a specific, condition-dependent SA/V that benefits the species most. Schaechter et al.[53] also observed a similar phenomenon. In our study, the change of relative abundance of bacteria with depth after carbon addition is therefore meaningful (Figure 3). In column 1, the significant increase of the NOB percentage at the top section and 30 cm in depth indicates that the bacteria community had not developed to the maximum extent of its capability in terms of optimized community structure between different species before carbon addition. In column 2, the top

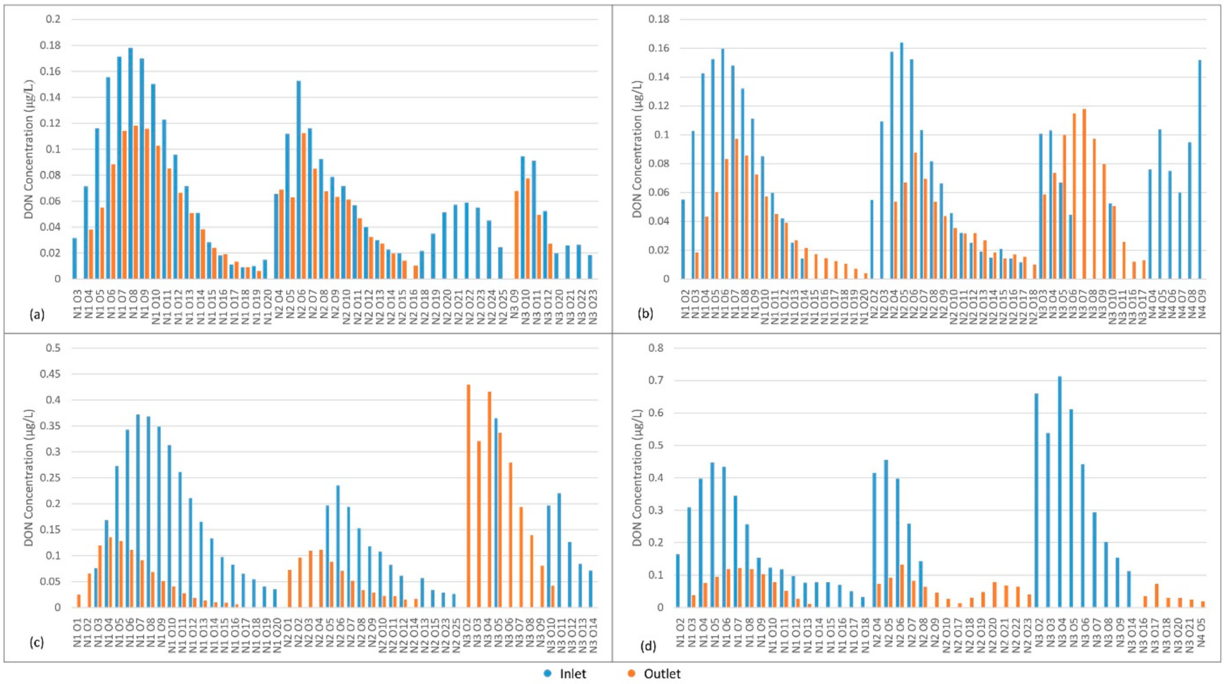

Figure 4. Calculated concentration of CHON classes in the low TN inlet for BAM with (a) no carbon addition (LSN), (b) carbon added (LSC), and in the high TN inlet with (c) no carbon addition (HSN) and (d) carbon added (HSC)

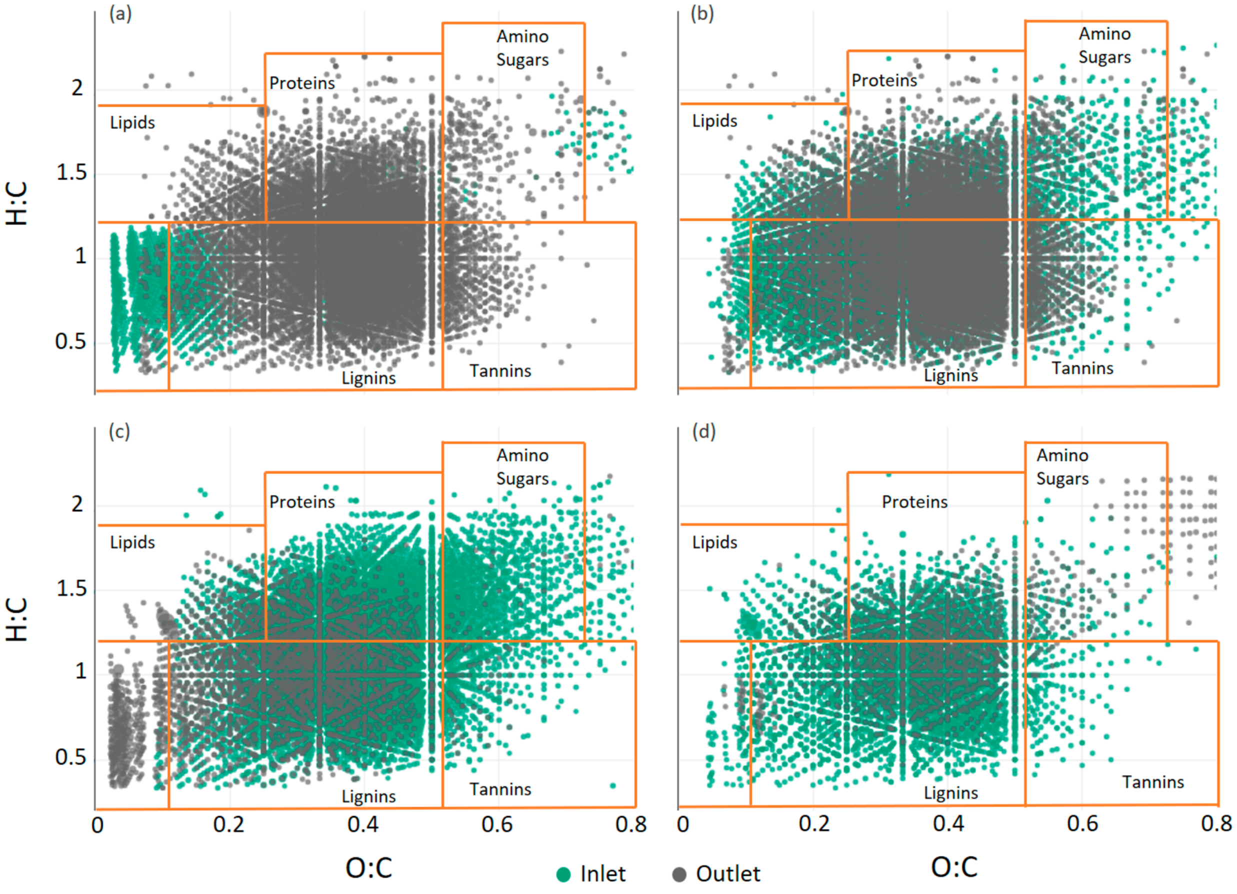

Figure 5. van Krevlen diagrams derived from negative-ion electrospray ionization FT-ICR mass spectral analysis for all N-bearing formulas in the mass spectra of the inlet and outlet with the low TN inlet for BAM with (a) no carbon addition (LSN), (b) carbon addition (LSC), and the high TN inlet with (c) no carbon addition (HSN), (d) carbon addition (HSC)

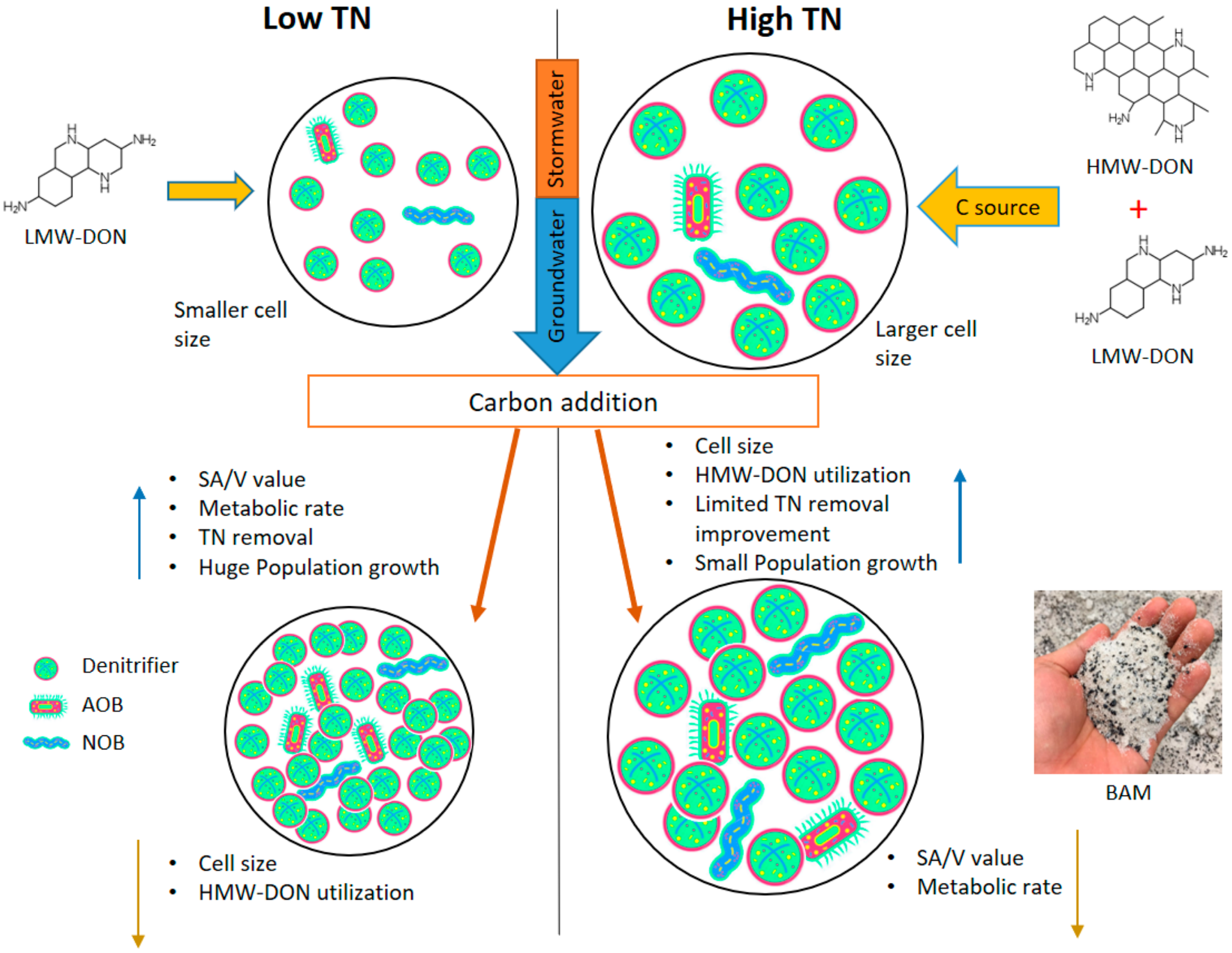

Figure 6. Schematic diagram of microbial community development (with different cell size) under different TN concentrations with carbon impacts (LMW, low molecular weight; HMW, high molecular weight)

layer has no significant change of NOB after carbon addition, which means it had already reached its optimal community structure, but the 30 cm in depth shows a significant NOB percentage increase because the community had not reached its maximum capability and the additional carbon and other nutrients can push the community toward an even better community structure.

The different microbial development in columns 1 and 2 also reflects the effectiveness of nitrogen removal under the impact of carbon addition given that the carbon source is important for denitrifiers in nutrient-poor conditions regardless of whether the treatment is for stormwater (COD = ∼15−20 mg/L) or groundwater treatment because the carbon source in groundwater is much lower (COD = 4−6 mg/L; Figures 2 and 3). For both columns, the top layer is the most active section for nutrient removal since the majority of the bacterial population exists there rather than in the lower sections.

4.2. Carbon Impact on DON Concentration/Composition. Experimental studies and literature reviews have confirmed the general allometric pattern of an inverse relationship between cell size and biomass-specific metabolic rates.[54−57] This pattern profoundly influences DON concentration and composition before and after treatment. The bacteria with a smaller size in column 1 prefer to use low molecular weight DON (LMW-DON) and release the metabolic products faster because their higher metabolic rate cannot effectively utilize high molecular weight DON (HMW-DON) with the limited shorter reaction time within small-size bacteria. Thus, some of the DON classes are harder to remove with column 1 (Figure 4), and column 2 seems able to remove more HMW-DON than column 1 (Figure 7). In column 1, the improvement of the total DON removal increased from 27% to 42% after carbon addition, a result that is probably driven by

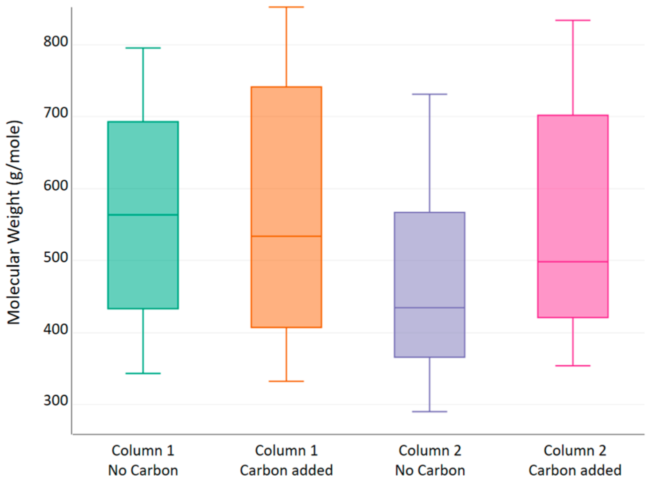

Figure 7. Comparison of outlet DON molecular weight for columns 1 and 2 with and without carbon addition.

the cell synthesis and higher DON consumption with the population growth (Figure 2), but the effluent DON composition is quite similar before and after carbon addition (Figure 5), as some of the DON classes can hardly be removed (Figure 4). Conversely, the nutrient-rich environment in column 2 triggers a longer reproduction period because of the slower metabolic rate as DON provides a carbon source to fuel respiration, as demonstrated by Jones et al.[51] This outcome stimulates the bacteria in column 2 to absorb and accumulate more DON components within their cells (Figure 4 and Figure 5), resulting in larger cell size and slow release of metabolites back into the water that shows lower DON species/concentrations from the effluent (Figure 5) and promotes better DON removal performance for both DON concentration and composition.

In addition to comparing the qualitative differences between relative abundance differences in heteroatom class distribution (CHO, CHOS, CHON, etc.) before and after BAM treatment in Figure 4 and Figure 5, we also performed a class-wise analysis to address how the heteroatom classes changed under various conditions. On the basis of the FT-ICR-MS results (Figure 4 and Figure 5), the carbon addition decreased the % relative abundance of overlapped DON classes from 66% to 59% for low TN cases, and from 46% to 35% for high TN cases after treatment (Table 5). Additional carbon shows the potential to remove more DON compounds from the initial influent, due to the presence of more available carbon from the enhanced bacterial population shown in Figure 3. Therefore, more DON classes were detected with a larger bacteria population in the effluent, and more bacteria population was observed indicating higher capability of consuming DON. Yet the average cell size, which has a direct relationship with inlet TN concentration as stated in section 4.1 (Figure 3), determines the ability of a microbial community to utilize HMW-DON.

Table 5. Comparison of DON Classes before and after Treatment

	low TN inlet		high TN inlet	
	no carbon	carbon added	no carbon	carbon added
overlapped DON classes	66%	59%	46%	35%
new DON classes after treatment	4%	25%	28%	33%

As shown in Table 5, after carbon addition, the relative abundance of new DON classes changed from 4% to 25% in low TN cases and from 28% to 33% in high TN cases, respectively. This could indicate that more carbon sources would increase the new DON classes as the microbial community with larger average cell size would produce more new DON classes due to consuming/converting more HMW-DON (evidenced by the amino corner of Figure 5d). However, for most of the new DON compounds, the concentration is normally low, as shown in Figure 4 directly and Figure 5 indirectly as evidenced by the density of those smaller dots. This observation is consistent with the microbial ecology assessment from the previous statement in the sense that more abundant bacteria with larger sized cells are present that can potentially uptake more DON classes but can also generate more DON classes as microbial community exudates with such enhanced activity. Moreover, this microbial conversion process of DON is also noticed as a potential pathway to enhance the biodegradability of the initial DON from the inlet due to lower molecular weight from the outlet (Figure 7).[37]

From the holistic assessment point of view, the microbial community structure will evolve to an optimized status to utilize all resources as much as possible, such as nutrients, additional carbon, growing space, etc. The utilization of DON is relatively difficult since some of them do not show appropriate biodegradability. However, more carbon and nutrient availability may further optimize the microbial community to evolve in terms of population, species structure, and cell status (size, bioactivity, etc.), as shown in Figure 3, which is also beneficial for DON consumption, as shown in Figure 4 and Figure 5, via such an enhanced microbial community. In general, the conversion from undissolved organics nitrogen to LMW-DON is known as degradation, whereby the further step of transferring LMW-DON to ammonia is called ammonification.

During the nitrification and denitrification processes, the most increased bacteria (in percentage) are in the order of AOB, NOB, and denitrifiers in the top layer, as shown in Figure 8. Additional carbon can work as an electron donor for denitrifiers. Since NOB relies on AOB to provide nitrite as food, which is also a toxic product for AOB, they form an interactive mutualism relationship. That is why the NOB population is significantly enlarged (1142% and 70% in column 1 and 2) with the enhanced AOB population (3992% and 155% in column 1 and 2). This cascade effect resulted in denitrifiers (386% and 67% in column 1 and 2); more nitrate was provided by NOB to support the development of denitrifiers. Carbon source (glucose) cannot provide any ammonia, which is essential for AOB to thrive, but carbon can boost the heterotrophic bacteria to digest more DON via ammonification, as stated in the previous paragraph (optimized microbial community). In other words, the sequential enhancement of AOB, NOB, and dentirifiers happened once more DON could be consumed and converted into ammonia.

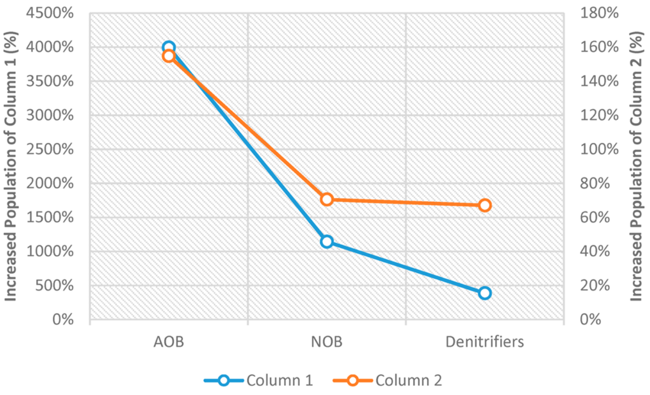

Figure 8. Population ratio of carbon added case to noncarbon case for AOB, NOB, and denitrifiers at the top layer

4.3. Final Remarks. The carbon addition impact on nitrogen removal for the cotreatment of groundwater and stormwater has been systematically evaluated in this study, in which the DON concentration/composition changes based on DOM for stormwater treatment were further realized with the help of FT-ICR-MS and qPCR together. The impact of carbon source is different for stormwater and groundwater; carbon is more important to TN removal in groundwater than in stormwater, as groundwater contains much less carbon in the first place, but carbon addition in this experiment did increase the ammonia concentration through the enhancement of ammonification for both stormwater and groundwater treatment. Nitrogen source variability resulted in different bacteria community development, in which low inlet TN cases tend to cultivate bacteria with smaller cell size while the high inlet TN cases end up favoring larger cell size bacteria that are quite different in terms of metabolic rate and population growth patterns. Carbon works as the essential component for cell reproduction under the nutrient-poor environment, but DON can be utilized as a carbon source for bacterial respiration in the nutrient-rich environment. The DON utilization can be enhanced with additional carbon, but more DON classes would be generated because of the improved microbiological activities with a cascade effect over different microbial species from AOB to NOB to denitrifiers. This difference provides the foundation for understanding the different scale of SA/V that results in very different microbial structural functionalities since the smaller cell size bacteria tend to reproduce faster with a higher metabolic rate and maintain a larger SA/V value that is beneficial for absorbing nutrients more effectively. Therefore, LMW-DON is preferable for smaller cell size bacteria while more HMW-DON can be utilized by larger cell size bacteria. The most abundant bacteria exist at the top layer with denitrifiers as the dominant species, and the additional carbon has much less of an influence at the depth of 60 cm. For real-world applications, we suggest that the depth of BAM should be less than or equal to 60 cm (2 feet).

Overall, stormwater and groundwater are very important alternative sources of water in the urban water cycle. If cost-effective nutrient removal in heterogeneous landscapes and engineering conditions can be made possible with the aid of green sorption media, it may maintain the essential ecosystem service across many green urban infrastructures. These green infrastructures may include, but are not limited to, green roof, bioswale or linear ditch, dry/wet pond, vegetated natural strip, exfiltration trench, lined underground piping networks with underdrain or reuse options, and bioswale. Our current study may lead to a deepened understanding of managing the nitrogen cycle in natural systems and the built environment as an integral part of the low impact development solution.

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Notes

The authors declare no competing financial interest.

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The interaction of dissolved organic nitrogen removal and microbial abundance in iron-filings based green environmental media for stormwater treatment

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ABSTRACT

Nonpoint sources pollution from agricultural crop fields and urbanized regions oftentimes have elevated concentrations of dissolved organic nitrogen (DON) in stormwater runoff, which are difficult for microbial communities to decompose. The impact of elevated DON can be circumvented through the use of green sorption media, such as Biosorption Activated Media (BAM) and Iron-Filing Green Environmental Media (IFGEM), which, as integral parts of microbial ecology, can contribute to the decomposition of DON. To compare the fate, transport, and transformation of DON in green sorption media relative to natural soil (control), a series of fixed-bed columns, which contain natural soil, BAM, and two types of IFGEM, respectively, were constructed to compare nutrient removal efficiency under three distinct stormwater influent conditions containing nitrogen and phosphorus. The interactions among six microbial species, including ammonia-oxidizing bacteria, nitrite-oxidizing bacteria, complete ammonia oxidation (comammox) bacteria, anaerobic ammonium oxidation (anammox) bacteria, dissimilatory nitrate reduction to ammonium bacteria, and iron-reducing bacteria, were further analyzed from microbial ecology perspectives to determine the DON impact on nutrient removal in BAM and IFGEM. Natural soil was only able to achieve adequate DON transformation at the influent condition of lower nutrient concentration. However, the two types of IFGEM showed satisfactory nutrient removals and achieved greater transformation of DON relative to BAM when treating stormwater in all three influent conditions.

1. Introduction

Nutrient pollution from nonpoint sources has been an increasing issue in stormwater treatment, with nitrogen and phosphorus being two primary contaminants of concern (Boserup, 2017; Chang et al., 2004; Commoner, 1991). Inorganic nitrogen such as nitrate (NO_3^-), nitrite (NO_2), and ammonia (NH_3)/ammonium (NH_4^+) in stormwater runoff can deteriorate the ecosystem structure and function in receiving water bodies. The impact of dissolved organic matters (DOMs), especially dissolved organic nitrogen (DON), has been investigated in drinking water treatment (Herzsprung et al., 2012; Liu et al., 2012) and wastewater treatment (Hu et al., 2018a). However, few studies have been performed in regard to the DON in real world stormwater runoff and the subsequent impact on nutrient removal in soils and filtration media (Chang et al., 2018a; Lusk and Toor, 2016a, 2016b). Deepening the understanding of the linkages between DON species and microbial ecology in soils and filtration media that affect nutrient removal in both the natural system and the built environment is thus deemed essential and critical (Chang et al., 2018a; Lusk and Toor, 2016a).

DON is the principal form of dissolved nitrogen in surface waters (Lusk and Toor, 2016b), which can be affected by land use and watershed characteristics (Pellerin et al., 2006). DON in surface waters corresponds to 0.5–10% of DOM by mass (de Vera et al., 2017). DON in surface waters is derived from soil leaching, wastewater disposal (Simsek et al., 2016), biological substances such as plants and algae (photosynthetic organisms), atmospheric deposition, and waste produced by living organisms (Jørgensen, 2009). DON compounds include nucleic acids (DNA and RNA), amino sugars, free amino acids, urea, and methylamines (Jørgensen, 2009). Aromatic compounds contain the second most abundant class of natural carbon, including lignins, tannins, and aromatic amino acids (Simon et al., 2005), in addition to man-made counterparts.

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These DON species are difficult to remove in wastewater treatment plants and are often found in nature at a higher concentration than dissolved inorganic nitrogen (Berman and Bronk, 2003). In the nitrogen cycle, the utilization and assimilation of DON by microorganisms allows the cycling and reutilization of DON by particle-feeding organisms (Hu et al., 2018b; Jørgensen, 2009). The removal of nitrogen is strongly associated with the nitrogen-cycle via a suite of biogeochemical processes, such as nitrogen fixation, ammonification, nitrification, denitrification, and dissimilatory nitrate reduction to ammonium (DNRA), produced by chemical reactions, plant uptake, and microorganisms (O'Reilly et al., 2012a). The understanding of the nitrification pathway has been enhanced through the discovery of complete ammonia oxidation (comammox) by aerobic bacteria, which achieves both ammonia and nitrite oxidation (Annavajhala et al., 2018; Dang and Chen, 2017). This two-step nitrification process was originally believed to be completed separately by ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) (Costa et al., 2006; Koch et al., 2019).

New green sorption media technologies have been developed for *in situ* treatment of stormwater to prevent contaminants from reaching lakes, streams, and other water bodies (O'Reilly et al., 2012b; Beecham et al., 2012). Biosorption activated media (BAM) (Hood et al., 2013; O'Reilly et al., 2012a) and iron-filing green environmental media such as IFGEM-1and IFGEM-2 (Chang et al., 2018c) are a few of the many developed filtration media that have been proven cost-effective and sustainable for removing nitrogen and phosphorus in stormwater runoff. However, only physicochemical properties have been explored for IFGEM-1, IFGEM-2 (Chang et al., 2018b) and IFGEM-3 (Valencia et al., 2019). Thus, the continuous exploration of the microbiological properties of the IFGEM series is critical for field applications due to its inclusion of sand-iron aggregate (IFGEM-1) or clay-iron aggregate (IFGEM-2 and IFGEM-3).

Iron and aluminum are known as phosphate precipitation metals (Roncal-Herrero et al., 2009), and have been used for iron oxide coated sand (Khiadani et al., 2013; Zhang et al., 2010). However, high concentrations of iron and aluminum ions might impact the environment (Baby et al., 2010), and they can be transported along with other heavy metals, bacteria, and nutrients in urban stormwater runoff (Mason et al., 1999). These iron and aluminum ions could originate from vehicle emissions, human activities (Khiadani et al., 2013), roads, and roofs (Mason et al., 1999). Previous studies performed on soil have indicated that the presence of heavy metals decreases the microbial bioactivity and population growth of the bacteria in the nitrogen cycle (Kandeler et al., 1996). Further, the impact of copper on BAM and its effect on the microbial community has also been explored (Wen et al., 2018, 2020b). However, ferrous iron (Fe (II)) has the capacity to precipitate phosphate especially in the presence of calcium (Thistleton et al., 2002), and the presence of ferrous iron can also impact microbial ecology, since ferric iron (Fe (III)) can be reduced to the ferrous state by iron reducing bacteria (IRB) (Straub et al., 1996). While iron oxidation bacteria can oxidize ferrous iron in the presence of nitrate. Anammox can act as nitrate dependent ferrous iron oxidation bacteria since it oxidizes ferrous iron with nitrate as an electron acceptor (Strous et al., 2006); it can also act as a ferrous iron reducing bacteria to reduce ferric iron with organic matter as an electron donor (Van De Vossenberg et al., 2008). Nevertheless, the reduction of iron is normally more predominant than the oxidation of iron bacteria (Snoeyenbos-West et al., 2000).

Studies of dissimilatory iron-reducing bacteria (IRB) and its activity in aquifers (Kanso et al., 2002; Wildung et al., 2004) and sediments have been previously undertaken (Cooper et al., 2016; Todorova and Costello, 2006). Two of the major IRB species include Shewanella and Geobacter (Todorova and Costello, 2006). In sediments, the heterotrophic bacteria species of Geobacter (Lovley, 1993) are known for the reduction of ferric iron (Smith et al., 2013). Two common iron-reducing species are Geobacter sulfurreducens and Geobacter metallireducens, in which the Geobacter metallireducens specie has more characteristics than its counterpart, such as the anaerobic oxidation of aromatic hydrocarbons (Smith et al., 2013). Geobacter metallireducens are a common metal reducer, which can reduce Fe(III) and Mn(IV) to Fe(II) and Mn(II) (Snoeyenbos-West et al., 2000), which is beneficial given that Fe(II) is the most soluble form of iron (Lee et al., 2002) that can be used for phosphate precipitation. Apart from reducing iron under anaerobic conditions, G. metallireducens can oxidize organic matter, such as aromatic hydrocarbons, to carbon dioxide with ferric iron as an electron acceptor (Lovley et al., 1993, 2004), while other members of this family can transfer electrons to insoluble metal oxides (Simon et al., 2005). Thus, DON can be utilized as food for different microbial bacteria, such as IRB (Amon et al., 2001).

Nitrogen augmentation for better ammonia nitrogen removal can influence the microbial community in the soil directly and indirectly via changes in soil pH (Zeng et al., 2016). According to Judd et al. (2006), changes in the microbial community were produced from changes in DOM. In stormwater, nitrogen (N) exists as NO_3^-, NO_2^-, NH_3, and NH_4^+, as well as dissolved organic nitrogen. However, inorganic N can be assimilated by plants and microorganisms into organic N (Collins et al., 2010). As parts of the nitrogen cycle, nitrification, denitrification, and ammonification processes can occur via physical, chemical, and biological interactions (van Breemen, 2002). The structure and function of microbial communities can perhaps be affected by the quantity and quality of DOM (Logue et al., 2016). Therefore, the retrieval of DON information is important for a deepened understanding of its role in an ecosystem, given that DOM can potentially provide carbon and nitrogen sources to microorganisms in the nitrogen cycle (Eppley and Peterson, 1979). DON information can be retrieved with Fourier transform ion cyclotron resonance spectrometry (FT-ICR-MS) (Eppley and Peterson, 1979). Furthermore, calcium and other chemicals present in stormwater can provide higher removal based on their reactions. Calcium concentrations in Florida can vary from 23.8 mg/L (Jones, 2013) to 2–4.6 mg/L in ponds, and 33–91.1 mg/L in rivers and streams (Dodd et al., 2017). Alkalinity may be examined as a substitute to determine its effect on nutrient removal if calcium cannot be directly measured in a study.

Hence, the objectives of this study are to: 1) compare the nutrient removal efficiencies of BAM, IFGEM, and natural soil at varying stormwater influent conditions in terms of the ammonia, total nitrogen (TN), total phosphorus (TP), 2) determine the impact that iron filing content has on bacteria growth and nutrient removal, and 3) explore the impact microbial communities have on DON removal under distinct stormwater conditions. The research questions to be explored are: 1) How do the varying influent nutrient concentrations impact the removal efficiencies of TN, TP, and ammonia in different filtration media? 2) How does iron filing as a media component in IFGEM-3 (new media with clay-iron aggregate) and IFGEM-1 (existing media with sand-iron aggregate) alter the efficiency of TP removal and its impact on the microbial ecology? 3) How do the microbial ecologies of BAM and IFGEM differ in terms of nitrification, denitrification, ammonification, and DNRA? 4) How can the DON composition/concentration be affected if DON is utilized by iron bacteria in IFGEM? 5) How can microbial assimilation of DON affect nitrogen composition? We hypothesize that: 1) the anammox population may be enhanced by the presence of iron as a media component, 2) IRB can exhibit a higher population in IFGEM, 3) the microbial communities can utilize and transform DOM, specifically DON obtained from stormwater, to enhance their growth, especially in IFGEM, and 4) more DON utilization may be present due to bacteria, such as IRB and DNRA, that make up the microbial ecology in IFGEM-3, resulting in a lower DON concentration and more variation of DON composition in the effluent. To answer these questions, a fixed-bed column study with four identical columns filled with IFGEM-1, IFGEM-3, BAM, and natural soil, respectively, was performed, as explained in the next section.

Table 1
Media matrix composition by weight.

Composition	BAM	IFGEM-1	IFGEM-2	IFGEM-3
Sand (kg/m^3)	1850.0	2094.0	1741.1	1806.0
Tire crumb (kg/m^3)	97.0	–	97.0	97.0
Clay (kg/m^3)	51.0	–	51.0	20.0
Iron filing (kg/m^3)	–	259.0	340.0	340.0

2. Material and methods

2.1. Properties of filtration media and natural soil

Natural soil and three green sorption media were selected for this experiment. The natural soil for this study was collected from a basin (known as Basin 9 B) located in Silver Springs, close to Silver Springs State Park in Florida. The soil from this basin was utilized as a control (base) in order to compare its nutrient removal with those of the three different green sorption media (filtration media). The media composition by weight for each green sorption media is detailed in Table 1. The BAM mixes were modified by adding ground iron-filing as a new media component to generate IFGEM-1 and IFGEM-3 as a continuation of our previous IFGEM series study based on IFGEM-2 (Chang et al., 2018b). IFGEM-1 and IFGEM-3 were then fully tested in this study to explore their physicochemical and microbiological properties.

2.1.1. Moisture content analysis

Moisture content is a media characteristic that can give insight to biofilm growth, thus to determine the moisture content of media samples, approximately 1–1.5 g of media samples were oven-dried at a temperature of 104 °C for 24 h. At the end of this time, media samples were measured, and the weight data were placed into Eq. (1) to obtain the moisture content from the different media in percentage.

$$MC = \frac{W - D}{W} * 100 \tag{1}$$

where W = wet media weight, and D = dry media weight.

2.1.2. Hydraulic retention time

A tracer study with rhodamine dye was conducted to determine the hydraulic retention time (HRT) to permit the understanding of the hydraulic patterns of the natural soil, BAM, IFGEM-1, and IFGEM-3. After adding approximately 1–2 mL of diluted dye to the top of each column, water samples were collected for the effluent of each column in 10–15 min time intervals. Collected water samples were analyzed immediately after collection using the AquaFluorTM fluorometer (model: 8000–010). The measured concentration (ppb) vs. time (min) of collection were plotted to observe the hydraulic pattern of the dye in each column.

2.2. Column study

Four identical columns were constructed, each consisting of a PVC pipe with a diameter of 10 cm (4 in) divided into 3 sections of 30 cm (12 in) for media sampling purposes. A filter with a layer of pebbles was placed at the bottom of each column section to prevent clogging, and the column sections were sealed to prevent outside interference. Columns identified with the letters A, B, C, and D were filled with natural soil, BAM, IFGEM-1, and IFGEM-3, respectively. Fig. 1 illustrates the setup of the fixed-bed column study, including the location of media sample ports 1 and 2. The column study procedure began with an incubation period of 4 weeks, during which stormwater from a stormwater wet detention pond beside the Student Union of the University of Central Florida was collected and utilized to constantly feed each column. At the culmination of the incubation period, stormwater spiked with nitrate (1000 mg/L standard solution) and phosphate (50 mg/L standard solution) at a concentration of 0.9 mg/L NO_3^- and 0.3 mg/L PO_4^{3-} for condition 1 (denoted as I1 hereafter) was utilized to feed each column for 3 h. Subsequently, water samples were collected from the influent and effluent ports of each column. Following, the columns were flushed with stormwater alone for more than 24 h to counteract any possible media changes due to the influent condition. The same process (after incubation) was repeated for two more time-varying influent conditions of 1.3 mg/L NO_3^-, 0.5 mg/L PO_4^{3-} for condition 2 (denoted as I2 hereafter), and 1.7 mg/L NO_3^-, 0.7 mg/L PO_4^{3-} for condition 3 (denoted as I3 hereafter). The downward influent flow rate of 8 ml/min (2.33 in/hr) was maintained constantly with peristaltic pumps.

2.2.1. Water sample collection and analysis

During the biofilm incubation process, water samples from the stormwater collection pond were collected on three occasions to obtain background information/composition of the stormwater. The time interval in between collection events was approximately 10 days. Additionally, water samples from the influent and effluent ports of each column were collected at the culmination of the 3-h feeding time for conditions 1, 2, and 3. Collected samples were analyzed in-house for pH, oxidation-reduction potential (ORP), and dissolved oxygen (DO) immediately after collection. The Waterproof Double Junction pH Testr® 30 was used to measure pH, while DO and ORP were measured using the HACH HQ40D IntelliCAL/MTC101.

2.2.2. Water parameter analysis

Water samples collected in triplicates were delivered to ERD laboratories (Environmental Research and Design, Inc) for measurement of TN, NOx, ammonia, TP, alkalinity, iron, and aluminum within 24 h of collection. DON was calculated as the difference between TN, NOx, and ammonia. The methods utilized for the parameter analysis follow the "Standard Methods for the Examination of Water and Wastewater, 22nd edition" (Carranzo, 2012), and the methods' identification numbers and names can be found in Table 2.

2.3. Physicochemical interactions

The physiochemical interactions, driven primarily by clay and iron, can reduce nitrate, adsorb ammonia, and precipitate and adsorb phosphate collectively. The interactions of iron and nitrate in water can reduce nitrate, producing ferrous ion and ammonium (Eq. (2)), which can be adsorbed by clay. The negative charges of clay particles enable the adsorption of cations such as ammonium and potassium to balance the charge (Nieder et al., 2011). Further, a series of precipitations of phosphate from interactions among ferrous or ferric ions and hydroxide from hydrolysis of water are expressed by Eqs. (3)–(5). Aluminum, which is a heavy metal oftentimes present in stormwater, can form a low soluble solid in the presence of phosphate (Eq. (6)).

$$4Fe^0 + NO_3^- + 10H_3O^- = 4FE^{2+} + NH_4^+ + 13H_2O \tag{2}$$

$$Fe^{2+} + H_2PO_4^- = FE_3(PO_4)_{2(s)} + H^+ \tag{3}$$

$$Fe^{+3} + PO_4^{3-} = FEPO_{4(S)} \tag{4}$$

$$Fe^{+2} + PO_4^{3-} = FE(OH)_{2(S)} \tag{5}$$

$$AI^{+3} + PO_4^{3-} = AIPO_{4(S)} \tag{6}$$

2.4. Microbial interactions in nitrogen cycle

2.4.1. Microbial communities in the nitrogen cycle

In the nitrogen cycle, nitrogen in the form of NH_4^+ is converted to NO_3^- through nitrification; and subsequently NO_3^- is converted to N_2 by the denitrification process, thus leaving the system. AOB and NOB

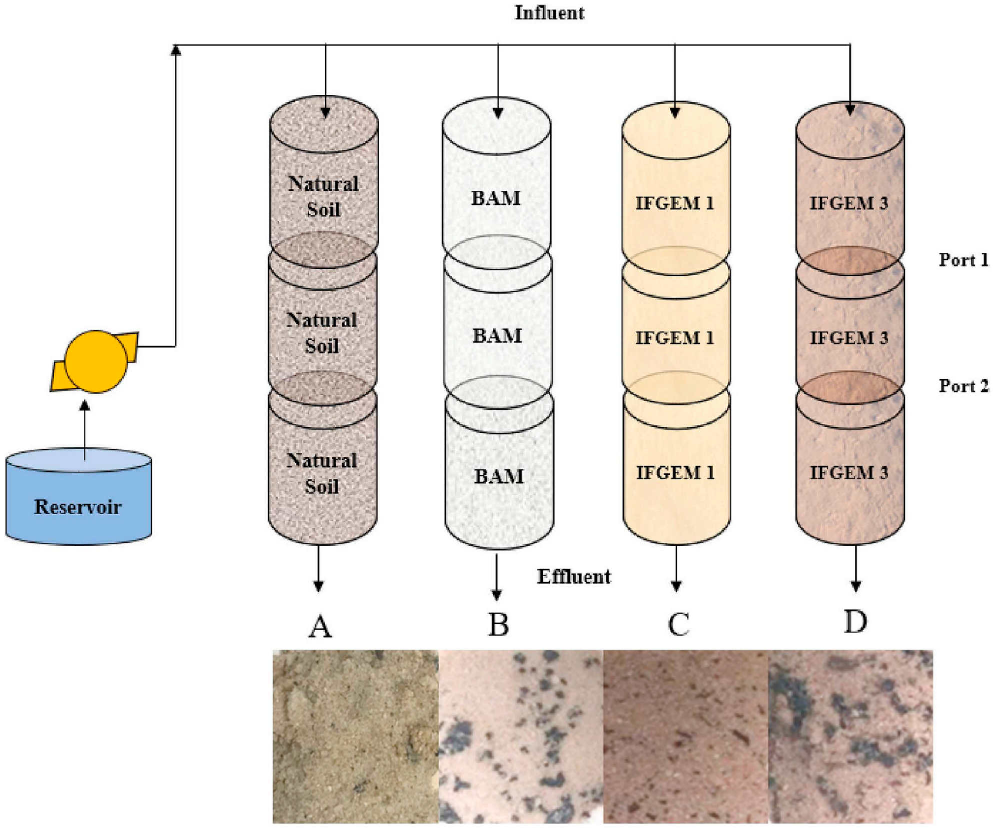


Fig. 1. Column study experimental setup. Columns A, B, C, and D correspond to natural soil, BAM, IFGEM-1, and IFGEM-3, respectively.

Table 2
Water parameter analysis methods.

Parameter	Method
TN	SM-21, Sec 4500 NC
NOx	SM-21, Sec 4500-NO3, F
Ammonia	SM-21, Sec 4500-NH3, G
TP	SM-22, Sec 4500 P F
Alkalinity	SM-21 Sec. 2320 B
Iron (dissolved)	SM-22 Sec. 3111 B
Aluminum (dissolved)	SM -22 Sec. 3111 D

form the first nitrification pathway, complemented by denitrifying bacteria (denitrifiers) in one of the two nitrate reducing pathways of dissimilatory nitrite reduction to nitrogen gas (Tugtas and Pavlostathis, 2007) (Fig. 2). However, the recent discovery of complete ammonia oxidizer (Commamox), which oxidizes NH_4^+ and reduces NO_2^- to NO_3^- through a single microorganism, provides a more holistic understanding of the nitrogen cycle, as this was originally believed to be a two-part process driven by AOB and NOB (Daims et al., 2015; Van Kessel et al., 2015).

In the second nitrate reduction pathway, NO_3^- can also be converted to NH_4^+ through the dissimilatory nitrate reduction to ammonium (DNRA) process, hence this analysis is important since it prompts an increase of ammonia while conserving N in the system (Giblin et al., 2013). The biological activity of DNRA bacteria in the presence of nitrate and organic carbon as an electron donor can generate ammonia (Tugtas and Pavlostathis, 2007). Furthermore, anaerobic denitrification in anoxic conditions performed by annamox bacteria can convert NH_4^+ with NO_2^- as electron acceptor to produce N_2 (Oshiki et al., 2016; Sonthiphand et al., 2014).

2.4.2. *Quantitative polymerase chain reaction (qPCR)*

For quantification of the microbial species in both the natural soil and the green sorption media quantitative polymerase chain reaction (qPCR) was used (Chang et al., 2018a). Media and soil samples were collected from the locations at the top (location 1), port 1 (location 2), and port 2 (location 3) of each column, two and four weeks after the beginning of the experiment (before the addition of spiked stormwater) to assess biofilm growth. All media samples were stored at -80 °C after collection until conducting qPCR analysis. The qPCR analyses were thus employed to help realize the microbial population dynamics and even microbial ecology. DNA extraction was performed via the DNeasy PowerSoil Kit (Qiagen) by following the steps recommended by the vendor. The primer and standards utilized were acquired from ThermoFisher Scientific and GenScript. A 48 well plate was used to process the samples via the Step-One-Plus qPCR instrument. Each well was composed of 10 μL of SybrGreen, 1.6 μL of primer (0.8 μL forward and 0.8 μL reverse), 5 μL of sample, and 3.4 μL of qPCR water. Table 3 provides a summary of the primer and oligonucleotide sequence, the qPCR running method, and the relevant reactions. The amoA genes were investigated for AOB and comammox (Dionisi et al., 2002; Xia et al., 2018), whereas nxrAB (Daims et al., 2015), nirS (Azziz et al., 2017), nrfA (Yin et al., 2017), and 16 S rRNA (Orschler et al., 2019) genes were explored to target NOB, denitrifiers, DNRA, and anammox, respectively.

2.5. *Dissolved organic nitrogen analysis*

Individual water samples collected at the culmination of each of the three inlet condition runs were stored for further DON analyses. Impurities were reduced by preparing samples via solid phase extraction by passing the samples through a filtration process employing Bond Elut$^{\text{TM}}$ PPL cartridge (200 mg, 3 mL) and methanol to elude the sorbed bed, following specifications by Lanza and Sellergren (2001), and preserved at -20 °C. These samples were delivered to the National High Magnetic Field Laboratory at Florida State University for molecular-

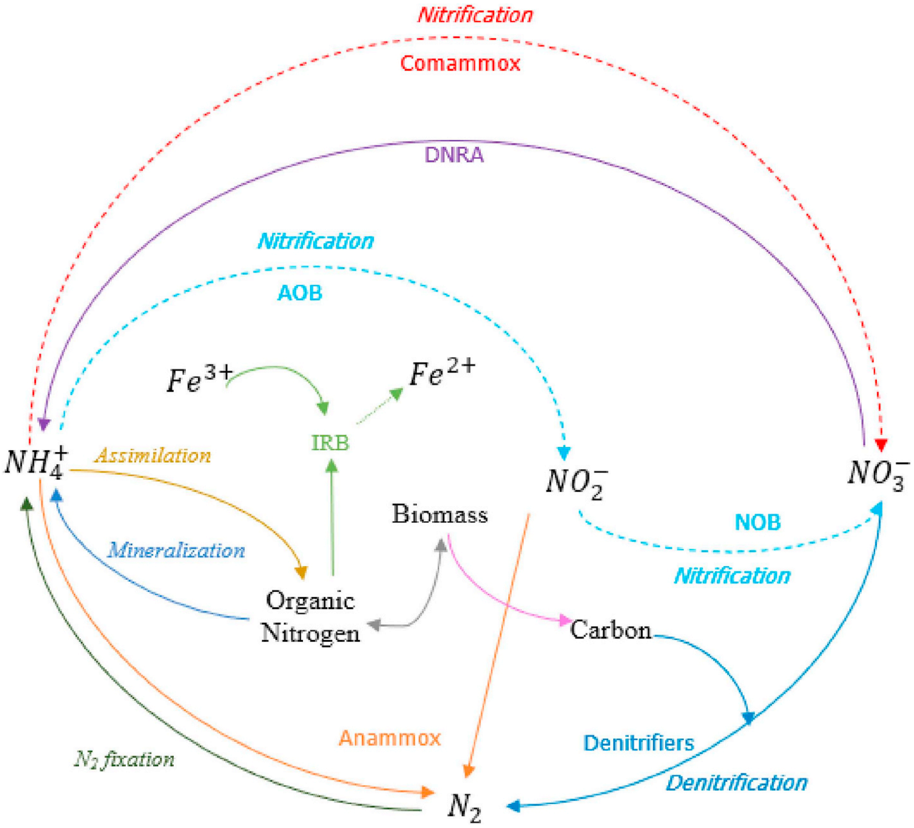


Fig. 2. Microbial communities in the nitrogen cycle.

level characterization of the dissolved organic compounds by Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS) at 9.4 T (Kaiser et al., 2011). In sample preparation, all solvents were HPLC grade (Sigma-Aldrich Chemical Co., St. Louis, MO) and SPE extracts were ran at 50 ppm carbon in methanol prior to analysis by negative ion electrospray ionization. Sample solution was infused via a microelectrospray source (Emmett et al., 1998) (50 µm i. d. fused silica emitter) at 500 nL/min by a syringe pump. Typical conditions for negative ion formation were: emitter voltage, −2.4–2.9 kV; tube lens, −250 V; and heated metal capillary current, 7 A. DOM extracts were analyzed with a custom-built hybrid linear ion trap FT-ICR mass spectrometer equipped with a 9.4 T superconducting solenoid magnet (Kaiser et al., 2011; Kaiser et al., 2013; Chen et al., 2014). The heteroatom class relative abundance, average number of C, average double bond equivalents, and average H/C for acidic compounds detected by FT-ICR MS were assigned elemental compositions with PetroOrg© software for comparison of the molecular composition of the influents and effluents (Corilo, 2014).

3. Results

3.1. Hydraulic retention time and soil moisture

The result of the hydraulic pattern pertaining to the infiltration and time required for stormwater to leave the system for each column is presented in Fig. 3. An extensive HRT of 726 min (12.1 h) was observed in natural soil, while IFGEM-1 and IFGEM-3 experienced similar HRTs of 137 min (2.28 h) and 124 min (2.25 h), respectively. The shortest HRT was observed in BAM at 73 min (1.22 h). The hydraulic patterns (HRT) herein pertain to the time for infiltration of stormwater during the experiment, which will aid in the field design.

The comparative results of the moisture content for each column section are further delineated in Fig. 4. For natural soil and BAM, the moisture contents at each location remained comparable between week 2 and week 4. From week 2 to week 4 the moisture content decreased at the top of IFGEM-1 but increased for the other locations. Similarly, the moisture content for IFGEM-3 decreased at the top layer from week 2 to week 4, but an increase in moisture content was observed for the middle and bottom locations during the same period. The low moisture contents at week 4 at the top location of IFGEM-1 and IFGEM-3 could be attributed to conduits formed in the top section that caused a faster infiltration, thus retaining less water moisture in these locations. The moisture contents are indicative of the moist environment of the media during biofilm cultivation and the effect on infiltration.

3.2. Nutrient removal

The removal efficiencies of natural soil, BAM, IFGEM-1, and IFGEM-3 for TN, TP, and ammonia were determined from the mean effluent concentrations. TN removal was comparable for columns C (IFGEM-1) and D (IFGEM-3), which achieved the highest TN removals (Table 4). The highest TN removal of IFGEM-1, 93.94%, was attained under condition I3 (1.7 mg/L nitrate, 0.7 mg/L phosphate), whereas the highest TN removal of IFGEM-3, 96.86%, was obtained under condition I2 (1.3 mg/L nitrate, 0.5 mg/L phosphate). The second highest TN removal of IFGEM-1, 90.46%, was obtained under condition I2 (1.3 mg/L nitrate, 0.5 mg/L phosphate), followed by IFGEM-3, with a TN removal of 94.35%, under condition I3 (Table 4). Natural soil and BAM achieved lower TN removal in the range of 46–73% for natural soil and 48–70% for BAM at all three conditions.

A trend for TP removal was not as apparent throughout the different influent conditions. The highest TP removals were achieved by IFGEM-1 with a TP removal of 91.64% for I3, IFGEM-3 with TP removal of 92.43% in I3, and BAM with 92.81% in I3. Overall, TP removal increased from natural soil to BAM, IFGEM-1, and IFGEM-3, with natural soil having limited TP removal. Furthermore, ammonia removal was

Table 3
Summary of target bacteria primer, running method and reaction.

Bacteria (target gene)	Prime Name	Oligonucleotide Sequence	Running method	Reaction	Reference
Ammonia Oxidizing Bacteria **(amoA)**	amoA1F amoA2R	GGGGTTTCTACTGGTGGT CCCCTKGSAAAGCCTTCTTC	2 min 50 °C and 2 min 95 °C; 45 cycles [15 s at 95 °C and 1 min at 62 °C]	$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$	Rotthauwe et al. (1997)
Nitrite Oxidizing Bacteria **(nxrAB)**	NSR113F NSR1264R	CCTGCTTTCAGTTGCTACCG GTTTGCAGCGCTTTGTACCG	2 min 50 °C and 2 min 95 °C; 45 cycles [15 s at 95 °C and 1 min at 62 °C]	$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$	Dionisi et al. (2002)
Anaerobic ammonium oxidation **(amx)**	amx809-F amx1066-R	GCCGTAAACGATGGGCACT AACGTCTCACGACACGAGCTG	2 min 50 °C and 2 min 95 °C; 45 cycles [15 s at 95 °C and 1 min at 62 °C]	$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O * NO_2^- + FE^{2+} \rightarrow FE_{3+} + NO + H_2O * * * organic\ matter + FE_{3+} \rightarrow CO_2 + Fe^{2+}$	Snoeyenbos-West et al. (2000);Tsushima et al. (2007)
Denitrifying bacteria **(nirS)**	Cd3AF R3Cd	GTSAACGTSAAGGARACSGG GASTTCGGRTGSGTCTTGA	2 min 50 °C and 10 min for 95 °C; 40 cycles [60 s at 95 °C; 60 s at 51 °C; and 60 s at 60 °C]	$NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + H_2O * * * NO_2^- + 2H^+ + e^- \rightarrow NO + H_2O$ $2NO_2^- + 2H^+ + 2e^- \rightarrow N_2O + H_2O$ $N_2O + 2H^+ + 2e^- \rightarrow N_2 + H_2O$	Azziz et al. (2017)
Dissimilatory nitrate reducing bacteria **(nrfA)**	nrfA2F nrfA2R	CACGACAGCAAGACTGCCG CCGGCACTTTCGAGCCC	2 min 50 °C and 10 min for 95 °C; 40 cycles [30 s at 95 °C; 60 s at 60 °C; 60 s at 72 °C]	$2CH_2O + NO_3^- + H_2O \rightarrow NH_4^+ + SO_4^{-2}$	Yin et al. (2017)
Complete Ammonia Oxidation **(amoA)**	A378f C616r	TGGTGGTGGTGGTCNAAYTAT ATCATCCGRATGTACTCHGG	2 min 50 °C and 5 min for 95 °C; 40 cycles [30 s at 95 °C; 30 s at 58 °C; 30 s at 72 °C]	$NH_4^+ + 2O_2 \rightarrow H_2O + H^+$	Xia et al. (2018)
Iron-reducing bacteria **(Gmet0909)**	0909QF 0909QR	ATTGCAACGACTGTCACGAT GGGATTATCCATTGCCTTGA	2 min 50 °C and 2 min 95 °C; 45 cycles [15 s at 95 °C; 60 s at 60.5 °C]	$* * * organic\ matter + FE^{3+} \rightarrow CO_2 + Fe^{2+}$	Stults et al. (2001)

*chemical iron oxidation of Fe (II) and NO_2^-
** Iron reduction by iron reducing bacteria.
*** step in denitrification performed with the aid of enzyme nirS.

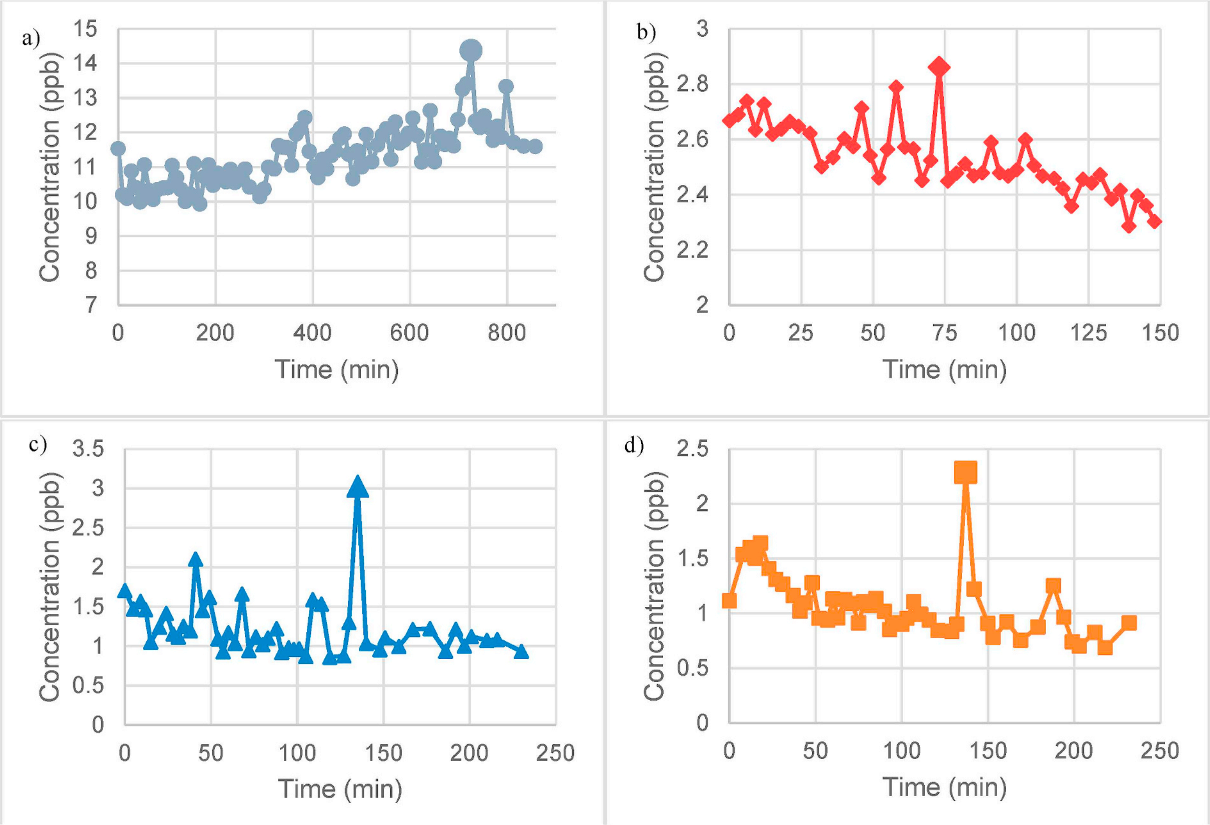


Fig. 3. Hydraulic characteristics for and patterns (a) natural soil, (b) BAM, (c) IFGEM-1, and (d) IFGEM-3.

observed for the majority of the columns, with ammonia generation occurring for IFGEM-1 in I1, and natural soil and IFGEM-1 in I2. Ammonia removal was minimal at I1, with natural soil and IFGEM-3 achieving ammonia removals of 35.64%, and 29.56%, respectively. Higher ammonia removals of 82.56% and 91.34% for IFGEM-3 in I2 and I3, followed by BAM with 61.63% in I2, and IFGEM-1 with 63.01% in I3, were displayed.

The concentrations of the NOx, ammonia, and DON components of TN obtained from the difference between the measured TN, NH_3, and NOx for each column are delineated in Fig. 5. Natural soil and BAM presented the highest effluent TN concentrations, wherein the primary components were NOx, followed by DON. Lower effluent TN concentrations were observed in IFGEM-1 and IFGEM-3. The ammonia concentration of the total TN also mirrored ammonia removal. The large quantity of ammonia correlates with ammonia generation by IFGEM-1 in I1 and natural soil in I2. Similarly, large NOx concentrations, which result in lower TN removal, were present in the natural soil and BAM columns at all conditions, and the IFGEM-1 column at I2. Lastly, the investigation of dissolved iron and aluminum present at the influent and effluents confirmed high dissolved aluminum in the effluent of BAM and slightly lower concentrations in natural soil, IFGEM-1, and IFGEM-3 (Fig. 6). The dissolved iron concentration fluctuated for each column at every condition, with a noticeable decrease in IFGEM-1 at all conditions, as well as natural soil, BAM, and IFGEM-1 at I3.

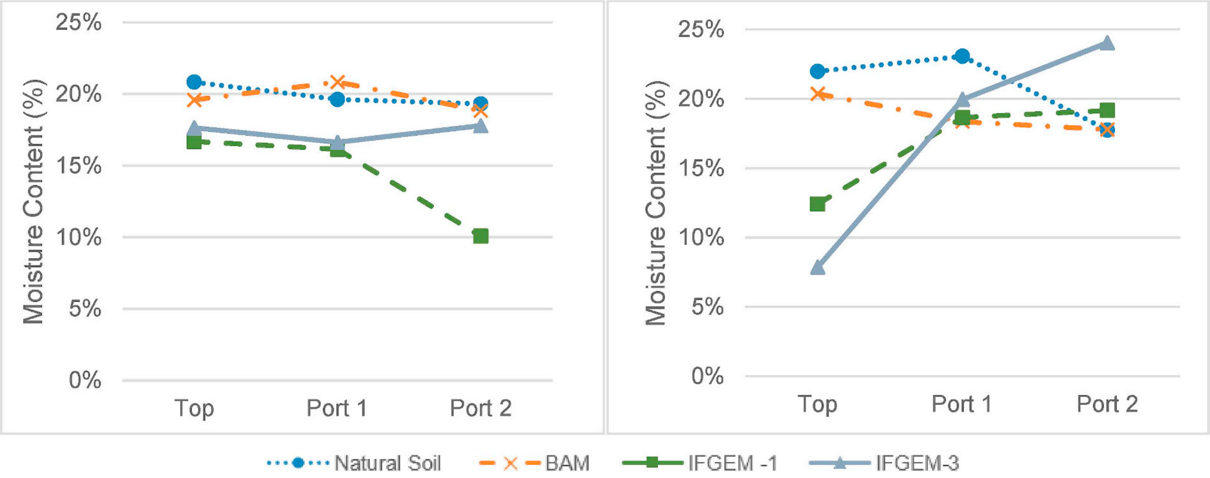


Fig. 4. Media moisture content at different sample locations (Top, Port 1, and Port 2) in (a) week 2 and (b) week 4.

Table 4
Summary of mean removal efficiencies (%) for measured parameters.

Column	Port	Total Nitrogen (%)	Total Phosphorus (%)	NOx (%)	Ammonia (%)	Dissolved Iron (%)	Dissolved Aluminum (%)	Alkalinity (%)
Influent = 0.9 mg/L Nitrate, 0.3 mg/L Phosphate (I1)								
A	Effluent	73.14	10.11	75.94	35.64	−5.01	−40.10	−166.04
B	Effluent	55.10	28.84	60.13	22.93	−144.88	−5075.25	−14.40
C	Effluent	85.39	81.65	98.76	−61.95	89.98	43.07	26.79
D	Effluent	80.83	50.19	98.85	29.56	−38.78	−63.37	4.91
Influent = 1.3 mg/L Nitrate, 0.5 mg/L Phosphate (I2)								
A	Effluent	46.09	−176.82	72.49	−191.86	−118.42	7.60	−162.05
B	Effluent	48.28	4.19	49.89	61.63	−95.61	−171.93	−13.66
C	Effluent	90.46	60.26	98.56	−22.09	46.49	43.27	15.27
D	Effluent	96.86	76.38	99.81	82.56	−89.47	45.03	21.69
Influent = 1.7 mg/L Nitrate, 0.7 mg/L Phosphate (I3)								
A	Effluent	66.62	63.85	71.76	56.94	41.22	63.11	−121.23
B	Effluent	70.70	92.81	69.85	29.77	62.60	−47.95	25.03
C	Effluent	93.94	91.64	99.23	63.01	62.60	95.08	34.86
D	Effluent	94.35	92.43	99.87	91.34	76.34	50.00	31.68

Note: Negative signs in this table exhibits the release rather than removal.

3.3. Water quality parameters

Changes in pH, ORP, DO, and alkalinity are critical indicators of variations in water quality characteristics. The measurements of pH, ORP, and DO for the fresh stormwater nutrient spiked influent and corresponding effluent are shown in Table 5. Overall, the pH in the effluent increased for every column, with the highest pH achieved by natural soil. In general, the ORP in the effluent declined for natural soil, IFGEM-1, and IFGEM-3, with the effluent ORP for BAM being the highest, and even surpassing the influent for most conditions. Similarly, BAM had the highest effluent DO, followed by natural soil. However, IFGEM-1 and IFGEM-3 exhibited the lowest DO, with column D having the smallest DO measurement for I1 and I2. The alkalinity increased between the influent and effluent of the natural soil; however, values similar to or lower than the influent were observed for BAM, IFGEM-1, and IFGEM-3 at all conditions (Fig. 7). In general, the DO concentration was high for high alkalinity concentrations, with a decreasing trend from natural soil to IFGEM-3.

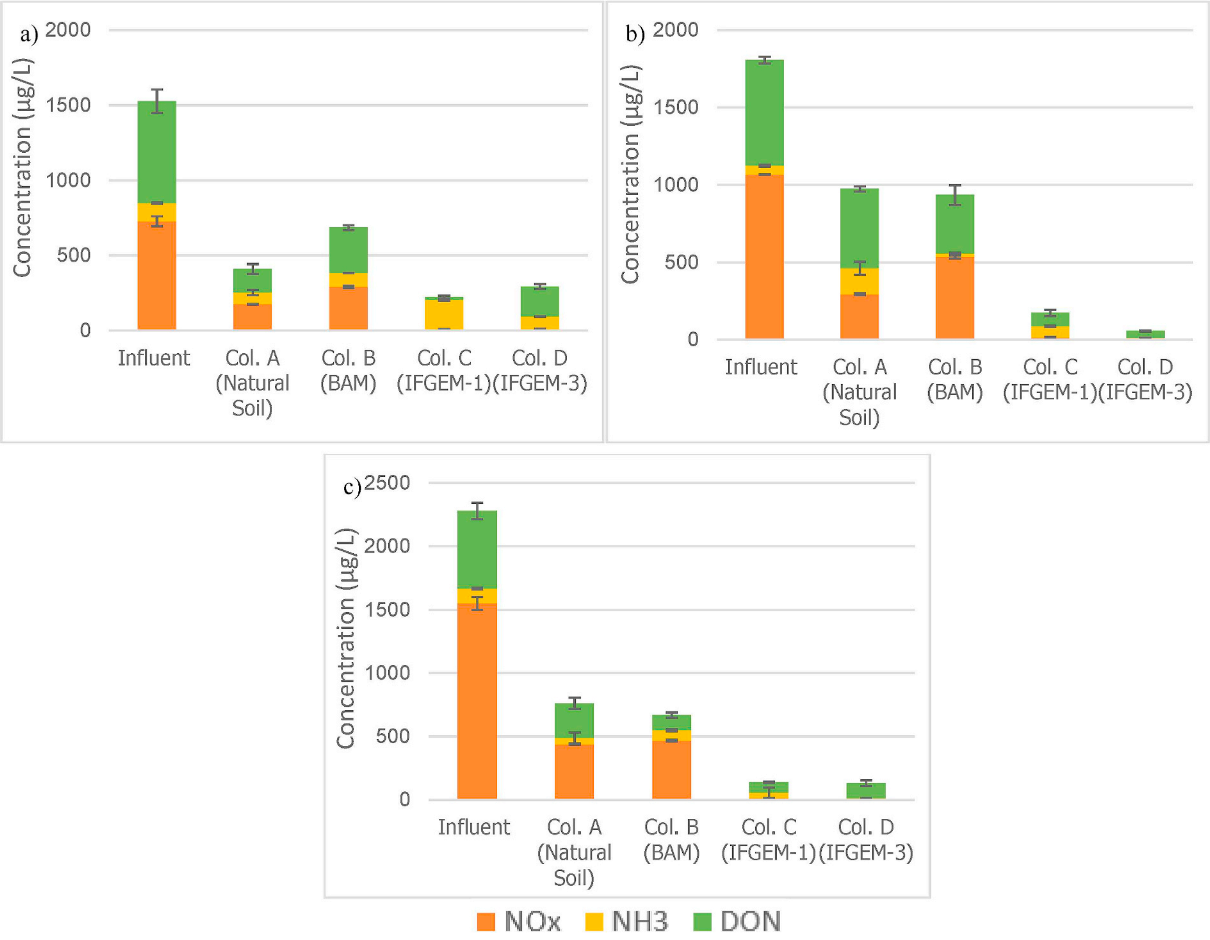


Fig. 5. NOx (nitrate-nitrite), ammonia, and DON (dissolved organic nitrogen) effluent concentrations for (a) influent condition 1 (I1), (b) influent condition 2 (I2), and (c) influent condition 3 (I3).

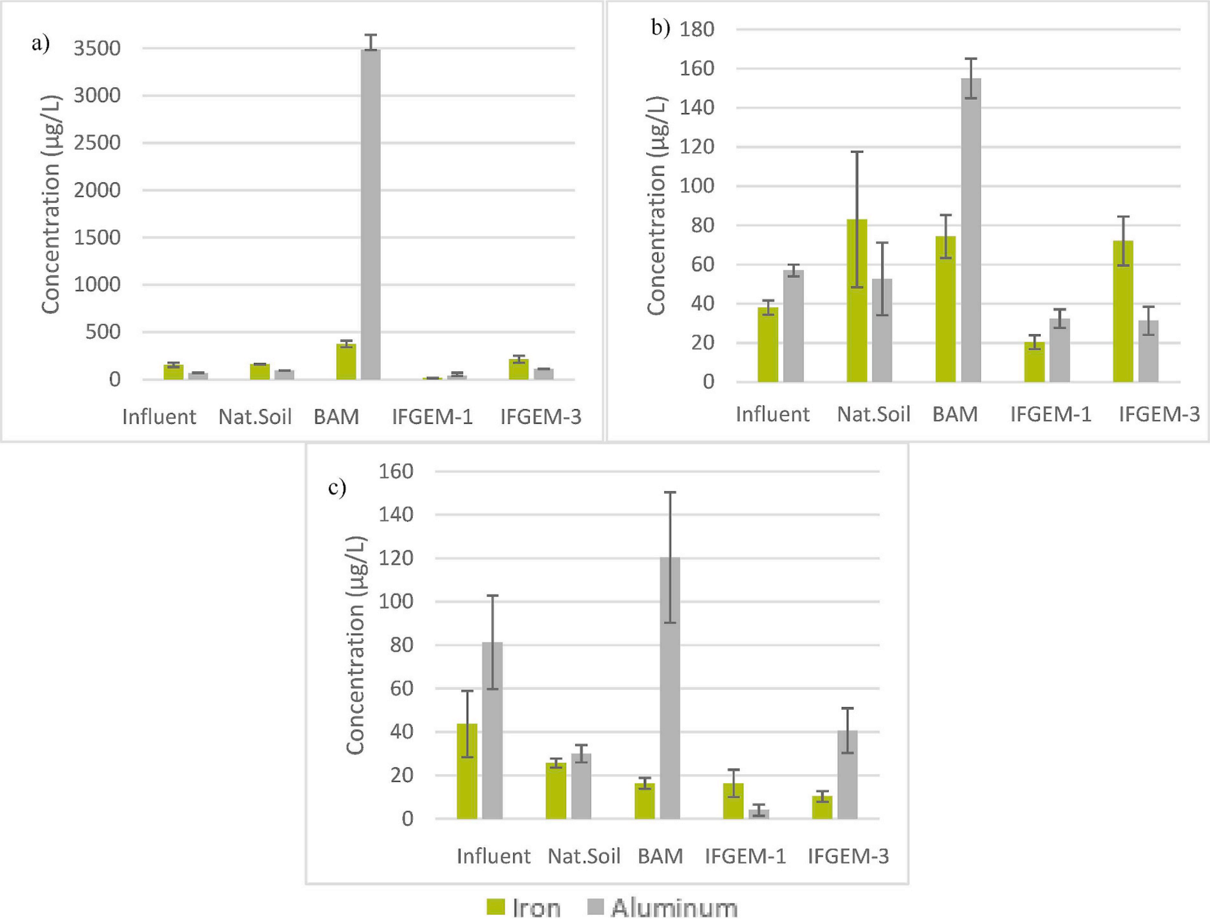


Fig. 6. Dissolved iron and aluminum effluent concentrations for (a) influent condition 1 (I1), (b) influent condition 2 (I2), and (c) influent condition 3 (I3).

3.4. Real-time polymerase chain reaction (qPCR)

The population density of the microbial ecology in charge of the nitrogen cycle was evaluated via qPCR for the natural soil and the three green sorption media at the second and fourth week of biofilm cultivation. The primary participants, based on their population densities, were NOB, comammox, denitrifiers, and DNRA, as the population of anammox was determined to be under detection limits in all columns. Furthermore, the population quantity of AOB was significantly lower in week 2 and increased in week 4. This phenomenon was discovered and quantified by qPCR at the top (location 1) of all of the media, and port 2 (location 3) of the natural soil (Fig. 8). Comammox was concentrated at the top port for the three-sorption media, and all ports for natural soil. Overall, the density of comammox increased from week 2 to week 4, with the exception of IFGEM-1, which experienced a decrease.

In general, the density of NOB in natural soil decreased from week 2 to week 4, with the highest quantities at the top (location 1) and port 3 (location 3). NOB population increased from week 2 to week 4 for BAM, IFGEM-1, and IFGEM-3, with significant quantities at the top (location 1). The denitrifier population increased from week 2 to week 4 at all media locations except for location 1 (top) in natural soil, and location 2 (port 2) in BAM and natural soil. A decrease in DNRA density between week 2 and week 4 was observed at locations 1 and 2 in natural soil, while an increase in DNRA population was found in BAM, IFGEM-1, and IFGEM-3. Lastly, the IRB microbial population was primarily detected at the top section (location 1) in week 2, with a decrease in population density observed from week 4, with the exclusion of location 2 in natural soil and location 1 in IFGEM-1.

3.5. Dissolved organic nitrogen (DON)

Information specific to the ratios of the number of hydrogen, carbon, and oxygen atoms, such as O/C and H/C, and molecular formulas of N compounds in the presence of C, H, O, and N elements can

Table 5
Average pH, ORP and DO measurements of column study.

Column	Port	Influent = 0.9 mg/L Nitrate, 0.3 mg/L Phosphate (I1)			Influent = 1.3 g/L Nitrate, 0.5 mg/L Phosphate (I2)			Influent = 1.7 mg/L Nitrate, 0.7 mg/L Phosphate (I3)		
		pH	ORP	DO	pH	ORP	DO	pH	ORP	DO
	Influent	8.13	319.47	8.33	7.80	256.05	8.05	7.48	192.63	7.76
A	Effluent	8.56	294.87	8.63	7.94	115.57	9.04	8.26	156.57	8.85
B	Effluent	8.31	340.80	8.91	7.58	125.50	9.07	8.09	232.63	9.10
C	Effluent	8.00	110.87	7.32	7.83	48.90	5.40	8.23	53.77	6.05
D	Effluent	8.34	95.50	4.37	7.87	62.30	4.19	7.96	174.93	6.54

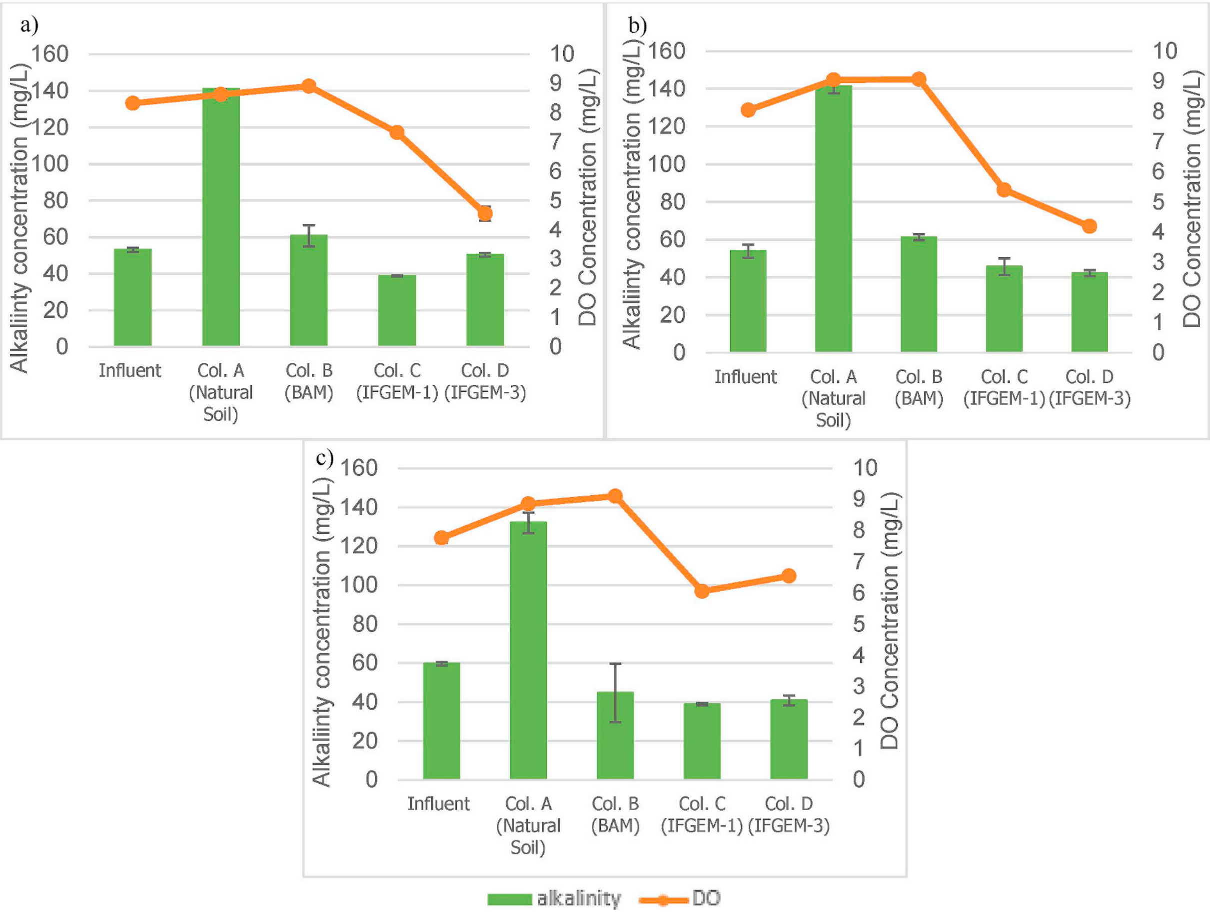


Fig. 7. Alkalinity and DO measurements from influent to effluent for (a) condition 1 (I1), (b) condition 2 (I2), and (c) condition 3 (I3).

be observed in van Krevelen diagrams and used for the classification of DON molecules. The difference between the DON composition distribution of O/C and H/C ratios and the relative abundance of DON heteroatom classes (nitrogen and oxygen atoms) between the influent and effluent are depicted in Fig. 9, Fig. 10, and Fig. 11 for I1, I2, and I3, respectively. The type of molecules corresponding to specific O/C and H/C ratios included in the van Krevelen diagram are lipid-like, proteins/amino sugars-like, lignins-like, carbohydrates-like, tannins-like, condensed aromatics-like, and unsaturated hydrocarbon-like compounds (Antony et al., 2014). Proteins, amino sugars, and lipids are products of microbial metabolisms (Wu et al., 2018). Thus, lipids can signify cell growth and energy storage from DON utilization, as well as quantitative information about microbial communities (Zhang et al., 2003).

The abundance of lignins, unsaturated hydrocarbons, condensed aromatics, lipids, proteins, amino sugars, carbohydrates, and tannins increased in I1 for the effluent of natural soil and IFGEM-3 in comparison to the influent (Fig. 9 (a),(d)). Further, the relative abundance of the N1O and N2O heteroatom classes increased in the effluent. However, the composition varied slightly for BAM and IFGEM-1, with the production of condensed aromatics in BAM and carbohydrates, tannins, proteins, and amino sugars in IFGEM-1 (Fig. 9 (b),(c)). The classes remained unchanged for BAM, and the relative abundance decreased in the effluent of IFGEM-1, which had fewer DON classes.

In I2 there was no substantial change in DON composition for natural soil and BAM, apart from the small production of condensed aromatic, protein, amino sugar, tannin and lignin compounds (Fig. 10 (a), (b)). This is corroborated by the consistency in the minimal change of classes from the relative abundance between the influent and effluent. Condensed aromatics were transformed into proteins, amino sugars, tannins, and carbohydrates by IFGEM-1 (Fig. 10 (c)), whereas carbohydrates, tannins, proteins, amino sugars, unsaturated hydrocarbons, condensed aromatics and lipids were produced in IFGEM-3 (Fig. 10 (d)). Yet, less change in DON compositions and relative abundance classes was observed in I3. There was a slight reshape in the influent and effluent compositions of natural soil and BAM with an increase in the effluent for condensed aromatic, lignin, tannin and carbohydrate compounds (Fig. 11 (a), (b)). Moreover, the condensed aromatic, tannins, and lignins in the influents were transformed to proteins, amino sugars, lignins, tannins, and carbohydrates in the effluent of IFGEM-1 and IFGEM-3 (Fig. 11 (c), (d)).

4. Discussion

4.1. Physical and chemical parameters in this column study

Hydraulic characteristics can reflect the impact of biological activity on media components and biofilm growth. Conversely, excessive biofilm growth can decrease infiltration, thus reducing HRT. The difference between the HRT of natural soil, BAM, IFGEM-1, and IFGEM-3 can be attributed to clay content. The longer HRT of the natural soil in this study had high clay content, which significantly decreases water infiltration, providing an opportunity for the influent to pond at the top section thus increasing moisture. Although BAM contained lower clay content than the natural soil, its media composition consisted of clay content compared to the absence of clay in IFGEM-1. However, the similarity in the HRT of IFGEM-3 and IFGEM-1 can be connected to the presence of iron filing particles and its possible effect on surface area and biofilm growth, which enhances the attachment of particles onto the media. The infiltration rates may have become comparable due to

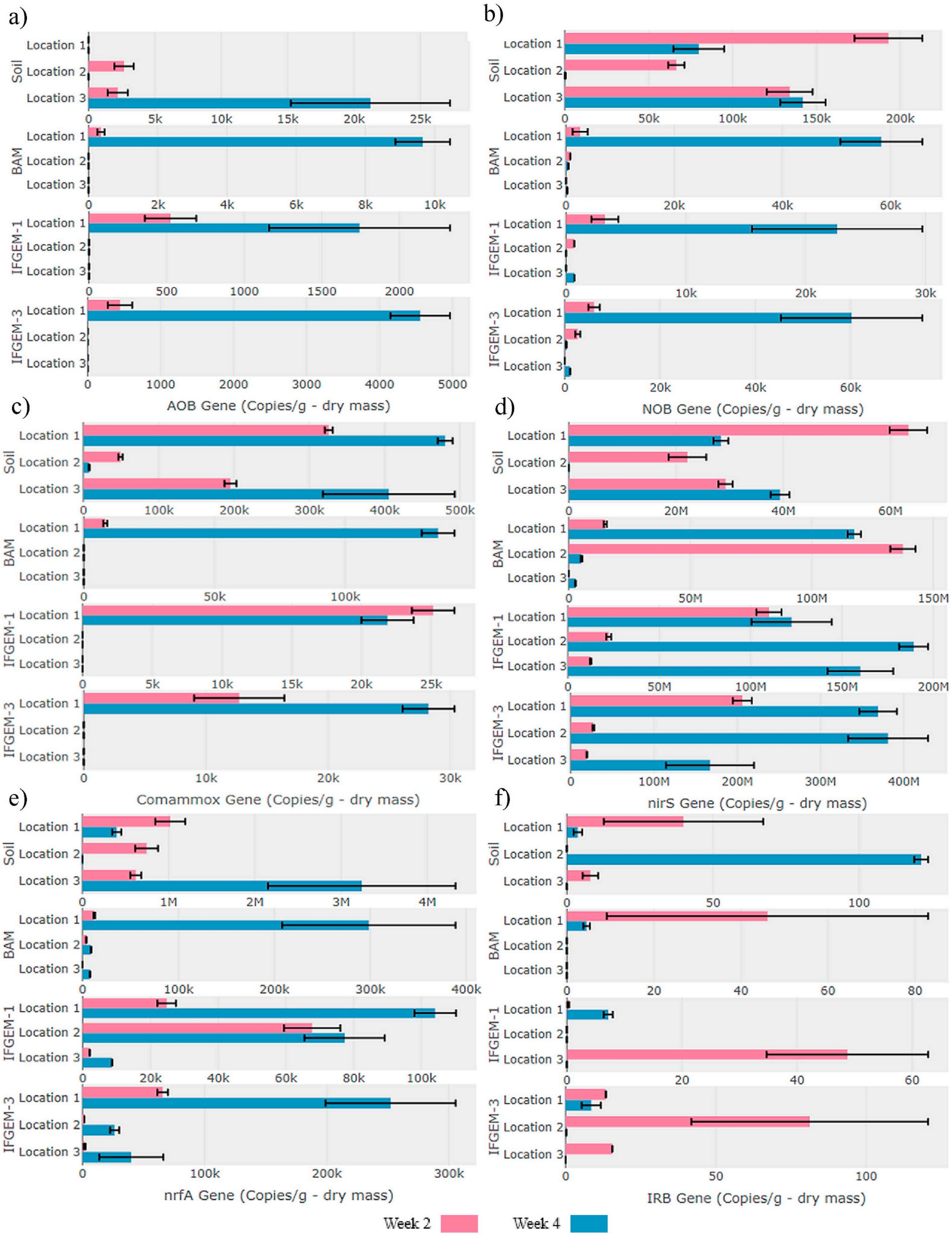


Fig. 8. Population density for (a) AOB, (b) NOB (enzyme nxrAB), (c) Comammox (d) denitrifiers (enzyme nirS), (e) DNRA bacteria (enzyme nrfA), (f) IRB (G. metallireducens) in copy/gram for samples collected at week 2 and week 4 of cultivation. Location 1 corresponds to the top section, location 2 corresponds to port 1, and location 3 corresponds to port 2.

the constant iron oxidation forming an oxidized layer at the top of the IFGEM, producing a decrease in infiltration. This promoted sections of anaerobic conditions at the top and port 1, and aerobic conditions at port 2.

The variations of pH, ORP, DO, and alkalinity in each effluent provide insight about the stormwater characteristics. ORP can be used as a monitoring parameter to justify the treatment process stability (Zhang et al., 2018) as a more consistent process control parameter than pH and DO because of its higher signal range (Lackner and Horn, 2012). Additionally, changes in pH can be associated with alkalinity

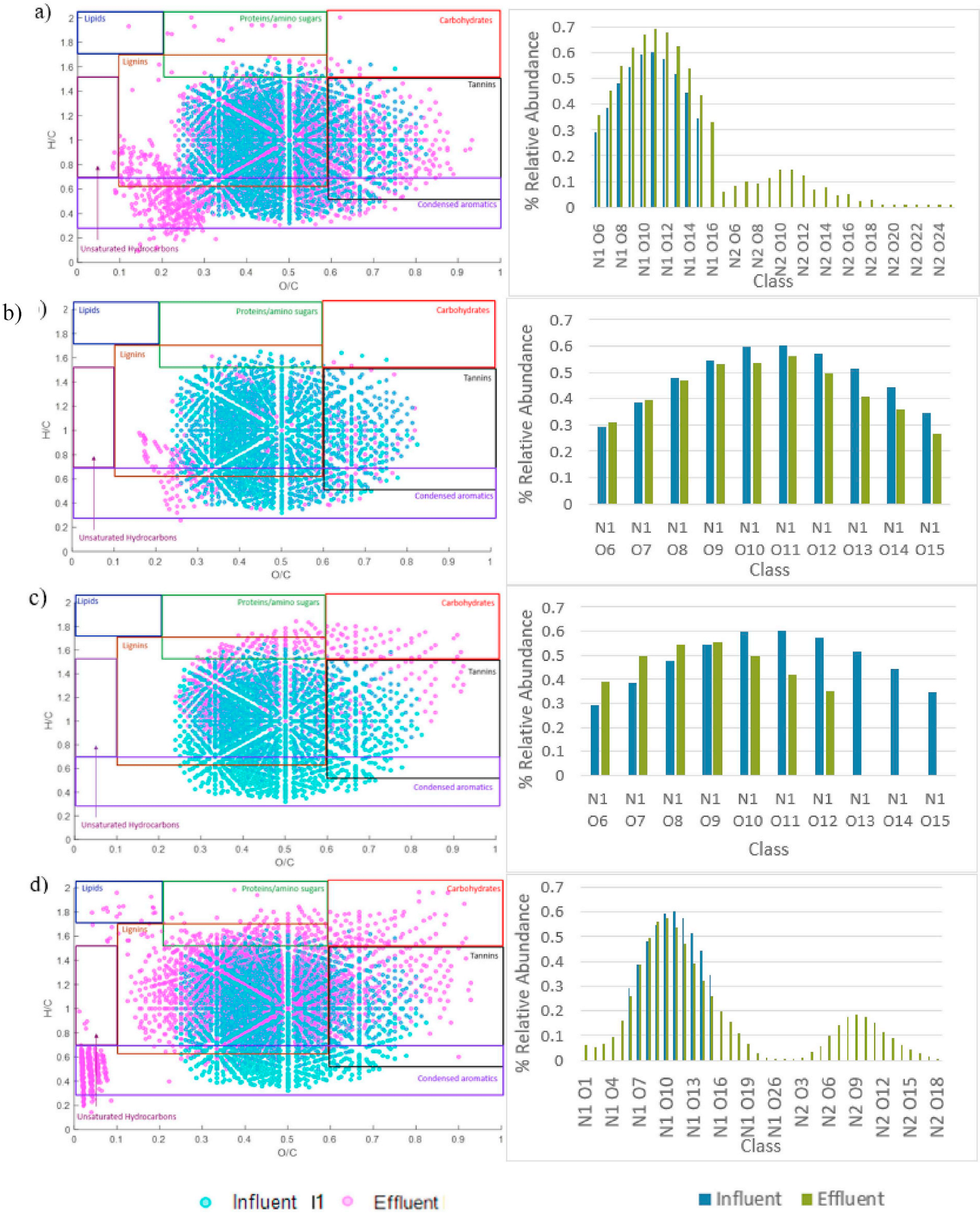


Fig. 9. van Krevelen Diagram of DON composition and relative abundance of classes for (a) Natural Soil, (b) BAM, (c) IFGEM-1, and (d) IFGEM-3 for influent condition 1 (I1).

where an increase in pH can be related to high alkalinity. While nitrate reduction from iron ions can be affected by pH; pH less than 5 is preferred, as nitrate reduction rates decrease with increasing pH (Bao et al., 2017). However, a pH range between 7 and 8 was observed suggesting that an adequate pH was maintained providing a suitable environment for most of the microbial community and the chemical reactions to occurr. Given that denitrification can be affected by low pH, maintaining a reasonable pH to accommodate both processes is ideal.

Likewise, the quantity of DO can inhibit or promote the growth of certain microbes based on the available oxygen in the biofilm. Since DO can be used to indicate the end of nitrification by aerobic bacteria (AOB, NOB and comammox), and ORP can be used indicate the end of denitrification, they can be further linked to microbial abundance (Li et al., 2019). Therefore, the reduction in ORP for natural soil, IFGEM -1 and IFGEM-3 can be associated to the reduction of nitrate and nitrite (Li

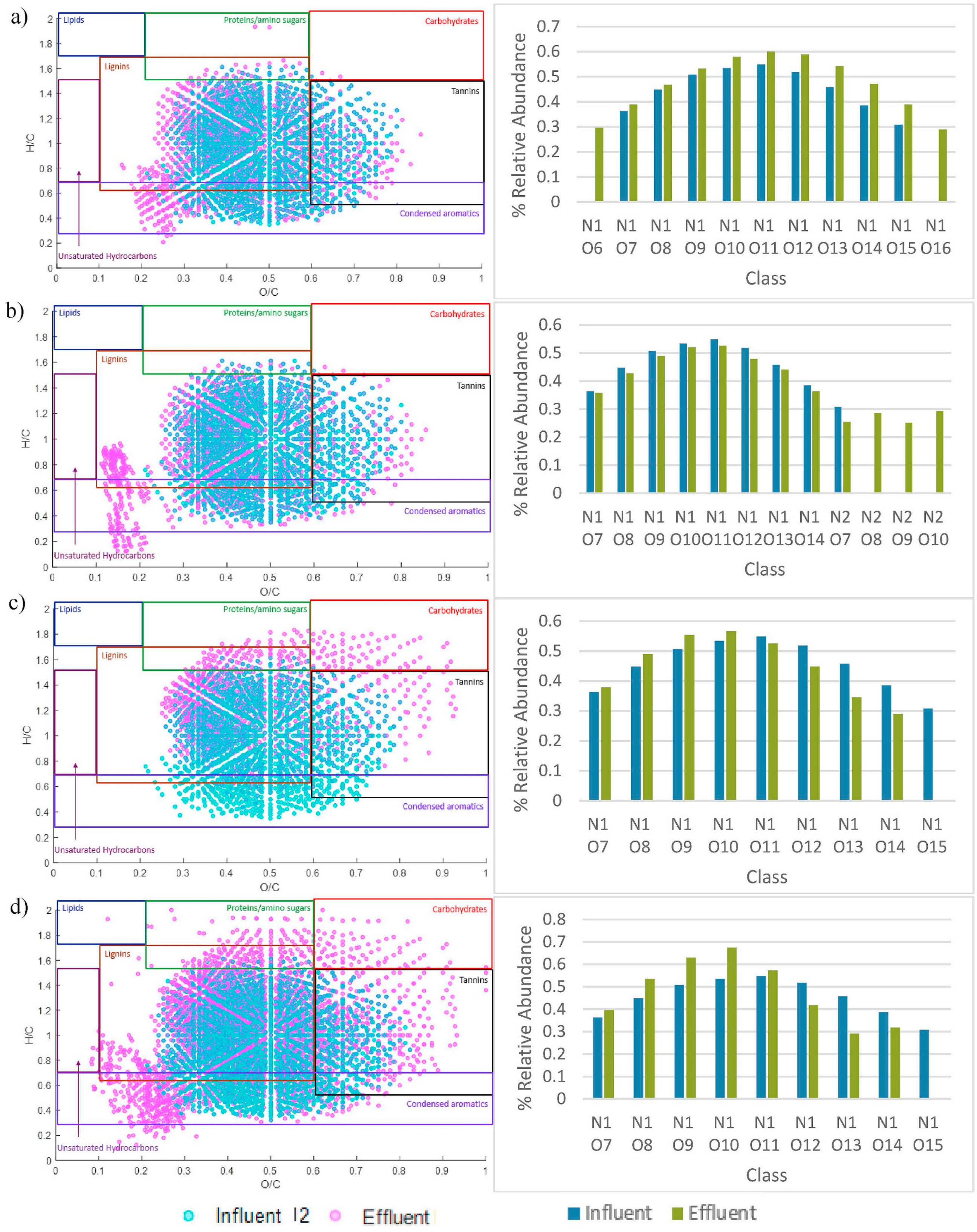


Fig. 10. van Krevelen Diagram of DON composition and relative abundance of classes for (a) Natural Soil, (b) BAM, (c) IFGEM-1, and (d) IFGEM-3 for influent condition 2 (I2).

et al., 2019) suggesting the presence of DNRA and denitrifiers. Conversely, the increase in OPR for BAM implies reduced quantity of denitrifiers and DNRA that can reduce oxide substances. Further, the microbial abundance of DNRA and denitrifiers, can consequently impact DON composition and transformation as denoted by the observable DON transformation for natural soil, IFGEM-1 and IFGEM-3.

Further, alkalinity concentrations can act as an indicator of microbial growth from the relation between consumption and biological

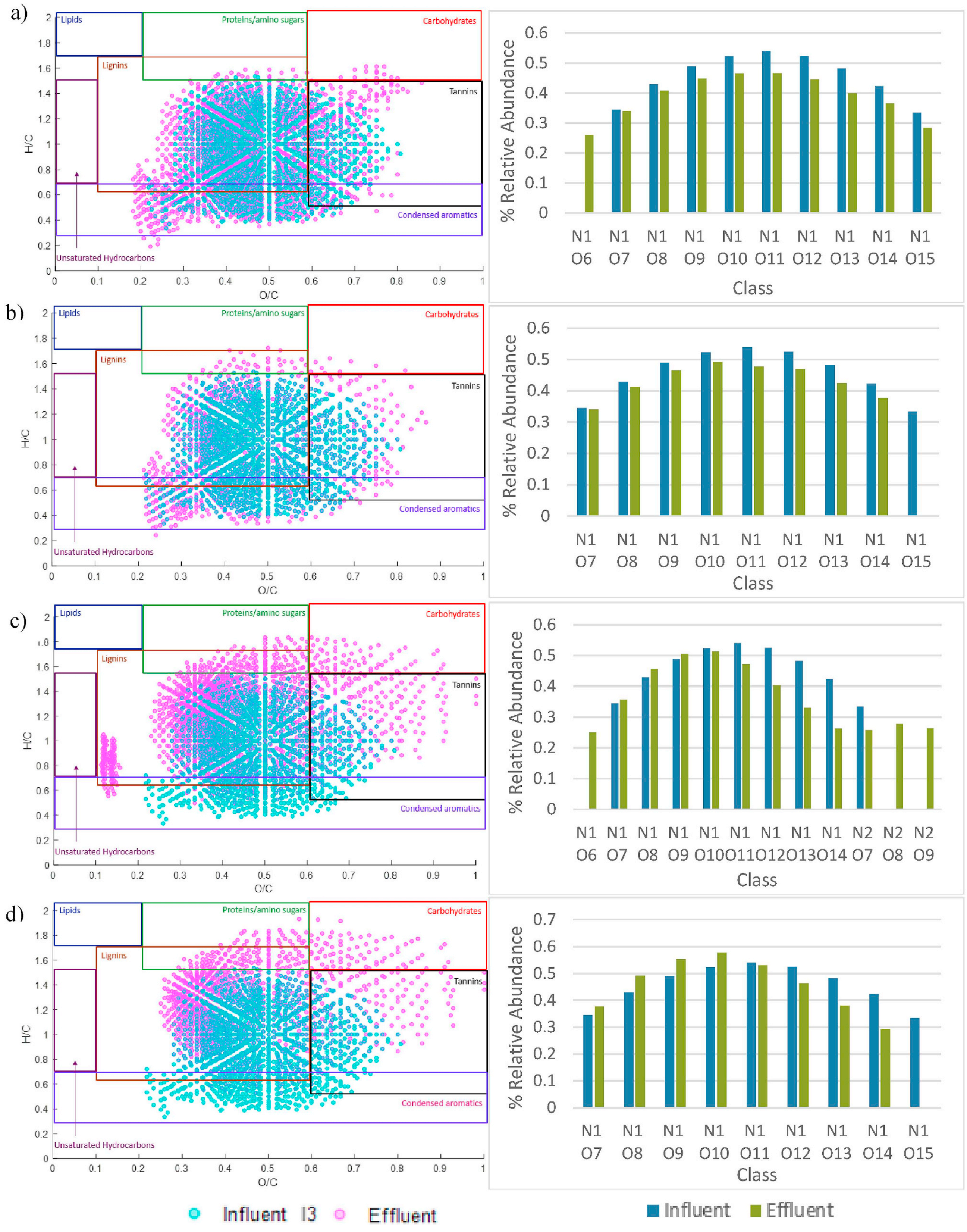


Fig. 11. van Krevelen Diagram of DON composition and relative abundance of classes for (a) Natural Soil, (b) BAM, (c) IFGEM-1, and (d) IFGEM-3 for influent condition 3 (I3).

activity (Bagchi et al., 2010) as nitrification consumes alkalinity and denitrification can increase alkalinity. The lower effluent alkalinity concentrations for BAM, IFGEM-1 and IFGEM-3 suggest alkalinity consumption from nitrification and calcium salt formation; however, individual calcium ions could have also participated in the chemical reactions. The change of alkalinity concentration encompassing hydrocarbon can provide insight as to the calcium available in stormwater, as calcium carbonate can form and possibly react with phosphate and nitrate, enabling removal. The formation of precipitates can explain the small reduction of alkalinity from the three sorption media at the given conditions. However, although microbial interaction can be related with increase in alkalinity, the very high concentration of alkalinity for natural soil can be attributed to calcium and magnesium ions resultant of the components of natural soil.

The presence of dissolved calcium in stormwater can be attributed to the weathering of rocks, as it has been found that aquifers can contain 30–100 mg/L of calcium (Sasidharan et al., 2017). The presence of calcium in stormwater can be assumed; thus, these reactions could have further contributed to the greater nutrient removal of IFGEM-1 and IFGEM-3 by forming calcium salts. The interactions of cation species in stormwater, including calcium, magnesium, potassium, and ammonium, can also aid in nitrate and phosphate adsorption and precipitation. Phosphate in the form of orthophosphates can be precipitated by binding with calcium, forming calcium phosphate salts such as dicalcium phosphate (Eq. (7)) and tricalcium phosphate (ATP) (Eq. (8)). Calcium nitrate salts can be produced via three chemical reactions involving calcium in stormwater, which can be represented in alkalinity. Calcium carbonate and/or calcium phosphate can react with nitric acid (Eqs. (9) and (10)), and calcium hydroxide and ammonium nitrate can also interact (Eq. (11)). At high temperatures, calcium nitrate can be decomposed to release nitrite ions (Eq. (12)).

$$\mathrm{Ca^{+2} + PO_4^{3-} + H^+ = CaHPO_4} \tag{7}$$

$$\mathrm{3Ca(OH)_2 + 2H_3PO_4 \rightarrow Ca_3(PO_4)_{2(S)} + H_2O} \tag{8}$$

$$\mathrm{CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_{2(S)} + CO_2 + H_2O} \tag{9}$$

$$\mathrm{CO_3(PO_4)_{2(S)} + 6HNO_3 + 12H_3\ O \rightarrow 2H_3PO_4 + Ca(NO_3)_{2(S)} + 12H_2O} \tag{10}$$

$$\mathrm{Ca(OH)_2 + 2NH_4NO_3 \rightarrow Ca(NO_3)_{2(S)} + 2NH_4OH} \tag{11}$$

$$\mathrm{2Ca(NO_3)_{2(S)} \rightarrow 2CaO + 4NO_2^- +} O_2 \tag{12}$$

In the presence of magnesium, magnesium nitrate is formed from the reaction of nitric acid. Magnesium phosphates such as $Mg_3(PO_4)_2{\cdot}8H_2O$ (bobbierite), $MgHPO_4{\cdot}3H_2O$ (newberyite), $Mg_3(NH_4)_2H_4(PO_4)_4{\cdot}8H_2O$ (hannayite), $Mg(NH_4)_2H_4(PO_4)_2{\cdot}4H_2O$ (shertelite), and $MgNH_4PO_4{\cdot}6H_2O$ (struvite) are products of the reaction of magnesium and phosphate in aqueous solutions (Golubev et al., 2001). These salts can form from magnesium ions or magnesium measured in alkalinity.

4.2. Chemical interactions and nutrient removal

The small quantities of NOx and ammonia components in TN composition (Fig. 5) confirm the TN and ammonia removals of IFGEM-1 and IFGEM-3 media. The presence of iron, which is coated by clay particles, promoted ammonia removal for IFGEM-3. A higher ammonia removal was observed for higher influent concentration, as an increase in adsorption rate was caused by adsorption sites becoming increasingly surrounded by ammonium when the initial concentration increased (Jing et al., 2017). In addition, ammonium fixation has been found to be affected by soil moisture (Nieder et al., 2011). According to Allison et al. (1953) and Gouveia and Eudoxie (2007), soil moisture can lower NH_4^+ fixation in wet environments. However, increased fixation under wet environments has also been observed (Chen et al., 1987; Nieder et al., 2011). The high TN removal efficiencies of IFGEM-1 and IFGEM-3 demonstrate their removal effects and the interaction between iron and clay in nitrate reduction from adsorption at the surface of the particles (Zhang et al., 2011). Whereas the production of ammonia in I2 and the low TP removals may also suggest its release from the nutrient saturated soil.

The presence of heavy metals such as zinc, chromium, cobalt, and aluminum are common in natural environments (Choksi and Joshi, 2007), and such metals can be dispersed to waterbodies through stormwater runoff. Its high concentration of dissolved aluminum suggests BAM was more likely to release or not retain dissolved aluminum in comparison to the other media. Less dissolved aluminum in the effluent of IFGEM-1 and IFGEM-3 was observed as a possible interaction between aluminum and phosphate precipitation (Fig. 6). It is possible that the interaction of aluminum and phosphate ions had stronger precipitate formation than iron for phosphorus removal (Atkári et al., 1996), as aluminum has stronger bonds that are difficult to displace from its reactiveness (Tassist et al., 2010).

The TP removals observed for BAM, IFGEM-1, and IFGEM-3 indicate chemical removal via phosphorus precipitation and adsorption. The primary form of TP removal from IFGEM-1 and IFGEM-3 supports the contribution of iron ions to precipitate formation. Overall, total phosphorus removal was greater in columns with IFGEM-1 and IFGEM-3. Bioadsorption (Tassist et al., 2010) and the adsorption of aluminum into clay (Choksi and Joshi, 2007) could have also contributed to the dissolved aluminum removal in the columns. According to Choksi and Joshi (2007), the removal of aluminum (III) ions by clay, starch, and charcoal (activated wood) was determined to be adequate. A further cause for differences in aluminum concentrations between the media could be the interaction between iron and aluminum ions. Since BAM achieved a high aluminum concentration in the effluent but this aluminum was not utilized for phosphate removal, it can be presumed that it lacked the interaction of iron and aluminum necessary to remove dissolved aluminum. The reaction between iron (III) oxide and aluminum can produce aluminum oxide solids, therefore possibly contributing to a decrease in dissolved aluminum in IFGEM-1 and IFGEM-3 effluents.

4.3. Interaction between microbial abundance and DON assimilation/nutrient removal

Investigating microbial communities and DON consumption is of importance, as the nitrogen cycle can also proceed via biochemical reactions and microbial interactions (Fig. 2). A comparison between the change in the microbial community in the biofilm during the second and fourth week of cultivation revealed denitrifiers to be the most prominent and dominant microbial specie, followed by DNRA, comammox, and NOB, suggesting that the aerobic nitrification pathway was the leading pathway for nitrate oxidation. Moreover, the quantification of comammox was higher in comparison to AOB, implying that the ammonia oxidation taking part in the first step of nitrification was primarily completed by comammox. As the population densities of comammox and NOB at each sampling location were comparative, some possible complementary interactions in the second step of the nitrification pathway could associate both NOB and comammox. Hence comammox was the principal converter of ammonia to nitrite, while both comammox and NOB participated in nitrite reduction.

The large DNRA population density at week 4 of the biofilm cultivation in the natural soil, BAM, IFGEM-1, and IFGEM-3 indicates an increase in ammonia production with nitrate consumption. However, efficient ammonia removal was achieved by IFGEM-1 and IFGEM-3 from complementary interactions between physicochemical characteristics corresponding to clay composition in each media and biological uptake from AOB and comammox. Moreover, the depletion of DO availability and alkalinity from BAM, IFGEM-1, and IFGEM-3 suggests the depression of nitrification (Bagchi et al., 2010). This corresponds with the larger NOB population densities observed in natural soil in comparison to BAM, IFGEM-1, and IFGEM-3. The decrease of ORP suggests the presence of DNRA and denitrifiers which can reduce nitrate and nitrite, while the microbial community is sustained by the high DNRA and denitrifier abundance quantified in week 4. However, alkalinity consumption and changes in alkalinity are related to nitrification (Sepehri and Sarrafzadeh, 2018) and possible phosphate and nitrate removal via precipitate formation from $Ca(OH)_2$ reactions (Eqs. (7)–(11)).

Furthermore, anammox population densities were under the detection limit, signifying that anaerobic ammonium oxidation was not favored in the biofilm and, in turn, nitrate reduction was achieved by denitrifying bacteria. Contrary to our hypothesis, the presence of iron did not enhance the anammox population. The small quantification and the decrease in population density of IRB from week 2 to week 4 implies that ferrous ion utilization in the chemical and physical reactions impacted IRB growth. Ferrous ion was oxidized when in contact with air to possibly form Fe_3O_2, and consequently was consumed much more rapidly over time by the physicochemical reactions than by bacteria. These chemical interactions contributed to phosphate removal and nitrate reduction while decreasing the availability of ferrous iron necessary for microbial uptake and growth.

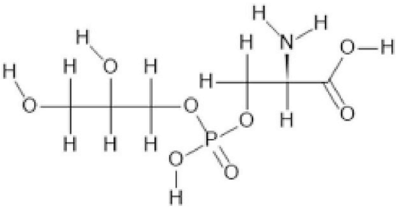
The microorganisms AOB, NOB, comammox, denitrifiers, DNRA and IRB in soil microbial communities participate in a cycle of development, growth, and mortality. The interactions between each microbial specie, and its products from biological reactions and the environment, affect sustained growth and population. Hence, microbial communities affect DON composition via its transformation and utilization within this cycle. The significant quantification of denitrifiers can be attributed to the utilization of DON to obtain their carbon source (electron donor) in the denitrification process. However, denitrification can also proceed in the presence of organic compounds like methanol and acidic acid (Eqs. (13) and (14)), which are used as electron donors when there is limited degradable organic matter (Gavazza et al., 2004). Microbial assimilation of DON by the IRB in natural soil could have provided more nitrogen compounds to the microorganisms in the community by transforming aromatic hydrocarbons in the iron reducing process, although a small population density was quantified. Other microorganisms that do not necessarily participate in the N-cycle can also utilize DON as a carbon source.

In addition, microbial growth and metabolism can be related to the consumption of DON, such as condensed aromatics, lignins, and tannins, and their consequent transformation into proteins, amino sugars, and carbohydrates, which represent the byproducts and microbial waste remaining after performing DON assimilation in the cell, specifically by denitrifiers and DNRA. Organic compounds such as glycerophosphine, a type of glycerophospholipids associated with bacteria cell membrane (López-Lara and Geiger, 2017), and glycoproteins discovered in living organisms (Shylaja and Seshadri, 1989) can be products of microbial metabolism and DON consumption (Eqs. (15) and (16)). This is possible, as the majority of denitrifying bacteria uptake and degrade organic matter to obtain carbon for microbial growth, releasing dissolved inorganic nitrogen (DIN) (Ward, 2013).

$$NO_3^- + CH_3OH \rightarrow N_2 + CO_2 + H_2O + OH^- \tag{13}$$

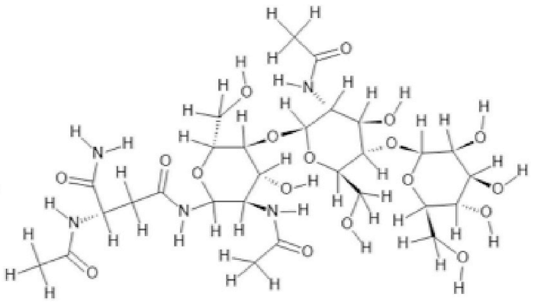
$$NO_3^- + CH_3COOH \rightarrow N_2 + CO_2 + H_2O + OH^- \tag{14}$$

$$org - N + NO_3^- \rightarrow N_2 + CO_2 + H_2O + OH^- +$$



(15)

$$org - N + NO_3^- \rightarrow N_2 + CO_2 + H_2O + OH^- +$$



(16)

The formation of proteins, amino sugars and carbohydrate like compounds by natural soil and IFGEM-3 in I1 indicates more intensive microbial interactions, resultant of large microbial populations that consumed DON compounds, producing the latter during their development. Further, the relative abundance classes exhibited less intersection between the influent and effluent, suggesting the occurrence of more biological reactions. This can be correlated to the large autotrophic densities of nitrifying bacteria contained in natural soil and IFGEM-3, which can produce carbohydrates and proteins in the biofilm (Liang et al., 2010; Lin et al., 2018). Although changes in DON composition were noted for the natural soil and the three media in I2 and I3, the overlap in the influent and effluent relative abundance suggests that the bacteria have not completely adapted to the higher nutrient conditions, which can be correlated to the DON concentrations. The effects of biofilm accommodation to changes in influent conditions (carbon/no-carbon) was demonstrated by Wen et al. (2020a), in which a sufficient cultivation period was allotted for microbial community in a biofilm to grow under carbon impact, providing enhanced nitrogen removal.

The change between the quantity of DON concentration for each influent and effluent presented in Fig. 5 can be related to the DON composition and transformation in the van Krevelen diagrams. The small DON concentrations achieved by IFGEM-1 and IFGEM-3 in comparison to BAM and natural soil in I1, I2 and I3 imply adequate effluent TN removal in both media. However, DON is the primary effluent constituent, signifying the availability of organic nitrogen as the indicator of promoted biological reactions. In I1, BAM obtained the smallest reduction in DON concentration, correlating with the minor transformation between influent and effluent DON (Fig. 9). In I2 and I3 alike, natural soil achieved the least effluent DON reduction, contributing to minimal change in DON composition (Figs. 10 and 11). In contrast, lower effluent DON concentrations can be connected to a more significant transformation of DON compounds, as observed for IFGEM-1 and IFGEM-3. Thus, the decrease in the effluent change of the heteroatom classes from I1 to I3 for natural soil and IFGEM-3 suggests that a lower nutrient condition is more appropriate for DON transformation, although appropriate DON reduction is also observed at I2 and I3 for IFGEM-3. Yet an increase in nutrient concentration improved DON transformation in BAM and IFGEM-1.

When observing the total microbial population at week 4 and the DON transformation in the van Krevelen diagram with the relative abundance classes, natural soil and IFGEM-3 achieve a visible transformation of DON at I1. IFGEM-3 has a higher total microbial population than natural soil; however, natural soil has larger comammox, NOB, and DNRA populations, implying that these three are the primary contributors to DON consumption. Further, the benefit between the microbial species can be analyzed to address their contribution to DON assimilation, and consequently organic and inorganic nitrogen removal. In this microbial community there is a beneficial relationship between 1) NOB and anammox benefiting from AOB and comammox, 2) denitrifiers and DNRA benefiting NOB, 3) AOB, comammox, and anammox benefiting DNRA, and 4) NOB benefitting from comammox. This fosters possible competition for resources pairwise between NOB and anammox, denitrifiers and DNRA, as well as AOB, comammox, and anammox. Both NOB and anammox require nitrite, which can be acquired from the AOB or the first reaction of comammox in the nitrification. However, anammox growth proceeds at a slower rate, as there are chemolithotrophs. In denitrification and DNRA pathways, nitrate serves as a reactant, thus fostering both competition and inhibition environments. The production of ammonia by DNRA supports AOB, comammox, and anammox pathways while encouraging competition between the three.

5. Conclusion

In this study, the ammonia, total phosphorus and total nitrogen removals obtained for natural soil, BAM, IFGEM 1, and IFGEM 3 at three different spiked stormwater conditions confirmed IFGEM-3 sorption media as the most appropriate for nutrient removal. Providing appropriate biological and chemical reactions enhanced nutrient removal through interactions that precipitated and assimilated phosphorus and nitrogen. DON in stormwater can be utilized, benefiting microbial communities that decompose and transform DON. Natural soil and IFGEM-3 were found to promote better DON transformation in condition 1 (I1). In condition 2 (I2) IFGEM-1 and IFGEM-3 achieved the least effluent DON concentrations, while in condition 3 (I3) BAM, IFGEM-1, and IFGEM-3 achieved a significant reduction in DON concentrations. As a result, IFGEM-1 and IFGEM-3 provided greater DON decomposition after treating the stormwater. Moreover, a holistic understanding of the microbial interactions that participate in the nitrogen cycle was achieved from the analysis of AOB, NOB, anammox, comammox, denitrifiers, and DNRA, which deepened the understanding of how microbial ecology works for DON decomposition and removal collectively.

Credit author statement

Andrea Valencia, performed lab-scale column study and real-time PCR data analysis. Diana Ordonez, performed lab-scale column study and real-time PCR data analysis. Dan Wen, conducted FT-ICR-MS analysis. Amy M. McKenna conducted FT-ICR-MS analysis. Ni-Bin Chang, proposed the IFGEM composition and research framework and improved part of the data analyses. Martin P. Wanielista, proposed the IFGEM composition and research framework and improved part of the data analyses. All authors wrote the manuscript together; all authors discussed the experimental results and reviewed the manuscript

Declaration of competing interest

The authors have no competing interest of this study.

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From: Chris Bogdan <chris.bogdan@ecs-water.com>
Sent: Tuesday, June 30, 2020 7:38 PM
To: Bays, Jim/TPA
Cc: Martin Wanielista; Chris Bogdan
Subject: [EXTERNAL] Re: Quick Check for C-43 Estimate

Jim,

I made a mistake and multiplied by 19 instead of 24. I did the correct math and got the same number of $177,669,648 for the construction of twenty-four 5-acre CTS cells.

I am sorry for the mistake and thanks for sending the email to verify the correct budget. Let us know if there is anything else we can provide and have a great evening.

Chris Bogdan, President
Environmental Conservation Solutions, LLC
407.608.9860 Cellular
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407.578.9393 Fax
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RETHINKING WATER MANAGEMENT SYSTEMS

On Tue, Jun 30, 2020 at 3:36 PM Bays, Jim/TPA <Jim.Bays@jacobs.com> wrote:

> Marty & Chris:
>
> Thanks for sending that supplemental material last Friday.
>
> We've noticed that there is a discrepancy in the cost summary following Table 1. Using you unit price of $7,402,902.00 for a 5-acre cell, I estimate that twenty-four 5-acre cells would cost 24 x $7,402,902 = $177,669,648. The cost table shows $140,655,138, which is equivalent to 19 cells.
>
> Is there a specific reason for costing 19 vs. 24 cells, or was this just an oversight?
>
> Let me know as soon as you can. For us to move forward, I'm inclined to use the $177,669,648 value, since I can show the basis for that.

Thanks in advance,

Jim

Jim Bays | Jacobs | Technology Fellow | Natural Treatment Systems | + 01.813.281.7705 | + 01.813.765.9286 mobile | + 01.813.874.3056 fax

Jim.Bays@jacobs.com | www.jacobs.com

Electrocoagulation

C43 RESERVOIR TREATMENT PROPOSAL
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JaACOBS **1May2020**
201 N. Franklin Street
Suite 1400
Tampa, FL, 33602

Attn: **Pieter De Wolf**
Environmental Engineer

Subj: C43 RESERVOIR TREATMENT
ElectroCoagulation ECpw

Dear Mr. De Wolf

We are pleased to submit information on our ElectroCoagulation (ECpw) technology as manufactured by Powell Water Systems, Inc. (PWS) as an innovative technology which can help provide an economical solution to the algae problems in Florida. Our technology has already been reviewed and accepted (24Sept2018) by FDEP's Andy Tintle and is listed in the D.E.A.R. Technology Library for Water Issues, #1505 submitted by Gerber Pumps International, Inc.

ECpw technology can do the following specifically as related to the algae problem:

1. **Remove TP** (Phosphorous) at very high levels (95 – 99+%)
2. **Remove TN** (total nitrogen) at high levels (60 – 80+%)
3. **Remove Algae** cells (3 – 5 micron size)
4. **Remove Cyanotoxins**

All the above is accomplished with our ElectroCoagulation ECpw™ technology simultaneously with no added chemicals and does not create a waste brine stream. Additionally. ECpw can coagulate colloidal size particulates from water with no polymers or additional chemicals as well as remove organics, pesticides, color, and many other contaminants. There is 83% less sludge production versus alum treatment and filters 67% better according to an EPA report.

ElectroCoagulation treatment of water being released into the Caloosahatchee River is the application that can greatly aid in reducing the harmful effects of nutrient rich and algal laden waters currently being released. Our research with the SJRWMD suggests that we can provide EC treatment at an O&M cost less than 5 cent per 1000 gallons.

We look forward to further discussions with on our PWS ECpw technology.

Respectfully submitted:
Gerber Pumps International, Inc.

Bert Gerber, PE MSE
President

CC: Scott Powell
President, Powell Water Systems, Inc.

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B. SOLIDS HANDLING

EXECUTIVE SUMMARY

C-43 RESERVOIR

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1May2020

EXECUTIVE SUMMARY:

The SFWMD is desirous of a water treatment system to treat the water to be discharged from the C43 10,000 acre / 55-billion-gallon reservoir currently being constructed by the USACE. The C43 reservoir functions as large surge storage for excess Lake Okeechobee (Lake O) water which must be discharged in the wet season to maintain safe dike height around the lake. The problem is that Lake Okeechobee (Lake O) has been polluted with excess nutrients of phosphorous and nitrogen from agricultural operations. Harmful algal blooms (HAB) arise in the receiving waters downstream from Lake O as well as estuaries far from Lake O.

Waters being discharged from Lake O eastward through the St. Lucie River are being treated via overland flows and STA treatment. However, excess water needing to be discharged westward through the Caloosahatchee River needs direct treatment as not enough land is available for land treatment for the waters flowing westward.

Currently, excess Lake Okeechobee water is discharged directly into the Caloosahatchee River creating harmful algal bloom (HAB) in the receiving waters and estuaries downstream in the Fort Myers area. The goal for this RFI is to reduce the total phosphorous by 50%, nitrogen by 33%, and suspended solids by 50%.

Powell Water Systems, Inc. (PWS) manufactures a unique ElectroCoagulation system (ECpw™) that can provide excellent treatment for C43 reservoir water with high removal rates of nutrients, as well as 3µ to 5µ sized algae, and related algal toxins prior to discharge into the Caloosahatchee River.

Gerber Pumps International, Inc. (GPi) conducted a phosphorous (TP) removal study in August 2016 for the SJRWMD on Lake Jesup water in Seminole County / Winter Springs, FL . The results from that study were excellent with TP removal of ≥ 95% and the **cost/# of TP removed was in the $54 to $100 range**. Total nitrogen (TN) was also removed simultaneously in the 60% to 80% range. For that study, the O&M costs for **power consumption and consumables were as low as $.073/1000-gal**.

We project that the required treatment for the average flow of 457 CFS can be accomplished by blending 51 to 53% of ECpw treated water with untreated water to arrive at the desired design goal for TP, TN, and TSS. We can process the total required flow with only a 10-sec HRT (ECpw chamber hydraulic retention/reaction time) versus a standard 60-sec HRT and still remove 95 to 99% of TP as well as meeting the targeted goals for TN and TSS.

The projected cost per 1000 gallons of EC processed water is less than $.048 (4.8 cents) for the energy and sacrificial plate replacement.

ECpw technology can do the following specifically as related to the algae problem:

1. **Remove TP** (Phosphorous) at very high levels (95 – 99+%)
2. **Remove TN** (total nitrogen) at high levels (60 – 80+%)
3. **Remove Algae** cells (3 – 5 micron size)
4. **Remove Cyanotoxins**

All the above is accomplished with our ECpw technology simultaneously with no added chemicals and does not create a waste brine stream. ECpw also does not add any additional TDS into the treated water as with chemical treatment with alum (aluminum sulfate) or iron salts of ferric sulfate or ferric chloride. We note that the active Al+3 ion in alum represents only 16% of the compound with the balance of the sulfate staying in the treated water as increased TDS.

EPA has stated that ElectroCoagulation technology produces 83% less sludge volume that alum treatment and the solids filter at a 76% better rate. *EPA Site Emerging Technology 1993*

Additionally, ECpw can coagulate colloidal size particulates from water with no polymers or additional chemicals as well as remove organics, color, pesticides, and many other contaminants.

We have included various studies in the appendixes as supporting documents. We note a study done for a major US oil company comparing EC treatment versus lime softening for silica removal. The conclusion reached by the design consultant was that for a 20-yr period the cost for EC was only 20% as much as lime softening mainly due to very low O&M cost and no chemicals consumed. Likewise, for this C43 reservoir project the non-use of additives and polymer reduces O&M costs, reduces sludge volume and increases sludge quality. EC also produces a superior discharge water quality with less TDS than the original water, unlike chemical treatment which will be adding tons of sulfates and/or chlorides to the treated water. This creates additional TDS in the discharge treated water as opposed to reducing it.

Powell Water Systems' unique and innovative ElectroCoagulation ECpw treatment of water being released into the Caloosahatchee River can greatly aid in reducing the harmful effects of nutrient rich and algal laden waters currently being released. We look forward to further discussions with JACOBS and the SFWMD regarding our ECpw technology.

Respectfully submitted:
Gerber Pumps International, Inc.

Bert Gerber, PE MSE
President

CC: Scott Powell
President, Powell Water Systems, Inc.

CALC Spread Sheets

C-43 RESERVOIR

- EXECUTIVE SUMMARY
- DESIGN PARAMETERS
- QUANTITY OF ECpw units
- O & M CSOTS
- SLUDGE PRODUCTION
- CLARIFIER DIMENSIUONS

EXECUTIVE SUMAMRY
C-43 RESERVOIR
ElectroCoagulation Treatment for Nutient Removal

A DESIGN Parameters:

INFLUENT (aver):	mg/l	DISCHARGE (Design)	mg/l	% Reduction (Design)
TP	0.16	TP	0.08	50%
TN	1.5	TN	1	33%
TSS	20	TSS	10	50%

FLOW	CFS	GPM/24Hr	GPM 20 Hrs/Da	MGD		%EC Blended
Aver	457	205102	246122	295		
Min	300	134640	161568	194		
Max	600	269280	323136	388		
Q%EC* - Aver	**240.5**	**107948**	**129538**	**155**	*	**53%**

B POWELL WATER SYSTEMS ECpw Units Required

Powell Water Systems Model #	GPM/Unit	HRT (sec)	GPM	# Units	# Units
GPiECpw_ M_3600 GPM_ 10-sec HRT	3600	10	129537.85	35.98	**36**

C POWER & SACRIFICIAL PLATED USAGE Requirements

CFS	GPM Total	GPM Total	MGD
241	107,948	**129,538**	**155**
Gal/Hr	6,476,893	7,772,271	
ENERGY Req'd	0.6	0.6	KWH/1000 gal
Total KWH/Hr	3886	4663	
Power Req'd	3.9	**4.7**	**MW**
KWH/24-Hr Da	93267		
KWH/Yr	**34,042,548**		
$0.06	**$ 2,042,553**	Energy Cost / Yr @ $0.06/KWH	
Fe Plate Cost/Yr	**$ 680,851**	Sacrifical Plate Cost / Yr	
O&M Cost / Yr	**$ 2,723,404**		
Cost / CFS	$ 0.000359		
Cost / MGD	$ 48.00		
Cost / 1000 Gal	$ 0.048		

O&M COSTS PER YEAR ENERGY & SACRIFICAL PLATES	
Cost / MGD	$ 48.00
Cost / 1000 Gal	$ 0.048

GerberPumps
international inc.

DESIGN PARAMETERS
C43 RESERVOIR
BLENDING of EC Treated Water
with
Untreated Raw Water

Powell Water

DESIGN PARAMETERS for ANALYSIS:

FLOW	CFS	GPM/24Hr	For Reqd CFS: GPM Based on 20 Hrs/Da	MGD
Aver	**457**	**205,102**	**246,122**	**295**
Min	300	134,640	161,568	**194**
Max	600	269,280	323,136	**388**
Q%EC* - Aver	**240.5**	**107,948**	**129,538**	**155**
Q%EC* - Max	315.8	141,726	170,072	**204**

	%EC Blended
*	**53%**

***Q%EC = % Total Flow Treated to Blend with Untreated Raw to achieve TP/TN/TSS Goals**

1 cfs =	448.8	GPM
1 MGD =	694.44	GPM

INFLUENT (aver):		DISCHARGE (Design)		% Reduction (Design)
TP	**0.16 mg/l**	**TP**	**0.08 mg/l**	**50%**
TN	**1.5 mg/l**	**TN**	**1 mg/l**	**33%**
TSS	**20 mg/l**	**TSS**	**10 mg/l**	**50%**

TP - Total Phosphoruous
TN - Total Nitrogen
TSS - Total Suspended Solids

BLENDING:

1_ElectroCoagulation is capable of removing **99^{+}%** of phosphorous

2_Blending % of EC processed water with % of Raw untreated water will result in the desired goal for removal of TP, TN, & TSS

BLENDING Calculations:

Total Phosphate (TP) Blended: EC-TP mg/l + Raw-TP mg/l = Total mg/l for TP after blended together

Q%EC*(1-%Rd)*Raw+(1-Q%EC)*Raw = Goal mg/l

Q%EC = (1- Goal/Raw)/%Rd

**** %TP removed dictates blend ratio of EC treated & Raw Untreated**

Raw =	**0.16 mg/l**	
Goal =	**0.08 mg/l**	
%Red of TP by EC =	**95%**	**
Q%EC =	**53%**	*Blend %
Q%Raw =	47%	

Q%EC*(1-%Rd)*Raw+(1-Q%EC)*Raw = Goal mg/l			**Q%EC = (1- Goal/Raw)/%Rd**
.53*(1-.95)*.16 +(1-.53)*.16 =	**0.07944**	**TP after Blend**	Q%EC = (1-.08/.16)/.95
(Calculated) Goal =	**0.080**		**Q%EC = 0.52632**

Quantity of ECpw Units & ECpw Spec

DESIGN PARAMETERS FOR ANALYSIS:

FLOW	CFS	GPM/24Hr Op	GPM/20Hr Op	MGD		%EC Blended
Aver	**457**	**205,102**	**246,122**	**295**		
Min	300	134,640	161,568	**194**		
Max	600	269,280	323,136	**388**		
Q%EC* - Aver	**240.5**	**107,948**	**129,538**	**155**	*	**53%**
Q%EC* -Max	315.8	141,726	170,072	**204**		

***Q%EC = % Total Flow Treated to Blend with Untreated Raw to achieve TP Goal**

1 cfs = 448.8 GPM
1 MGD = 694.44 GPM

Quantity of ECpw Units Required

Powell Water Systems Model #	GPM/Unit	HRT (sec)	GPM	GPM Total / GPM Ea	# Units	
GPiECpw_ M_3600 GPM_ 10-sec HRT	***3,600***	***10***	***129,538***	*35.98*	**36**	**Aver. Q With Dilution**
GPiECpw_ M_3600 GPM_ 10-sec HRT	3,600	10	170,072	47.24	48	Max Q with Dilution

NOTES:	**1_Thirty six (36) ECpw Units can process the required average Flow (Q) of 457 CFS by ElectroCoagulation treatment of approximately 51 to 53% of the total flow and blending with the balance of untreated water.**

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Operation & Maintenance Costs
for
ElectroCoagulation Units
Power / Plate Consumption

Powell Water

DESIGN Flow:

FLOW	CFS	GPM / 24-Hr Oper.	GPM / 20-Hr Oper.	MGD		
Aver	457	205,102	246,122	295		
Q%EC*	240.5	107,948	129,538	155	*	53%

Q%EC = % Total Flow Treated to Blend with Untreated Raw to achieve TP Goal

#ECpw Units Required Powell Water Systems

Powell Water Systems Model #	GPM/Unit	HRT (sec)	GPM	# Units	# Units Reqd
GPiECpw_ M_3600 GPM_ 10-sec HRT	3,600	10	129,538	35.98	36

POWER USAGE & Requirements

	CFS	GPM Total	GPM Total	MGD		
Q%EC*	240.5	107,948	129,538	155	*%Blended	53%
	Gal/Hr	6,476,893	7,772,271			
	ENERGY Req'd	0.6	0.6	KWH/1000 gal		
	Total KWH / Hr Op	3,886	4,663			
	Total MWH / Hr Op	3.89	4.66	MW		

	KWH/24 hr Da	93,267	
	KWH/YR	34,042,548	
$/KWH	0.06	$ 2,042,553	Projected Energy Costs/Yr
$/KWH	0.075	$ 2,553,191	
$/KWH	$0.10	$ 3,404,255	

Sacrificial Fe (Iron) PLATE Consumption

Fe lbs/1000 gal	0.03	
Fe lbs/MGD	30	
Total Q/Da	155	MGD
Fe lbs/Da	4,663	
$ / lb Fe	$0.40	
Fe Cost/Da	$1,865	
Fe Cost/Yr	$680,851	

Sacrifical Fe Plates / EC unit (LBS)	37,420
No. ECpw Units	36
Total lbs Fe Plates	1,347,120
Days Between Plate Replacement	269
Energy Cost / Yr	$ 2,042,553
Fe Plate Cost/Yr	$ 680,851
	$ 2,723,404

Summary of O&M Cost per Yr for Power & Sacrificial Fe Plates	per / CFS	$ 0.00036
	per/ MGD	$ 48.00
	per/1000 Gal	$ 0.048

SLUDGE Production
(# per Day)

DESIGN Parameters:

Parameter (Est)	Berfore Treatment (mg/l)	After EC (mg/l)	Removed (mg/l)	% of Solids
Phosphate	1.6	0.8	0.8	3.3%
Nitrogen	1.5	1	0.5	2.1%
TSS	20	10	10	
		Condstituents Removed	**11.3**	mg/l
		Fe Blade Consumption	**13**	
		Removed from EC treated water	**24.3**	mg/l

	CFS	GPM per 24-Hr	GPM per 20-Hr Oper	TOTAL/Da MGD		Total Q EC Treated
Q%EC* - Aver	**240.5**	**107,948**	**129,538**	**155**	*	**53%**
Q%EC* -Max	**315.8**	**141,726**	**170,072**	**204**		

***Q%EC = % Total Flow Treated to Blend with Untreated Raw to achieve TP Goal**

1 Gal =	3.785	liter
1 cfs =	448.80	GPM
1 MGD =	694.44	GPM

SLUDGE Mass & Volume

Solids Removed per Day for: **155** **MGD of EC processed reservoir water**

Solids DMB (Dry Mass Basis)

(Removed mg/l)*(MGD)*8.34 = **31,503** **# DMB / Da**

#/Da (DMB)	Dirt = 100#/cu ft			
31,503	**/((62.4#/CuFTw)1.65) =**	**315**	**CuFt/Da**	**at 100% solids, Cw**
		12	**CuYd/Da**	

MGD	Sludge Voume/Da (est)		Cw (% by wt.)	
155	**7,876**	**CuFt**	**4**	**solids, Cw**
155	**292**	**CuYd**		
155	**1,575**	**CuFt**	**20**	**solids, Cw**
155	**58**	**CuYd**		
155	**1,260**	**CuFt**	**25**	**solids, Cw**
155	**47**	**CuYd**		

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CLARIFIER
Dimensions

SIZING OF STANDARD UPFLOW CIRCULAR CLARIFIERS

DownTube: Slurry enters clarifier downward thru CenterWell and is "filtered" by the formed sludge blanket as it flows upward

Change Oper. Hrs. per day for a given MGD to determine required GPM of flow

Total Volume minus CenterWell

Insert different sidewall depths for total gallonage capacity of a particular diam.

Total Vol. Minus CenterWell/DownTube Vol.

Colored cell indicates where changes can be made

🟨 HRT/Dia./Water Depth
🟦 Input Flowrates: MGD or GPM

	MGD	# Hr/Da	GPM	Clarifier HRT Gal/2 hrs		Full Dia	Down Tube Dia.	Cu FT/ft ht Volume Clarifier	Gal/Ft ht Volume Clarifier	Sq Ft	Goal of <0.10 Vel Up (ft/s)	Ht.(ft) 13	
1	50	20	34,722	4,166,640		250	20	48,773	364,825	48,749	**0.089**	4,742,724	**GALLONS: Clar. Vol. Want > 2-Hr HRT**
2	50	20	34,722	4,166,640		200	20	31,102	232,642	31,086	**0.139**	3,024,351	
3	16	20	10,800	1,296,000		115	15	10,210	76,373	10,382	**0.130**	992,846	
4	16	20	10,800	1,296,000		135	15	14,137	105,747	14,307	**0.094**	1,374,707	

BUDGET COSTS

C-43 RESERVOIR

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international inc.

Powell Water

1May2020

BUDGETARY QUOTATION:

We make the following comments regarding the pricing attached on the following page.
Our own supply of ElectroCoagulation equipment is accurate at this point in the process regarding our normal scope of supply and related costs and items that are handled by others.

The costing for the balance of the equipment, building, clarifying and thickening equipment is an educated estimate from an excellent contractor, Wharton Smith, Inc., who participates in large scale municipal and industrial projects so am confident we are in the ballpark with the size and scope of the project. The budget pricing was in response for orders of magnitude for a structure to house the EC units and clarify and thicken the treated water and removed solids. Some roadwork around the building and clarifiers as well as some pumping equipment is included in the cost estimate. t

Respectfully submitted,

Gerber Pumps International, Inc.
Bert Gerber, PE MSE
President

CC: Scott Powell
President, Powell Water Systems, Inc.

QUOTATION SUMMARY

Budget Prices based on May 2020

Item #	Description	Qty	Unit Cost	Total
1	ElectroCoagulation units GPiECpw_M_3600_10-sec HRT	36	$2,157,620	$77,674,320
2	Miscellaneous - Feed & CIP tanks	36	$30,000	$1,080,000
			Sub Total ECpw	**$78,754,320**
	Contractor Estimate for Preliminary "Rough" Scope			
3	Metal Building with raised structural mezzanine for EC support, Hurricane rated (1850' x 140' x 25')	1	$25,229,431	$25,229,431
4	Clarifiers: 250' Dia. Rated 52 MGD ea.	1	$18,211,359	$18,211,359
5	Thickeners & Dewatering (GBTs & Centrifuges)	1	$4,774,787	$4,774,787
6	Electrical and I&C	1	$13,668,282	$13,668,282
7	Site Work & Piping	1	$7,717,156	$7,717,156
			Sub Total GC	**$69,601,015**
	Additional Estimates:			
8	Roads - $6/sq foot	20 ft wide	$120	per ft length
	Options (Solids Separation):			
9	5 Star Disk Filter (replace clarifiers) (Will Require smaller thickeners for backwash solids)	36	$292,000	$10,512,000
10	Huesker Dewatering bags	5 / Da.	$1,500 / bag	
11	Slow Rate Sand Filters 465 ft x 465 ft	3	?	

DESIGN PARAMETERS

C-43 RESERVOIR

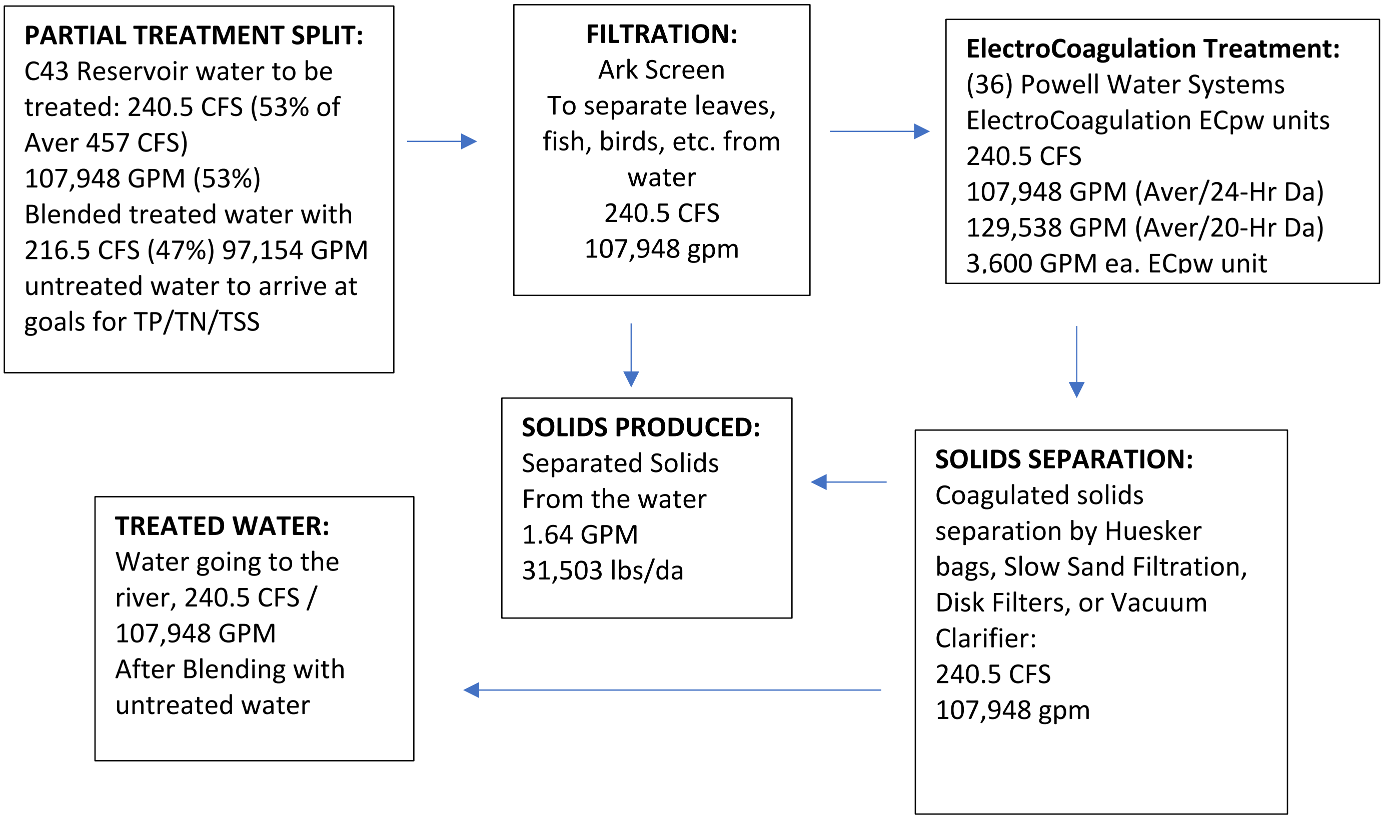
The proposed ElectoCoagulation system will provide treatment to 53% of the average 457 CFS flow and blend the EC treated water with the balance of the of the untreated water to arrive at the design target removal rates and discharge limits given of .08, 1, 10 mg/l for TP, TN, TSS respectively.

Reservoir water flowing at 240.5 CFS / 155 million gallons per day will be electrocoagulated and filtered to separate 31,503 pounds per day of coagulated solids from the water as described in Table 1 below:

Table 1: Reservoir water design criteria.

Parameter (Est)	**Mg/l**	**After EC mg/l**	**Removed mg/l**
Phosphate	1.6	0.8	0.8
Nitrogen	1.5	1	0.5
TSS	20	10	10
		Constituents Removed	**11.3**
		Fe Blade Consumption	**13**
		Total solids	**24.3**

Flow Summary **1: of Reservoir water design criteria listed in Table 1 above.**



PARTIAL TREATMENT SPLIT:
C43 Reservoir water to be treated: 240.5 CFS (53% of Aver 457 CFS)
107,948 GPM (53%)
Blended treated water with 216.5 CFS (47%) 97,154 GPM untreated water to arrive at goals for TP/TN/TSS

FILTRATION:
Ark Screen
To separate leaves, fish, birds, etc. from water
240.5 CFS
107,948 gpm

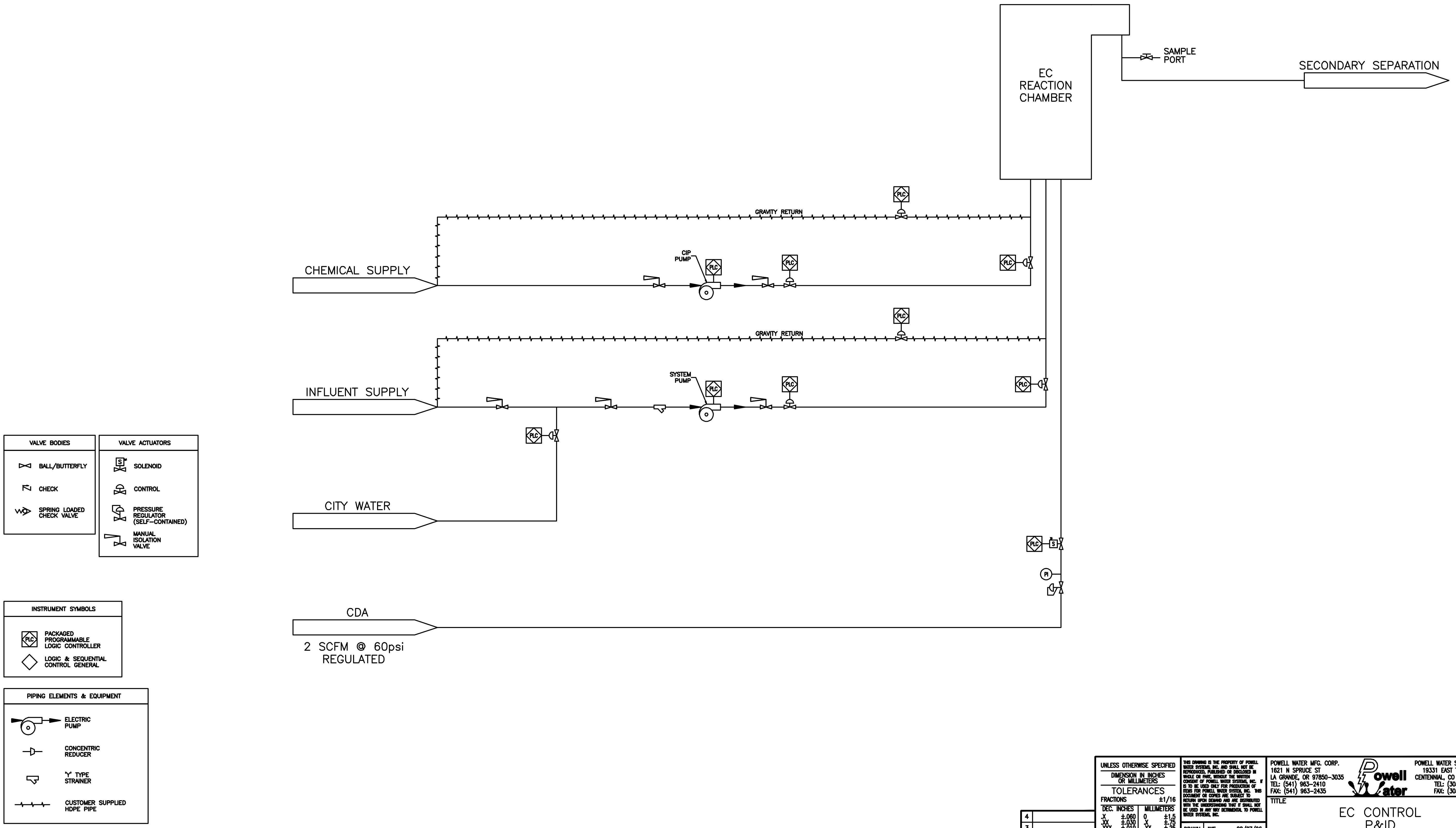
ElectroCoagulation Treatment:
(36) Powell Water Systems ElectroCoagulation ECpw units
240.5 CFS
107,948 GPM (Aver/24-Hr Da)
129,538 GPM (Aver/20-Hr Da)
3,600 GPM ea. ECpw unit

SOLIDS PRODUCED:
Separated Solids
From the water
1.64 GPM
31,503 lbs/da

SOLIDS SEPARATION:
Coagulated solids separation by Huesker bags, Slow Sand Filtration, Disk Filters, or Vacuum Clarifier:
240.5 CFS
107,948 gpm

TREATED WATER:
Water going to the river, 240.5 CFS / 107,948 GPM
After Blending with untreated water

REVISIONS				
REV	ZONE	DESCRIPTION	DATE	APPROVED
A	C-5	INSERT CENTRIFICAL PUMPS	05/25/06	JWF



http://www.powellwater.com

4	
3	
2	
1	.
NEXT ASSEMBLY	

THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED
DIMENSION IN INCHES
OR MILLIMETERS
TOLERANCES
FRACTIONS ±1/16

DEC. INCHES		MILLIMETERS	
.X	±.060	0	±1.5
.XX	±.030	.X	±.75
.XXX	±.010	.XX	±.25

ANGLES ±1/2°
MACHINE FINISH in 125√
MACHINE FINISH mm 3√
BREAK SHARP EDGES .010-.020
ALL SMALL FILLETS .020-.040
DO NOT SCALE

DRAWN	JWF	08/07/06
CHCK'D	JWF	08/07/06
ENG	JWF	08/07/06
APP'D	JWF	08/07/06
APP'D		

POWELL WATER MFG. CORP.
1621 N SPRUCE ST
LA GRANDE, OR 97850-3035
TEL: (541) 963-2410
FAX: (541) 963-2435

Powell Water

POWELL WATER SYSTEMS, INC.
19331 EAST TUFTS CIRCLE
CENTENNIAL, CO 80015-5820
TEL: (303) 627-0320
FAX: (303) 627-0116

TITLE
EC CONTROL
P&ID

SYSTEM	SIZE	DRAWING. NO.	REV
600/360	D	14.10232	A

SCALE: N/A
SHEET 1 OF 1

EQUIPMENT SPECIFICATION & QUANTITY

C-43 RESERVOIR

Treatment Process

Thirty-six (36) Powell Water Systems ElectroCoagulation ECpw units will each process 3,600 GPM of untreated filtered water from C43 reservoir. Following is some information regarding the operation of our ECpw units.

Solids Removal and Disposal

EC treatment will create flocs of coagulated and precipitated solids which need to be removed from the treated water prior to discharge back to the river.

There are a number of different processes for clarifying and filtering the solids from the water. We have not endeavored to evaluate or test if one method works better than another with our EC system but will be happy to discuss those options with you. Manpower and operational budgets may dictate one technology over another.

Likewise thickening dilute slurry to a dryness acceptable for disposal and perhaps economic gain is another study in manpower, operating costs, and capital costs.

We have included some information regarding sand filtration and SoilTan slurry thinkening systems that may be of interest.

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Powell Water

1May2020

EQUIPMENT SPECIFICATION:

The equipment sizing and number of units required of the Powell Water System ECpw unit was based on a 20-Hr/Da operating cycle for each ECpw unit to allow for CIP acid cleaning and periodic plate replacement.

The average flow based on 53% being EC treated is 240.5 CFS or 107,948 GPM based on a 24-Hr/Da operation of the EC units and 129,538 GPM based on a 20-Hr/Da operation of the ECpw units.

Thirty-six (36) of the Powell Water Systems Model **GPiECpw_M_3600 GPM_10-sec HRT** ECpw units can treat the required **240.5 CFS** flow in a 20-HR/Da operating cycle. The proposal is for 36 units to be housed in a hurricane rated covered metal building approximately 1850’ in length by 140’ in width and approximately 24’ tall. They will be elevated on a structural steel mezzanine to allow for gravity flow for CIP cleaning and free flow of the treated water to the next process phase of solids separation.

Each ECpw unit includes the following equipment:

1. Atmospheric reaction chamber up to 140 F
2. 1/8-inch screen filter (customer must prescreen to 1/32 of an inch)
3. System supply pump
4. Air purge
5. 480 Volt AC to DC power supply with current control, programmable logic controller, and polarity reversing.
6. Steel and aluminum 217 blade set with 2,229,000 square inches per set.
7. Automated drain back cleaning in place five valve system.
8. Customer input contact for normally open & normally closed contactors to accommodate surge tanks, pH probes, etc.
9. Two days onsite operator training.
10. The assembled skids are 18 by 17 feet, 7 foot tall.

The ElectroCoagulation process is a surface electro-chemical reaction and our PWS system by Powell Water Systems has engineered an optimized EC system that is able to be maintained and operated successfully for many years providing superior water treatment and adding no additional dissolved solids or salt complexes of sulfates or chlorides as with conventional alum and ferric chemical treatments.

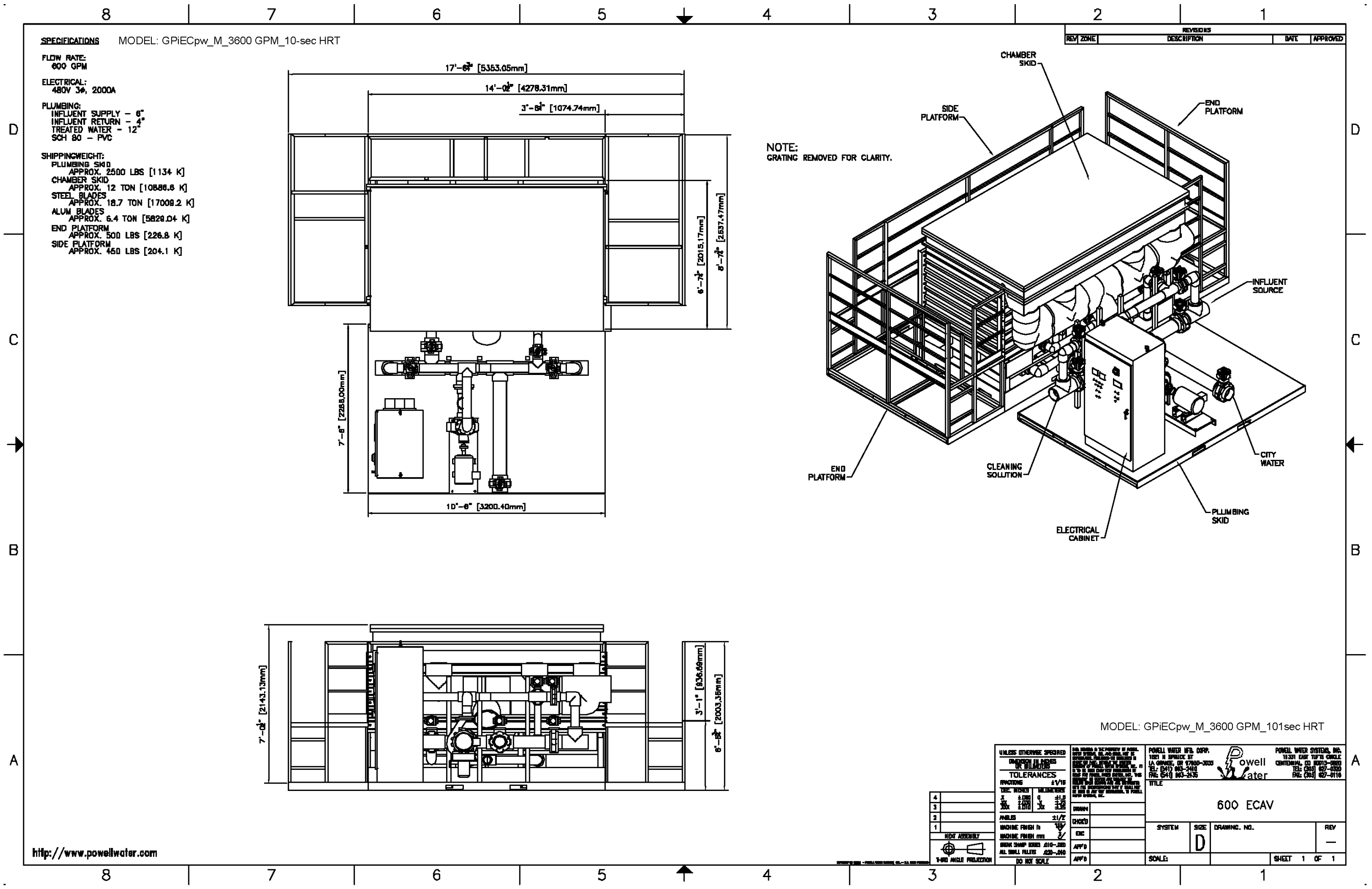
The PWS ECpw system is the only atmospheric, non-pressurized up-flow ElectroCoagulation system in the world. Due to the patented design and proprietary technology and expertise of its inventor, Scott

Wade Powell, the EC unit is able to process various waters at low operations and maintenance costs. The system is directly scalable to sizes to handle the flowrates as large as those from the C43 reservoir.

Below is a picture of the ECpw 3,600 GPM size unit. The 36 ECpw units for the C43 project will be elevated on a structural fabricated mezzanine to allow for ease of operation and handling of the treated waters by gravity where possible.

The EC chamber and control panels are blue on the elevated structure. The CIP acid tanks are below.

Following is a typical layout of a single sized "M" unit with walkways around the EC chamber. The 36 ECpw units will be positioned and have common catwalks accordingly for the number of units required for this project.



OPERATION OF THE ECpw UNITS:

The ElectroCoagulation ECpw units are easy to operate and do not require continual operator attendance. The estimated time for replacement of the sacrificial iron or aluminum plates is approximately 8 ½ months (270 days).

An automated clean-in-place (CIP) system is included. It typically will take place daily or as needed. The CIP fluid is an acid, typically sulfuric, but can also be hydrochloric or phosphoric. The operator presses the CIP button to start the CIP process when needed or it can be automated on a programed cycle, the frequency determined by field experience. The power is then automatically shut off to the EC chamber plates and the feed pump is turned off. Automatic valves are opened to drain the EC chamber back to the EC feed water tank. When the EC chamber is empty, the valves switch over to the CIP acid day tank. The acid is then pumped up into the EC chamber until the anode plates are covered and remain submerged for approximately 5 minutes allowing the acid to clean the iron plate surfaces. The valve then switches back to the CIP day tank to allow acid drainage back to the day tank for use in the next cleaning cycle. After repeated uses, when the acid is spent and no longer cleans the plates effectively, the spent acid is pumped into the EC feed tank and the spent acid is processed in the EC chamber along with the raw untreated water. The day tank is then replenished with fresh CIP acid.

As noted, the sacrificial iron plates will last approximately 8 to 9 months with about 93% of the 1/8” plates having been dissolved in the EC process. After a spent plate is removed from the EC chamber, new plates are inserted into EC chamber slots from above with the aid of an overhead hoist.

GPI GERBERPUMPS international inc.

Typical Scope of Supply

Powell Water

3Mar2016

CUSTOMER

Attn:

Subject: **ElectroCoagulation system for water treatment**

We are very pleased to offer the ***GPiECPW™ POWELL Water ElectroCoagulation*** system for treatment of ______________________ water/wastewater. Our ECpw system will remove Multiple Contaminants from an aqueous stream including color, nutrients, organics, silica, phosphorous, metals, and bacteria/viruses as well as other compounds to a very high degree and provide an efficient, effective, and easy to operate water/wastewater treatment system.

The system comes standard as **480V / 3PH**. Detailed electrical requirements will can be forwarded at a later date. We have based the sizing upon 22 hr per day plant operation.

The following are our typical Scope of Supply:

A: GPiECPW_M_600gpm_60RT ElectroCoagulation system(s) with a 60 second ECpw chamber Retention/Reaction Time (RT) with each unit capable of treating **792,000 GPD** based upon 22-hr/da. operation.

Includes the following equipment

1. ECpw UpFlow Atmospheric Reaction Chamber (PWS patented)
2. 1/8 inch screen filter (customer must prescreen to 1/32 of an inch)
3. System supply pump
4. Air purge
5. 480 Volt AC to DC power supply with current control, programmable logic controller, and polarity reversing.
6. Steel blade set and Aluminum blade set: 217 Blades/set; 2,229,000 in^2/set
7. Automated CIP (Cleaning in Place) valve system.
8. Customer input contact for normally open & normally closed contactors to accommodate surge tanks, pH probes, etc.
9. Two days onsite operator training. Additional construction supervision and onsite training is available upon request.
10. The assembled skids are each approximately 18 ft x 17 ft x 7 ft tall

Items NOT PROVIDED include but are not limited to;

1. Freight
2. Site grading and preparation.
3. Building enclosure and associated heating, lighting,
4. Ventilation, floor drains, sumps, and safety provisions.
5. Foundations and slabs for equipment and the building.
6. All piping external to the terminal points of the Powell Water Systems Inc equipment.
7. All power control wiring external to the terminal points of the Powell Water Systems Inc equipment.
8. Sludge disposal
9. Unloading and storage of equipment.
10. Field equipment installation.
11. Any required insulation and or heat tracing.
12. All necessary permits.
13. Prescreening to 1/32 of an inch of the water to be treated.
14. All applicable fees, taxes, and licenses.
15. Level control signal (Hi-Lo) from finished water storage tank and incoming water supply tank to turn system on and off.
16. Bulk acid storage tanks and transfer system.
17. Code standard no code stamp.
18. Finish painting.
19. pH adjustment system if desired.
20. Compressed air

NOTE: We can provide some of the items listed above on our NOT SUPPLIED if list if desired.

Lake Jesup Study

C-43 RESERVOIR

ElectroCoagulation:

Water & Wastewater

Treatment

CASE STUDIES Report:

Phosphorous Removal

REMOVAL from:

Lake Jesup

Sandford, FL USA

BY: Bert Gerber, P.E., MSE
Chief Engineer, GPi
Gerber Pumps International, Inc.

29AUG2016
Vol. EC2016, Issue 1

ElectroCoagulation

Alternative
Water & Wastewater Treatment

SYSTEM CAPABILITIES:

- Processes **Multiple Contaminants**
- Removes **Phosphates** & **Nutrients**
- Destroys/Removes **Bacteria** & **Viruses**
- Removes **Dissolved Gases** (**D.O.** & **H_2S**)
- Removes **Hardness** & **Color**
- Removes **Complex Organics, THMs, HAA5s**
- Removes/Destroys **Cyanotoxins / Geosims / MIBS**
- Removes **Heavy Metals** as **Oxides**
- Sludge passes **TCLP (non-Leaching)**
- Removes **Suspended** and **Colloidal** solids
- Breaks **Oil Emulsions** in water
- Removes **Fats, Oil,** and **Grease**
- ***"1"*** **Technology** for ***Multiple*** **Treatments**
- **1 GPM** to **4+ MGD** modules **(40$^+$ MGD)**

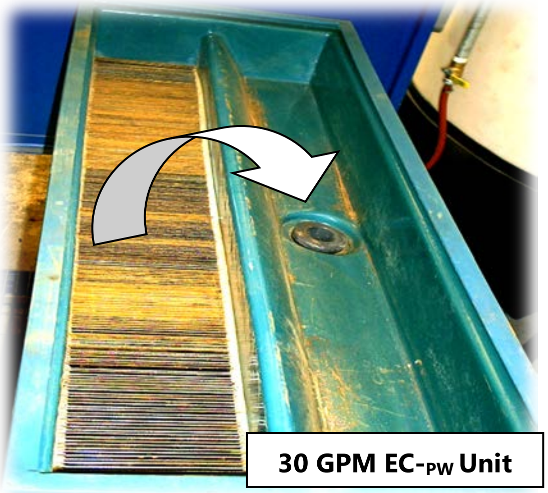
500 GPM EC-PW Unit

APPLICATIONS:

- **Lake / River / Effluent** Phosphorous removal
- **Potable Water** Organics/THM/HAA5 removal
- **Algae Toxins & Odor / Taste** removal
- **Cooling Towers** MakeUp & BlowDown H2O
- **Industrial PreTreatment –** Arsenic & others
- **Oily Water treatment**
- **ASR Well** PreTreatment (D.O. & Disinfect)

Electro**C**oagulation (EC) is the process of destabilizing suspended, emulsified, and/or dissolved contaminants in an aqueous medium by introducing an electrical current into the medium as it flows past sacrificial iron or aluminum plates. The electrical current provides the electromotive force to drive the chemical reactions. When reactions are driven or forced, the elements or compounds will approach the most stable state.

Of special note is that ECpw only adds the pure metal ions of either $Fe^{+2/+3}$ or Al^{+3} to the water being treated which are then coagulated and removed from the treated water along with the contaminants. No sulfate or chlorides are added which increase the TDS to the final treated water as with chemical treatment using alum or various ferric treatments.



30 GPM EC-PW Unit

CONTACT for Water Evaluation:
Gerber Pumps Int'l., Inc. 407.834.9104 sales@gerberpumps.com

ElectroCoagulation (EC) is the process of destabilizing suspended, emulsified, and/or dissolved contaminants in a aqueous medium by introducing an electrical current into the medium as it flows past sacrificial iron or aluminum plates. The electrical current provides the electromotive force to drive the chemical reactions. When reactions are driven or forced, the elements or compounds will approach the most stable state.

ElectroCoagulation is a technology that was first patented in 1906 by Dietrich using a variety of anode and cathode geometries, including plates, balls, fluidized bed spheres, wire mesh, rods, and tubes.

Scott Wade Powell of Powell Water Systems Inc. (PWS) has patented a new refined EC process which increases removal rates and flow capacity as well as greatly reducing capital and operating costs. The Powell Water ECpw units have the ability to remove multiple contaminants with only "1" technology. Due to the capability of the ECpw technology it is applicable to many different industries and processes. Potable water treatment for surface water sources is an ideal application for the PWS ECpw ElectroCoagulation system. Likewise, ReUse water treatment responds very well to EC treatment removing PCPs, EDCs, pathogens, nutrients, and metals. Also, many industrial applications can benefit from the use of ECpw technology.

The Powell Water Systems patented ECpw technology utilizes a specialized EC chamber with an atmospheric vertical up flow design. This innovative design dramatically reduces energy consumption by 95%, eliminates flow restrictions due to gas and solids buildup, and allows easy access for inspection and sacrificial blade replacement.

Of special note is that ECpw only adds the pure metal ions of either Fe$^{+2/+3}$ or Al^{+3} to the water being treated. No sulfate or chlorides are added which increase the TDS to the final treated water as with chemical treatment using alum or various ferric treatments.

ElectroCoagulation Processes during ECpw treatments:

- Seeding (Fe$^{+2/+3}$, Al^{+3})
- Electron Flooding
- Emulsion Breaking
- Halogen Complexing
- Bleaching
- Oxidation – Reduction
- EC Induced pH Change

As noted the PWS ECpw water treatment system is applicable to multiple industries and processes and can process various water streams at greatly reduced O&M costs. This results in increased profits and reduced tax dollars requirement for operation.

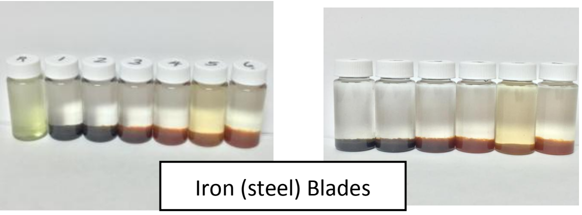
Some applications include:

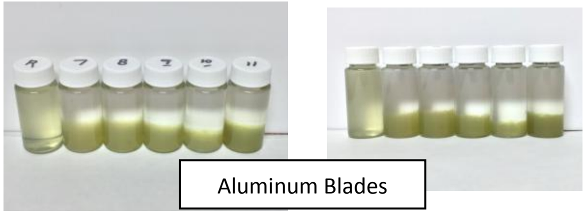
- Lake/River/ReUse Effluent – Nutrient Removal
- Potable Water – Organics/Color/THM Removal
- ASR Well Water – PreTreatment
- Cooling Tower – BlowDown & MakeUp Water Treatment
- Industrial PreTreatement – Metals (Hg, Pb, Cr, Fe, Au, Cu, Zn, Mn, Mg, etc.) Silica, Arsenic, Cyanide, Pesticides, EDCs, ECCs & others

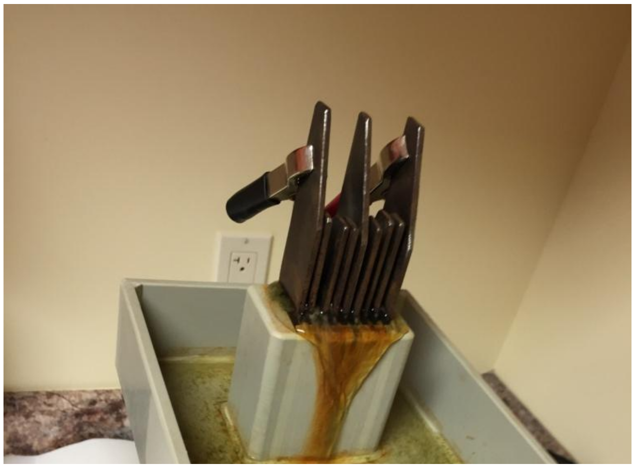
GPi and PWS welcome the opportunity of sharing our "Creative Solution" technology with you and can provide ECpw water treatment demonstrations on your specific waters.

Lake Jesup: Phosphorous Removal Test

Electro Coagulation


Iron (steel) Blades


Aluminum Blades



Powell Water

GPI GerberPumps international inc.

Phosphorous & Nitrogen Removal
ElectroCoagulation Testing Summary
Source Water: Lake Jesup, FL

Customer: **Lake Jesup, FL - SJRWMD RFI** **Dates:** 29-Aug-2016

Blade Type	**Run #**	**No. Term.**	**RT SEC**	**TP mg/l**		**% Red.**	**TN mg/l**	**% Red.**	**UVA254 mg/l**	**% Red.**
RAW Untreated Water (before EC)				**0.1310**			**3.30**		**0.447**	
Fe	1EC-Fe-60-2	2	60	**0.0170**		87.0%	**0.67**	80%	**0.086**	81%
Fe	2EC-Fe-45-2	2	45	**0.0150**		88.5%	**0.53**	84%	**0.100**	78%
Fe	3EC-Fe-30-2	2	30	**0.0100**		92.4%	**0.50**	85%	**0.111**	75%
Fe	4EC-Fe-20-2	2	20	**0.0060**	**u**	95.4%	**0.92**	72%	**0.144**	68%
Fe	5EC-Fe-10-2	2	10	**0.0060**	**u**	95.4%	**1.20**	64%	**0.200**	55%
Fe	6EC-Fe-10-3	3	10	**0.0060**	**u**	95.4%	**0.72**	78%	**0.158**	65%
Al	7EC-Al-60-2	2	60	**0.0060**	**u**	95.4%	**0.59**	82%	**0.090**	80%
Al	8EC-Al-45-2	2	45	**0.0060**	**u**	95.4%	**0.38**	88%	**0.090**	80%
Al	9EC-Al-30-2	2	30	**0.0060**	**u**	95.4%	**0.30**	91%	**0.110**	75%
Al	10-EC-Al-20-2	2	20	**0.0060**	**u**	95.4%	**0.70**	79%	**0.121**	73%
Al	11EC-Al-10-2	2	10	**0.0060**	**u**	95.4%	**0.70**	79%	**0.163**	64%
Al	12EC-Al-10-3	3	10	**0.0060**	**u**	95.4%	**0.65**	80%	**0.135**	70%

SUMMARY:

- Gerber Pumps Int'l (GPi) performed ElectroCoagulation treatment on water from Lake Jesup (Sanford, FL) for phosphorous (TP) and nitrogen (TN) removal.
- The lake water was greenish in color from a lot of algae.
- Most of the tests resulted in TP being below detection MDL even for faster processing at low energy input.
- 99% of the TN was in the form of TKN with the balance being nitrate and nitrite
- TP reduction ranged from 87% up to virtually 100%.
- TN reduction ranged from 64% up to 91%.
- TP: 1.361 # removed per 1 M gallons processed via ElectroCoagulation
- TN: 18.014# removed per 1 M gallons
- RT: EC chamber hydraulic retention/reaction time

GPI
GerberPumps
international inc.

Volume of Water Required to be Processed

Volume of Water Reqd to meet TP Removal Goals

TP

	Aver. TP (Used for Calcs)		Rmvl % (Used for Calcs)		TP Rmvd	
Aver mg/l removed:	**0.17**	mg/l TP	**96.0%**	removed	**0.16320**	mg/l

Goal	Unit	#/yr TP	#/Day	(Oper. Time) # Days/Yr	MGD Rqd.	(Operating Time) GPM	22	Hrs/Da
1	metric tn/yr	**2,204.6**	6.04	365	**4.438**	**3,362**		
			8.82	250	**6.479**	**4,908**		
2.3	metric tn/yr	**5,070.6**	13.89	365	**10.207**	**7,732**		
			20.28	250	**14.902**	**11,289**		

NOTES:
1- GPi processed Lake Jesup water with a 10-sec HRT and achieved non-detectable at .006 mg/l TP
2- #/Da of TP required to be removed based upon Goal and # Days/Yr operating
3- MGD (Million Gal per Day)
4- #/Da based upon Days/Yr operating
5- GPM based upon MGD and Hrs per day operating
6- Input variable (Dark yellow cells)

Volume of Water Reqd to Remove 1# of TP

Formulas **1-MGD Rqd to remove X#/Yr of TP desired based on average TP in water column of:**

#/Da = (MGD)(mg/l)(8.34) or MGD = (#/Da)/((mg/l)(8.34))

Volume of Water to Process Rqd to remove 1# of TP

= (MG)(mg/l)(8.34) Based on: **0.16320** mg/l removed

MG = 1#/((.16320)(8.34))

Volume Rqd./# TP	**MG = 0.7347064**	**Gal = 734,706**

TN

Nitrogen Removal <u>along with</u> Phosphorus Removal

Note: Lab analysis showed TN was 3.3 mg/l

	Aver. TN (Used for Calcs)		Rmvl % (Used for Calcs)		TN Rmvd	
Aver mg/l removed	**2.7**	mg/l TP	**80.0%**	removed	**2.16000**	mg/l

(Based on 2.7 mg/l TN) #/Yr of TN	Metric Ton TP / Yr
29,179	1
29,179	1
67,111	2.3
67,111	2.3

#/Yr TN = (#/Da)*Da/Yr = (MGD)(mg/l)(8.34)*(Da/Yr)

 # TN / MGD = (1 MGD)(2.16 mg/l)(8.34) = **18.0144** #/1MGD

0.056	**MGD Volume will remove 1 # TN**

GPI
GerberPumps
international inc.

Powell Water

Operations & Maintenance Cost Estimates per # of TP

Phosphorous Removal
Source Water: Lake Jesup

29-Aug-2016

	HRT (Sec)	LPM Flow rate	% TP Rmvd		% TN Rmvd	Volts DC	Amps DC	KWh/ 1000 gal	$ / KWH	Elec Cost $/1000 gal	Elec Cost $/MG	Sacrifical Blades $ Cost/MG	O&M Cost/MGD (Elec & Blades)	Cost per # of TP removed
1EC-Fe-60-2	60	1	**87.0%**		80%	95	2.5	3.75	$ 0.10	$ 0.37	$ 375	$ 60	$ 435	**$ 319**
2EC-Fe-45-2	45	1.33	**88.5%**		84%	96	2.5	2.84	$ 0.10	$ 0.28	$ 284	$ 45	$ 329	**$ 242**
3EC-Fe-30-2	30	2	**92.4%**		85%	96	2.5	1.89	$ 0.10	$ 0.19	$ 189	$ 30	$ 219	**$ 161**
4EC-Fe-20-2	20	3	**95.4%**	**u**	72%	96	2.5	1.26	$ 0.10	$ 0.13	$ 126	$ 20	$ 146	**$ 107**
5EC-Fe-10-2	10	6	**95.4%**	**u**	64%	96	2.5	0.6	$ 0.10	$ 0.06	$ 63	$ 10	$ 73	**$ 54**
6EC-Fe-10-3	10	6	**95.4%**	**u**	78%	90	8.5	2.0	$ 0.10	$ 0.20	$ 201	$ 10	$ 211	**$ 155**
7EC-Al-60-2	60	1	**95.4%**	**u**	82%	97	2.5	3.8	$ 0.10	$ 0.38	$ 382	$ 250	$ 632	**$ 465**
8EC-Al-45-2	45	1.33	**95.4%**	**u**	88%	97	2.5	2.9	$ 0.10	$ 0.29	$ 287	$ 188	$ 474	**$ 348**
9EC-Al-30-2	30	2	**95.4%**	**u**	91%	96	2.5	1.9	$ 0.10	$ 0.19	$ 189	$ 125	$ 314	**$ 231**
10EC-Al-20-2	20	3	**95.4%**	**u**	79%	96	2.5	1.3	$ 0.10	$ 0.13	$ 126	$ 83	$ 210	**$ 154**
11EC-Al-10-2	10	6	**95.4%**	**u**	79%	96	2.5	0.6	$ 0.10	$ 0.06	$ 63	$ 42	$ 105	**$ 77**
12EC-Al-10-3	10.00	6	**95.4%**	**u**	80%	92.00	9.00	2.18	$ 0.10	$ 0.22	$ 218	$ 42	$ 259	**$ 191**

Note:

1_ Replacement steel cost are approximately $.03 - $.08 / 1000 gallons processed

$ 0.06 per 1000 gal used for calcs

$ 60.00 per MG

2_ Replacement steel cost are approximately $.15 - $.25 / 1000 gallons processed

$ 0.25 per 1000 gal used for calcs

$250.00 per MG

3_ Powell Water Systems, Inc. 1 LPM Lab unit used for testing

4_ LPM: Liters per minute

5_ **734,706** gallons reqd to be processed to remove 1# TP **0.734706 MG**

6_ Cost per # of TP removed:

(**0.7347** MG)*(O&M Elec+Blade cost/MG)

7_ Some additional O&M costs to include Labor and CIP acid

8_ Energy costs estimated at $0.10/ KWH (actual may be 30 - 40% cheaper)

9_ u - Below laboratory detection limits

NOTE: 13.2# of Nitrogen are removed along with every 1 # of Total Phosphorous removed at Zero additional costs.

Cost Estimates per
of TP & TN

Phosphorous Removal
Source Water: Lake Jesup

29-Aug-2016

	HRT (Sec)	LPM Flow rate	% TP Rmvd		% TN Rmvd	KWh/ 1000 gal	Cost per # of TP removed	("Free" - No Cost Since Removed with TP) Cost per # of TN removed
1EC-Fe-60-2	60	1	**87.0%**		80.0%	3.75	$ **319**	$ **24**
2EC-Fe-45-2	45	1.33	**88.5%**		84.0%	2.84	$ **242**	$ **18**
3EC-Fe-30-2	30	2	**92.4%**		85.0%	1.89	$ **161**	$ **12**
4EC-Fe-20-2	20	3	**95.4%**	u	72.0%	1.26	$ **107**	$ **8**
5EC-Fe-10-2	10	6	**95.4%**	u	64.0%	0.6	$ **54**	$ **4**
6EC-Fe-10-3	10	6	**95.4%**	u	78.0%	2.0	$ **155**	$ **12**
7EC-Al-60-2	60	1	**95.4%**	u	82.0%	3.8	$ **465**	$ **35**
8EC-Al-45-2	45	1.33	**95.4%**	u	88.0%	2.9	$ **348**	$ **26**
9EC-Al-30-2	30	2	**95.4%**	u	91.0%	1.9	$ **231**	$ **17**
10EC-Al-20-2	20	3	**95.4%**	u	79.0%	1.3	$ **154**	$ **12**
11EC-Al-10-2	10	6	**95.4%**	u	79.0%	0.6	$ **77**	$ **6**
12EC-Al-10-3	10.00	6	**95.4%**	u	80%	2.18	$ **191**	$ **14**

Note:

1_ **734,706** gallons reqd to be processed to remove 1# TP (Total Phosphorous)
55,511 gallons reqd to be processed to remove 1# TN (Total Nitrogen)

2_ TN is removed at greater amount due to higher mg/l content and therefore at less cost per #.

3_ TN is therefore removed at **Zero additional cost** as it is removed simultaneously with TP.

4_ LPM: Liters per minute

5_ Some additional O&M costs to include Labor and CIP acid

6_ Energy costs estimated at $0.10/ KWH (actual may be 30 - 40% cheaper)

ElectroCoagulation Overview

C-43 RESERVOIR

The following attachment to the FDEP RFI No. 2020001 request provides a detailed comprehensive overview of our ElectroCoagulation technology and hopefully gives the reader a better understanding of the science and mechanics of the process.

GPI
GerberPumps
international inc.

Powell Water
ElectroCoagulation

This response to SFWMD's RFI provides a good description and explanation of the ElectroCoagulation process and technology and is included for the readers review and enlightment.

15July2019
Florida Department of Environmental Protection
Procurement Section, Carr Building
3800 Commonwealth BL-VD., MS#93
Tallahassee, FL 32399-3000

Attn: **Wanda Norton**
Procurement Officer

Subj: DEP RFI No. **RFI 2020001**
Methods to Prevent, Combat, or Clean up Harmful Algae Bloom

Dear Ms. Norton:

We are pleased to submit information on our ElectroCoagulation (ECpw) technology as manufactured by Powell Water Systems, Inc. as an innovative technology which can help provide an economical solution to the algae problem in Florida. Our technology has already been reviewed and accepted (24Sept2018) by FDEP's Andy Tintle and is listed in the D.E.A.R. Technology Library for Water Issues, #1505 submitted by Gerber Pumps International, Inc.

ECpw technology can do the following specifically as related to the algae problem:

1. **Remove TP** (Phosphorous) at very high levels (95 – 99+%)
2. **Remove TN** (total nitrogen) at high levels (60 – 80+%)
3. **Remove Algae** cells (3 – 5 micron size)
4. **Remove Cyanotoxins**

All the above is accomplished with our ECpw technology simultaneously with no added chemicals and does not create a waste brine stream. Additionally. ECpw can coagulate colloidal size particulates from water with no polymers or additional chemicals as well as remove organics, pesticides, color, and many other contaminants.

ECpw treatment of water being released into the St. Lucie and Caloosahatchee Rivers is the application that can greatly aid in reducing the harmful effects of nutrient rich and algae laden waters currently being released. We look forward to further discussions with DEP on our ECpw technology.

Respectfully submitted:
Gerber Pumps International, Inc.

Bert Gerber, PE MSE
President

CC: Scott Powell
President, Powell Water Systems, Inc

SECTION 3.00 – INTERESETED ENTITY’S CONTACT INFORMATION

Primary Contact: (Submittal & Schedule)

Bert Gerber, PE MSE
Email: bert@gerberpumps.com
Ph: 407.257.3407 Cl
Ph: 407.834.9104 Wk
Gerber Pumps International, Inc.
2100 N. Ronald Reagan Blvd., Suite 1056
Longwood, FL 32750

Company Website: www.gerberpumps.com

Type of Organization: Gerber Pumps International, Inc. is a Subchapter S Corporation registered and headquartered in Florida

Length of Time in this type of business: GPi has been representing Powell Water Systems for 11 years. Scott Powell, Powell Water Systems, Inc. has been in the ElectroCoagulation business for over 25 years. Bert Gerber has been in business since 1987 in central Florida manufacturing and representing creative innovative technologies for pumping and water treatment.

Location of Project Manager: Longwood, FL

Location of Regional Sales Manager serving the Department: Longwood, FL

Section 4.00 REQUESTED INFORMATION

1_ GENERAL DESCRIPTION

ElectroCoagulation, the passing of electrical current through water, has proven very effective in the removal of multiple contaminants from water-based fluids. The EC process with our patented Powell Water System, Inc. ECpw unit involves the passing of raw untreated water up vertically past electrically charged sacrificial steel or aluminum plates. Electrical voltage is applied to the sacrificial plates. As the water flows past the plates, either iron +2/+3 (Fe+2/+3) ions or aluminum +3 (Al+3) ions leave the plates metallic matrix and are dissolved into the passing water.

The EC process acts on BOTH suspended and dissolved contaminants. Suspended colloidal solids and dissolved contaminants are both removed simultaneously from the treated water. Colloidal particles coagulate without the aid of polymers or other chemical addition in subsequent clarification are removed from the clarified treated water.

Dissolved contaminants form precipitates with the metallic seeded ions and the introduction of excess electrons from the power grid. After precipitation, they coagulate and are removed from the treated water via conventional clarification means. Both TSS and TDS are removed with the process of ElectroCoagulation.

Our ECpw technology can remove multiple contaminants simultaneously, which results in a much simpler process train and greatly reduced operational and maintenance costs. This can dramatically reduce the cost per 1000 gallons treated in comparison to multiple processes required to treat for the same contaminants as removed by one ElectroCoagulation process. Testing done for the SJRWMD demonstrated removal cost for phosphorous at <u>$54 to $100 per pound of phosphorous removed</u>.

The ECpw system removes organic compounds of 6-carbon chain molecules and longer very effectively with high removal efficiency. Algal toxins are 14 carbon chains in length and greater and can be removed very effectively (90+%) and at rapid ECpw chamber throughput of 15-seconds as opposed to our baseline of 60 second HRT (ECpw chamber Retention/Reaction Time). Phosphorous removal at high (95 – 99%) efficiencies have been demonstrated with only a short 10-second HRT which means our 500 GPM ECpw unit can process 3,000 GPM instead of its rated 500 GPM at 60-sec HRT. Our 2,500 GPM ECpw unit can process 15,000 GPM with a 10-sec HRT. Capital costs/1000 gallons are greatly reduced at the shorter HRT times.

1.a_Yes, the ElectroCoagulation technology is based on known and accepted scientific principles.

ElectroCoagulation is a technology that was first patented in 1906 by Dietrich using a variety of anode and cathode geometries, including plates, balls, fluidized bed spheres, wire mesh, rods, and tubes.*1*

1Dietrich, A. E., Electric Water Purifier, United States of America Patent No. 823,671 June 19, 1906.

> *The electrocoagulation process is based on valid scientific principles involving responses of water contaminants to strong electric fields and electrically induced oxidation and reduction reactions. This process is able to take out over 99 percent of some heavy metal cations and also appears to*

> *be able to electrocute microorganisms in the water. It is also able to precipitate charged colloids and remove significant amounts of other ions, colloids, and emulsions. When the system is in place, the operating costs including electric power, replacement of electrodes, pump maintenance, and labor can be less than $1 per thousand gallons for some applications.*
>
> *Potential applications to agriculture and quality of rural life include removal of pathogens and heavy metals from drinking water and decontamination of food processing wash waters.2*

2 United States Department of Agriculture (USDA), Agricultural Research Service: 12/18/95

> *Chemical coagulation has been used for decades to destabilize suspensions and to effect precipitation of soluble metal species, as well as other inorganic species from aqueous streams, thereby permitting their removal through sedimentation or filtration. Alum, lime, and/or polymers have been the chemical coagulants used. These processes, however, tend to generate large volumes of sludge with high bound water content that can be slow to filter and difficult to dewater. These treatment processes also tend to increase the total dissolved solids content of the effluent, making it unacceptable for reuse within industrial applications.3*

3 EPA, a SITE Superfund Innovative Technology Evaluation: *EPA/640/S-937504. EPA, a SITE Superfund*

Scott Wade Powell of Powell Water Systems Inc. (PWS) has patented a new refined EC process which increases removal rates and flow capacity (40+ MGD) as well as greatly reducing capital and operating costs. The Powell Water ECpw units have the ability to remove multiple contaminants with only “1” technology. Due to the capability of the ECpw technology it is applicable to many different industries and processes.

<u>Treatment of various waters for nutrient removal is an IDEAL application for the ElectroCoagulation technology by PWS</u>. Nutrient removal of phosphorous and nitrogen, as noted above, is especially beneficial in depriving algae of its growth enhancers. Additionally<u>, algal toxins removal/destruction from water</u> introduced into the St. Lucie and Caloosahatchee Rivers further enhances the viability of the water entering those water bodies and the estuaries they supply. The <u>small 3 to 5 micron sized algae cells themselves are also removed</u> from ECpw treated water along with the other coagulated contaminants, and therefore, will not be part of the Lake Okeechobee/surge reservoir discharged water. This will prevent introducing additional algae into the receiving waters where they can add to the algal growth problems of HAB.

Potable water treatment for surface water sources is also an ideal application for the PWS ECpw ElectroCoagulation system. Also, many industrial applications can benefit from the use of ECpw technology.

The Powell Water Systems’ patented ECpw technology utilizes a specialized EC chamber which dramatically reduces energy consumption by 95%, eliminates flow restrictions due to gas and solids buildup within the system, and allows easy access for inspection and sacrificial blade replacement.

Of special note is that ECpw only adds the pure metal ions of either Fe+2/+3 or Al+3 to the water being treated which are subsequently removed from the treated water along with the precipitated and coagulated contaminants. No sulfate or chlorides are added which increase the TDS to the final treated water as with chemical treatment using alum or various ferric treatments. There is, therefore, no waste brine stream requiring additional disposal systems and costs. Typically, 99% of the treated water is available for beneficial use downstream; only the contaminants of nutrients, algal toxin, and algae cells are removed.

1.b_Yes, the technology has been deployed successfully in the USA and overseas. ElectroCoagulation is very broad in its applicability to various industries and applications. There is a 50 GPM unit at a central waste facility in Denver, CO, that is open for site visits with Scott Powell. Many of our ElectroCoagulation customers have NDAs with us and are not at liberty to divulge their contact information.

1.c_Success is typically measured on the basis of the % removal of a particular contaminant of concern or on the amount of contaminant left in the treated clarified water after ElectroCoagulation treatment.

1.d_Yes, the water with nutrients, algae, and cyanotoxins being discharged will need to be treated through the EC unit or partial EC treatment with blending of EC and non-EC treated waters could be an option depending on the levels of nutrients desired in the final water being discharged into the various waterways and estuaries.

2. FLOW RATE OF OUR ECpw systems - Our standard line of ECpw units range from 1.5 GPM up to 2,500 GPM based on a 60-sec HRT through the ECpw chamber. If we can remove sufficient nutrients in 10-sec HRT, then the Model N 2,500 GPM unit module can be rated at 15,000 GPM (33.4 cfs). Flowrates of 2,500 cfs can be achieved by multiple 15,000 GPM N-10sec HRT units.

3. Treatment Costs: A study was conducted for SJRWMD to determine the cost to remove a pound of TP (total phosphorous) from Lake Jesup in Seminole County FL. The lake water had .17 mg/l of TP and 3.3 mg/l of TN. Based on those starting values we achieved the following estimated costs:

$ per #TP removed: **$54 to $107** 95.4% (actually much higher as <.006 mg/l were undetectable)

$ per #TN removed: **no additional cost as it was removed along with the phosphate**

$0.07/1000 gallons to **$0.15/1000gal for O&M costs including sacrificial blade replacement costs.**

Additional items removed from EC treated water could be color, TSS, pesticides, metals, etc. As with the nitrogen, there are no additional costs to remove these contaminants along with the phosphorous as they all are removed simultaneously.

4. **Disposal costs:** We are not able to determine disposal costs currently. The actual location of the water needing treated and the mg/l of various contaminants needs to be known in order to determine volumes of sludge removed needing to be disposed.

5. Time to deploy technology: Normal production time for our larger 500 GPM units is 13 – 16 weeks after order and 50% down payment. We do have pilot demonstration units available depending upon availability. The area size required depends on the specific EC units purchased. We do note that the ECpw unit itself is quite small in area. Subsequent clarification or solids removal scenarios can optimized depending on the particular location and availability of land. An in-ground clarification regimen could be a cost effective solution, however, there are a number of solids separation scenarios that can be investigated to optimize that part of the EC process.

6**. Infrastructure required:** 480V/3 Ph power is required for units up 600 GPM. 2300 V/3 pH is required for the larger 2,500 GPM unit. Level concrete pad is required for the EC units to sit on. A permanent installation should house the ECpw unit in an enclosed location. The 500 GPM ECpw unit requires 480V/3ph power and 2,000 ampacity. FPL will very likely be interested in the EC technology as an additional market which can operate for 22 hours per day increasing its normal off demand power consumption.

7. Staging and Operational Foot print: Our 500 & 600 GPM units (based on 60-sec HRT) will come fully assembled and skid mounted with only minor piping involved to connect up the EC feed tank with the EC suction intake. The GPi_L_3,000 GPM_10sec_HRT 3,000 GPM unit requires about 20' x 20' of space. The clarifier and thickener take up additional space but we need to know the size and number of ECpw units that will be required.

8. Estimated time: Again, the size of the unit purchased and ancillary equipment to be provided will dictate the timing.

9. MDS: 15 – 20% Sulfuric acid is typically used for our Clean-in-Place (CIP) plate cleaning operation.

10. The sulfuric acid concentration should be dilute enough (15- 30%) to be corrosive.

11. Chemical used: Sulfuric Acid is used for the CIP cleaning of the sacrificial plates. Other acids such a phosphoric or muriatic acid could also bd utilized. The sacrificial plates will need a periodic acid cleaning.

12.: Demobilization time: Depending on the unit size, estimate 2-4 weeks to demobilize.

13. Powell Water has 30 years' experience in applying EC technology for various industrial applications.

Acknowledgements: Dr. Michael Mickley:

"The project benefited substantially from the input and support of Scott Powell, the President of Powell Water Systems, Inc. His experience with and knowledge of the electrocoagulation technology and its field capabilities provided a strong starting context for the project and for many insightful and enjoyable discussions during the project".

PRETREATMENT CAPABILITIES AND BENEFITS OF ELECTROCOAGULATION
Prepared for
Office of Naval Research
Under contract No. N00014-04-C-0027
Jan. 2004 – Dec 2004
Researcher:
Michael Mickley
Mickley & Associates
Boulder, Colorado

Scott Powell has lent his expertise to many researchers exploring the potential benefits of ElectroCoagulation technology for various applications. We are including as attachments several research projects which utilized the Powell Water Systems bench scale 1 LPM ECpw units to perform their research. I enjoyed working with two PhD candidate researchers at the University of South Florida in 20126 who used our PWS 1 LPM lab scale unit for researching Endocrine disruptors, pathogens, pharmaceuticals, and personal care products. They are now Dr. Erin Symonds and Dr. Monica Cook.

14. Additional Information:

Excerpts for Dr. Michael Mickley research for the Office of Naval Research; 2004

EC is the application of electrical potential across electrodes placed in a moving solution to be treated. Above a characteristic voltage dependent on the electrode material, some of the electrode will dissolve (become ionized) in solution. In this way, and only this way, EC resembles chemical coagulation - in that iron or aluminum ions, for instance, may be introduced into the solution to be treated. The EC process goes beyond chemical coagulation in that electrical current moves through the solution and promotes several other mechanisms that influence removal of species from solution. This includes the destabilization of colloids and oxidation-reduction reactions to name just two.

Although EC equipment has been available for several years and significant removal capabilities have been reported, only recently have design improvements made cost-effective and larger volume treatment possible.

The sweet spot for our ElectroCoagulation technology that can have tremendous positive impact on the two rives leading away from Lake Okeechobee is to treat the water prior to being discharged into the rivers. ElectroCoagulation has extremely high % nutrient removals, especially for phosphorous both as TSS and TDS constituents. Dissolved phosphorous of only .13 mg/l apparently enhances algal growth quite well, but our ECpw technology can reduce that level to below .006 mg/l.

Our ECpw technology removes the three (3) major components of nutrients, cyanotoxins, and algae cells which contribute to Harmful Algal Bloom (HAB). ECpw also removes other additional constituents such as pesticides that adversely affect water quality and safety.

Our research for phosphorus and nitrogen removal for the SJRWMD Lake Jesup project demonstrated that ElectroCoagulation is an ideal technology for fighting the algae bloom problems. We do not add any additional TDS to the treated water as conventional chemical treatment of alum or ferric salts.

We do note that EC can be utilized in fresh, brackish, or salt water with equal effect.

15. Constituents of concern that ECpw is capable of treating.

One of the significant differences between EC treatment and conventional “wet” chemistry is that EC will still remove the same per centages at both high and low levels of the contaminant whereas the efficiency of removal at low levels of the contaminant in the raw water tend to reduce greatly over from the removal per cent when the contaminant is at a high level of mg/l in the raw water.

The following are typical removal efficiencies of ElectroCoagulation when acting on these contaminants.

CONTAMINANT	BEFORE (mg/L)	AFTER (mg/L)	REMOVAL RATE (%)
Aldrin (pesticide)	0.0630	0.0010	98.40
Aluminum	224.0000	0.6900	99.69

Ammonia *	49.0000	19.4000	60.41
Arsenic	0.0760	<0.0022	97.12
Barium	0.0145	<0.0010	93.10
Benzene	90.1000	0.3590	99.60
BOD	1050.0000	14.0000	98.67
Boron	4.8600	1.4100	70.98
Cadmium	0.1252	<0.0040	96.81
Calcium *	1,321.0000	21.4000	98.40
Chlorieviphos (pesticide)	5.8700	0.0300	99.50
Chromium	139.0000	<0.1000	99.92
Cobalt	0.1238	0.0214	82.71
Copper	0.7984	<0.0020	99.75
Cyanide (Free)	723.0000	<0.0200	99.99
Cypermethrin (pesticide)	1.3000	0.0700	94.60
DDT (pesticide)	0.2610	0.0020	99.20
Diazinon (pesticide)	34.0000	0.2100	99.40
Ethyl Benzene	428.0000	0.3720	99.91
Fluoride	1.1000	0.4150	62.27
Gold	5.7200	1.3800	75.87
Iron	68.3400	0.1939	99.72
Lead	0.5900	0.0032	99.46
Lindane (pesticide)	0.1430	0.0010	99.30
Magnesium *	13.1500	0.0444	99.66
Manganese	1.0610	0.0184	98.27
Mercury	0.7200	<0.0031	98.45
Molybdenum	0.3500	0.0290	91.71
MP-Xylene	41.6000	0.0570	99.86
MTBE	21.5800	0.0462	99.79
Nickel	183.0000	0.0700	99.96
Nitrate	11.7000	2.6000	77.78
Nitrite	21.0000	12.0000	42.86
Nitrogen TKN	1,118.8800	59.0800	94.72
NTU	35.3800	0.3200	99.10
O-Xylene	191.0000	0.4160	99.78
PCB (Arochlor 1248)	0.0007	<0.0001	85.71
Petroleum Hydrocarbons	72.5000	<0.2000	99.72
Phosphate	28.0000	0.2000	99.28
Platinum	4.4000	0.6800	84.55
Potassium **	200.0000	110.0000	45.00
Proptamphos (pesticide)	80.8700	0.3600	99.60
Selenium	68.0000	38.0000	44.00
Silicon	21.0700	0.1000	99.50
Sulfate	104.0000	68.0000	34.61

CONTAMINANT	BEFORE (mg/L)	AFTER (mg/L)	REMOVAL RATE (%)
Silver	0.0081	0.0006	92.59
Tin	0.2130	<0.0200	90.61
Toluene	28,480.0000	0.2270	99.99
TSS	1,560.0000	8.0000	99.49
Vanadium	0.2621	<0.0020	99.24
Zinc	221.00	0.14	99.90
Americium-241	71.9900 pCi/L	0.5700 pCi/L	99.20
Plutonium-239	29.8500 pCi/L	0.2900 pCi/L	99.00
Radium	1093.0000 pCi/L	0.1000 pCi/L	99.99
Uranium	0.1300 mg/L	0.0002 mg/L	99.83
Bacteria	110,000,000.00 cfu	2,700.00 cfu	99.99
Coliform	318,000.0000 cfu	<1.00 cfu	99.99
E coli Bacteria	>2,419.20 mpn	0.00 mpn	99.99
Enterococcus Bacteria	83.00 mpn	<10.00 mpn	82.87
Total Coliform Bacteria	>2,419.20 mpn	0.00 mpn	99.99

We note that ElectroCoagulation drives the chemical/electrical reaction to their most stable form as oxides as opposed to hydroxides. The end result is a precipitated solid that will not dissolve when subjected to the TCLP test and therefore, the solids are classified as Non-Hazardous for easier and cheaper disposal options.

16. Range of Concentrations and percent reductions

ECpw can remove 99+% of phosphorous and 60 – 85% Total nitrogen. All the algae that are treated with our ECpw system will be removed from the EC treated water. Due to the small 3 to 5 micron size of many algae species, they are hard to remove from the water itself. If they are filtered with a 1 micron filter, the filter will clog quite quickly so filtration without first EC treatment is very problematic.

EC will coagulate the 3-5 micron size algae into much larger flocs that are readily clarified and separated from the water.

For mineral colloids we can effectively treat up to about 5% (50,000 ppm). For organic much type material, EC will work but the concentration of the fine muck type silt will be in the 5,000 to 10,000 mg/l range. We can dilute higher concentrations for effective coagulation of the colloids and then use the clarified water as dilution for subsequent treatments.

For river and lake water we would not need any dilution and can treat it effectively at its normal mg/l levels. We recently treated some industrial water that that about 1,000 mg/l of silica and were able to get effectively removal of the silica.

17. Influent water characteristic requirements

1. pH levels range from 3.7 up to 12 pH
2. Salinity can be from fresh to full ocean salt water. The higher conductivity water is actually more efficient in power consumed than very non-conductive water
3. Alkalinity for hardness reduction needs to be >100. For phosphorous reduction I don’t believe low alkalinity would be a problem.

18. Land Area required

The following generally describes the flow process for our ECpw system.

1. Source water is pumped to a feed tank from which the raw water is pumped through the ECpw chamber itself. The water needs to be prescreened to 1/32”.
2. The EC treated water with the precipitated and coagulated solids flow out of the EC chamber to some type of clarifier or solids separation unit which could also be a geotextile type material to capture the solids and allow the clarified treated water to them be discharged wherever desired. The exact solids separation device will likely depend on the flowrates desiring to be treated.

5 cfs equates to 2,244 GPM which would be treated with our 500 GPM ECpw unit operating at 10-sec HRT thereby increasing its treatment capability up to 3,000 GPM. That size unit costs $1.7M. The EC unit itself is approximately 20’ x 20’ in size. That unit needs to be supplied with 480V/3Ph power and 2,000 amps.

2500 cfs is a really large system, but is one we could handle with multiple ECpw units. 2,500 cfs equates to 1,122,000 GPM. Our largest size unit will process 15,000 GPM with a 10-sec HRT. It would take 75 of those ECpw units to handle the flowrate. Each 15K GPM unit costs $6.3 M. Each unit is approximately 20-‘ x 95’ long.

19. Proof of concept

YES, we can provide proof that our claim to the high percent removal of phosphorous from lake water is accurate and true. Our Lake Jesup SJRWMD study demonstrated that fact to me and am attaching it to our RFI submittal if we are able to do so.

20. Chemicals

NA as we don’t use chemicals.

21. FLORIDA Criteria

NA, as we don’t use chemicals

22. NA, AS before

23. We do not use biological organisms

24. Yes, there will be the precipitated and coagulated TDS and TSS solids that are removed from the water.

25. Yes. Our waste solids are non-toxic and non-hazardous

26. NO,

27. NO

28. Not at the present time. We can certainly come up with a strategy for disposal once the scope of the project is defined and we are made aware of the options that are available for disposing of the solids.

Our ECpw technology can effectively remove the contaminants that are wreaking havoc on the downstream water sheds. Even if a land fill has to be created to store the solids removed from the water, that would be a small price for solving the problem of discharging algae and nutrients into the current watersheds.

Our submission of this information on our ElectroCoagulation technology is for the purpose of making the decision makers aware that this technology exists and can be a silver bullet to effectively and quickly deal with the algae issues.

Powell Water Systems, Inc. is the preeminent ElectroCoagulation supplier of EC equipment that works and is maintainable. I am a Florida native and grew up on a dairy south of Winter Haven. I have been

in business since 1987 representing very creative and innovative technologies of which the Powell Water Systems ECpw is one. Gerber Pumps International, Inc. is a small business that represents unique products solve problems. We welcome the opportunity of taking the next step with the DEP to discuss and demonstrate our truly amazing technology.

29. YES. However, I did not see what the actual plans are as the RFI indicated this RFI was strictly for gaining helpful information, but we certainly are amenable to pursing the next step.

Respectfully submitted.

Gerber Pumps International, Inc.

Bert Gerber

Bert Gerber, PE MSE

President

Phosphorous Removal

C-43 RESERVOIR

GerberPumps
international inc.

ElectroCoagulation:
Water & Wastewater Treatment

CASE STUDIES Report:

Phosphorous & EC

REMOVAL from:

- Surface Water
- ReUse Water
- Ground Water

BY: Bert Gerber, P.E., MSE
Chief Engineer, GPi
Gerber Pumps International, Inc.
4Mar2014
Vol. EC2015, Issue 1

ElectroCoagulation

"Water & Wastewater Treatment"

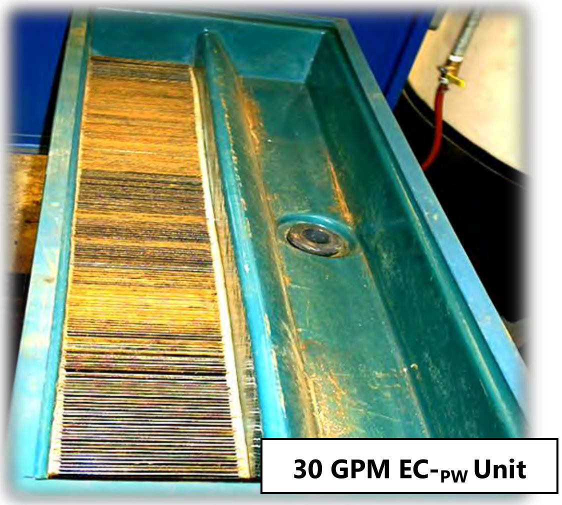
"*E*lectro*C*oagulation (ECpw^{tm}), the passing of electrical current through water, has proven very effective in the removal of multiple contaminants from water."

SYSTEM CAPABILITIES:

- Processes **Multiple Contaminants**
- Removes **Phosphates** & **Nutrients**
- Destroys/Removes **Bacteria** & **Viruses**
- Removes **Dissolved Gases** (**D.O.** & **H_2S**)
- Removes **Hardness** & **Color**
- Removes **Complex Organics, THMs, HAA5s**
- Removes **Heavy Metals** as **Oxides**
- Sludge passes **TCLP (non-Leaching)**
- Removes **Suspended** and **Colloidal** solids
- Breaks **Oil Emulsions** in water
- Removes **Fats, Oil,** and **Grease**
- Excellent **Membrane PreTreatment**
- *"1"* **Technology** for ***Multiple*** **Treatments**
- **1 GPM** to **4+ MGD** modules **(40^+ MGD)**

APPLICATIONS:

- **Lake/River/Effluent** Phosphorous removal
- **Potable Water** Organics/THM/HAA5 removal
- **ASR Well** PreTreatment (D.O. & Disinfect)
- **Cooling Towers** MakeUp & BlowDown H2O
- **Industrial PreTreatment –** Arsenic & others
- **Oily Water treatment**



30 GPM EC-$_{PW}$ Unit

500 GPM EC-$_{PW}$ Unit

ElectroCoagulation
Background & Capabilities

ElectroCoagulation (EC) is the process of destabilizing suspended, emulsified, and/or dissolved contaminants in a aqueous medium by introducing an electrical current into the medium as it flows past sacrificial iron or aluminum plates. The electrical current provides the electromotive force to drive the chemical reactions. When reactions are driven or forced, the elements or compounds will approach the most stable state.

ElectroCoagulation is a technology that was first patented in 1906 by Dietrich using a variety of anode and cathode geometries, including plates, balls, fluidized bed spheres, wire mesh, rods, and tubes.

Scott Wade Powell of Powell Water Systems Inc. (PWS) has patented a new refined EC process which increases removal rates and flow capacity as well as greatly reducing capital and operating costs. The Powell Water ECpw units have the ability to remove multiple contaminants with only “1” technology. Due to the capability of the ECpw technology it is applicable to many different industries and processes. Potable water treatment for surface water sources is an ideal application for the PWS ECpw ElectroCoagulation system. Also, many industrial applications can benefit from the use of ECpw technology.

The Powell Water Systems patented ECpw technology utilizes a specialized EC chamber with an atmospheric vertical upflow design. This innovative design dramatically reduces energy consumption by 95%, eliminates flow restrictions due to gas and solids buildup, and allows easy access for inspection and sacrificial blade replacement.

Of special note is that ECpw only adds the pure metal ions of either $Fe^{+2/+3}$ or Al^{+3} to the water being treated. No sulfate or chlorides are added which increase the TDS to the final treated water as with chemical treatment using alum or various ferric treatments.

ElectroCoagulation Processes during ECpw treatments:

- Seeding ($Fe^{+2/+3}$, Al^{+3})
- Electron Flooding
- Emulsion Breaking
- Halogen Complexing
- Bleaching
- Oxidation – Reduction
- EC Induced pH Change

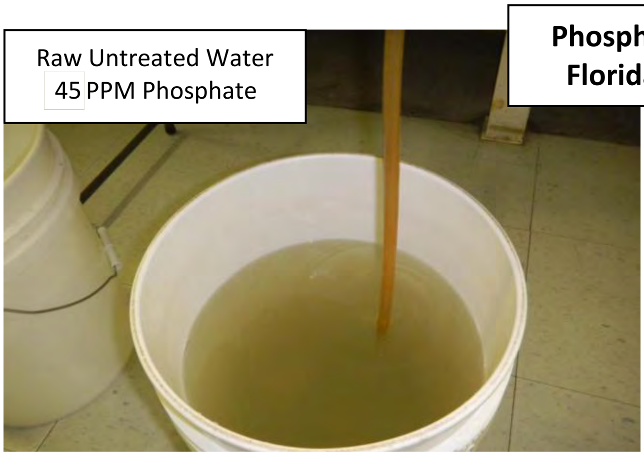
As noted the PWS ECpw water treatment system is applicable to multiple industries and processes and can process various water streams at greatly reduced O&M costs. This results in increased profits and reduced tax dollars requirement for operation.

Some applications include:

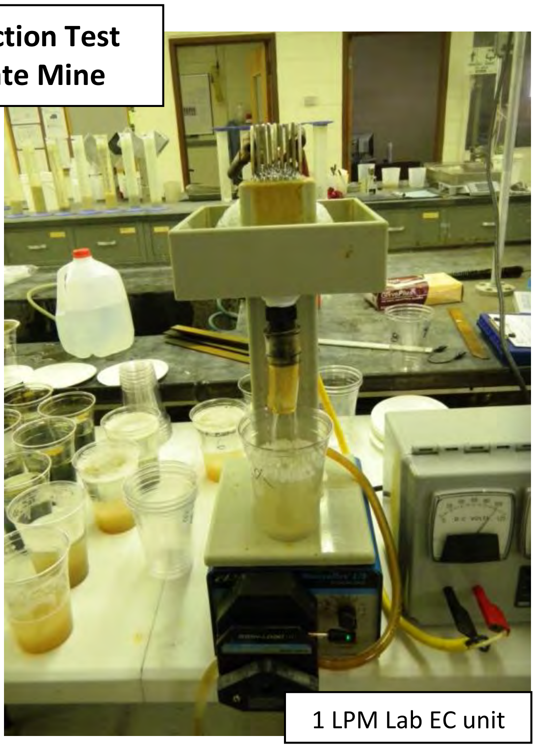
- Lake/Rive/ReUse Effluent – Nutrient Removal
- Potable Water – Organics/Color/THM Removal
- ASR Well Water – PreTreatment
- Cooling Tower – BlowDown & MakeUp Water Treatment
- Industrial PreTreatement – Metals (Hg, Pb, Cr, Fe, Au, Cu, Zn, Mn, Mg, etc.) Silica, Arsenic, Cyanide, Pesticides, EDCs, ECCs & others

GPi and PWS welcome the opportunity of sharing our “Creative Solution” technology with you and can provide ECpw water treatment demonstrations on your specific waters.

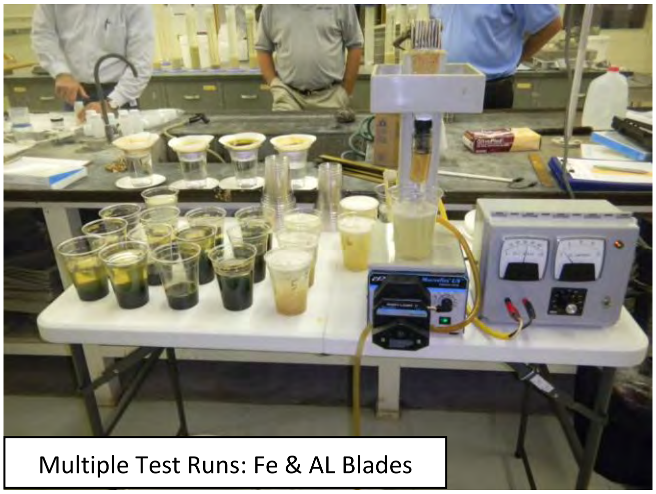
Phosphate Reduction Test
Florida Phosphate Mine



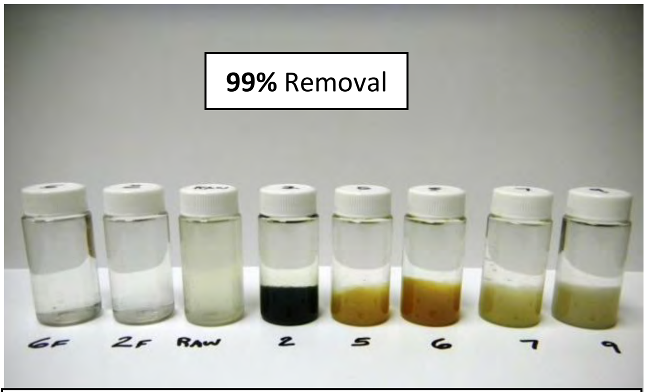
Raw Untreated Water
45 PPM Phosphate



1 LPM Lab EC unit



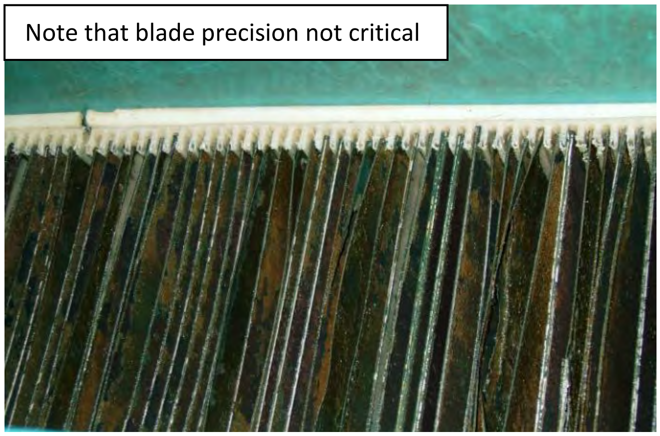
Multiple Test Runs: Fe & AL Blades



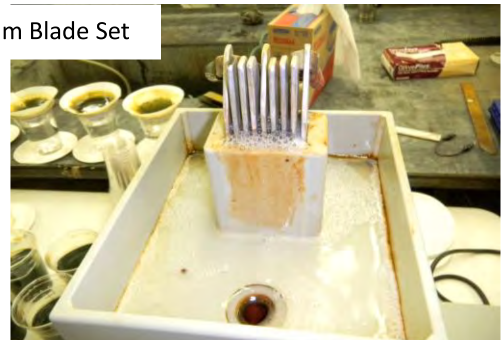
99% Removal

#6F	#2F	Raw	#2 Fe	#5 Fe	#6 Fe	#7 Al	#9 Al

Run Numbers: "F" is filtered; others just settled



Note that blade precision not critical



Aluminum Blade Set

Examples of Typical Sacrificial Blades

NOTES:

- New Blade – left side
- Center Blade – Needs replaced
- Other 3 blades still okay
- Blades replaced at owners discretion

Lab test date:

8June20112

Electro Coagulation Test Data Sheet **Date: 6/8/12** **Testing for Phosphorous Removal**

Description	Process Water	Plate Type	Pump Setting	RT (secs)	No. Term'l	Volts	Amps	Watts	pH	Ortho P (ppm)	Total P (ppm)	Ortho P % rem'd	Total P % rem'd
Process Water - Bucket 1									6.3	48.113	46.890		
Process Water - Bucket 1									6.3	45.296	45.400		
Average Bucket 1										**46.705**	**46.145**		
Process Water - Bucket 2										46.706	45.200		
Process Water - Bucket 2										45.054	47.630		
Average Bucket 2										**45.880**	**46.415**		
Run 1	Bucket 1	Fe	2	32	2	50	1.4	70.0	7.9	0.351	0.371	**99.2%**	**99.2%**
Run 2	Bucket 1	Fe	3	20	2	67	1.9	127.3	8.34	0.510	0.409	**98.9%**	**99.1%**
Run 3	Bucket 1	Fe	2	32	2	65	2.5	162.5	8.7	1.066	0.762	**97.7%**	**98.3%**
Run 4	Bucket 1	Fe	2	32	2	90	5.0	450.0	9.1	0.675	0.458	**98.6%**	**99.0%**
Run 5	Bucket 1	Al	2	32	2	50	1.4	70.0	8.23	0.623	0.071	**98.6%**	**99.8%**
Run 6	Bucket 1	Al	3	20	2	67	1.9	127.3	8.11	0.136	0.025	**99.7%**	**99.9%**
Run 7	Bucket 2	Al	2	32	2	75	1.5	112.5	8.37	0.061	0.100	**99.9%**	**99.8%**
Run 8	Bucket 2	Al	2	32	2	100	1.9	190.0	8.6	0.009	0.157	**100.0%**	**99.7%**
Run 9	Bucket 2	Al	2	32	3	98	6.0	588.0	8.7	0.009	0.068	**100.0%**	**99.9%**

WQ Results for the ElectroCoagulation Demonstration

South Florida Water Management District - West Palm Beach, FL USA

SFWMD (WPlmBch) Test Date: 3Aug2012
New Alternative Treatment Technologies (NATA) Program

135

SAMPLE_TYPE SAMP

PARAMETER CODES

WQ RESULTS

TREATMENT	TPO4	TDPO4	OPO4	DOP	PP	TN	TKN	TON	NOX	NH4	SO4	TOTAL	TOTFE	ALKA	LPH	LCOND
Raw Water	0.072	0.035	0.017	0.018	0.037	2.156	1.820	1.716	0.336	0.104	47	36	5	180	8.0	798
Run 1 (Fe blades @ 80 W, 32 sec RT)	0.018	0.018	0.006	0.012	0.000	1.094	0.790	0.629	0.304	0.161	39	24	44	102	9.2	601
Run 2 (Fe blades @ 91 W, 20 sec RT)	0.016	0.016	0.006	0.010	0.000	1.12	0.790	0.642	0.330	0.148	38	27	48	105	8.8	643
Run 3 (Fe blades @ 30 W, 32 sec RT)	0.012	0.012	0.005	0.007	0.000	1.207	0.860	0.729	0.347	0.131	37	24	78	142	8.7	713
Run 4 (Fe blades @ 388 W, 32 sec RT)	0.017	0.014	0.007	0.007	0.003	0.935	0.710	0.466	0.225	0.244	25	26	40	55	9.6	517
Run 5 (Al blades @ 78 W, 32 sec RT)	0.006	0.005	0.002	0.003	0.001	1.08	0.830	0.629	0.250	0.201	39	3767	9	103	8.7	628
Run 6 (Al blades @ 88 W, 20 sec RT)	0.005	0.005	0.002	0.003	0.000	1.095	0.830	0.644	0.265	0.186	40	3346	5	113	8.6	657
Run 7 (Al blades @ 32 W, 32 sec RT)	0.005	0.006	0.002	0.004	-0.001	1.29	1.000	0.808	0.290	0.192	40	3574	5	123	8.6	669
Run 8 (Al blades @ 228 W, 32 sec RT)	0.004	0.004	0.002	0.002	0.000	1.208	1.050	0.774	0.158	0.276	28	9042	3	81	8.9	540

Parameter Codes
ALKA = alkalinity (as mg $CaCO_3$/L)
DOP = dissolved organic phosphorus (mg P/L) => TDPO4 - OPO4
LCOND = lab conductivity (µS/cm)
LPH = lab pH (s.u.)
NH4 = ammonia nitrogen (mg N/L)
NOX = nitrate + nitrite nitrogen (mg N/L)
OPO4 = soluble reactive phosphorus (mg P/L)
PP = particulate phosphorus (mg P/L) => TPO4 - TDPO4
SO4 = sulfate (mg/L)
TDPO4 = total dissolved phosphorus (mg P/L)
TKN = total Kjeldahl nitrogen (mg N/L)
TN = total nitrogen (mg N/L) => TKN + NOx
TON = total organic nitrogen (mg N/L) => TKN - NH4
TOTAL = total aluminum (µg/L)
TOTFE = total iron (µg/L)

Project Objective: Evaluate the effectiveness of the ElectroCoagulation technology to remove phosphorus and

PI/Contractor: Mike Chimeny / GPi - Bert Gerber
Proj. Mgr. : Kim O'Dell

Method:
This was a bench-top study conducted at the District's Chemistry Laboratory using water collected from the C-51 canal at the S5A Laboratory.

The demonstration of the ElectroCoagulation unit was conducted by Mr. Bert Gerber of Gerber Pumps International, Inc. Water used in the test was collected from the C-51 canal at the S5A Laboratory on the previous day and stored in the laboratory at room temperature until used. Water for the filter paper control also collected from the C-51 canal and processed immediately.

PhosAcid Plant, FL USA
CNPW Electro-Coagulation Pilot
Study Analytical Results

27-Sep-12

		Run #1 Fe		**Run #2 Fe**		**Run #3 Fe**		**Run #4 Al**		**Run #5 Al**		**Run #6 Al**	
	RAW EC	**Fe 28V-2.5A**	**% Red.**	**Fe 40V-3.5A**	**% Red.**	**Fe 78V-7.5A**	**% Red.**	**Al 31V-2.2A**	**% Red.**	**Al 44V-3.2A**	**% Red.**	**Al 92V-6.0A**	**% Red.**
pH	7.09	8.83	-25%	8.76	-24%	9.20	-30%	8.28	-17%	8.61	-21%	8.40	-18%
Flouride	5.23	5.03	4%	4.93	6%	4.44	15%	0.93	82%	0.79	85%	0.71	86%
Conductivity	618	433	30%	425	31%	334	46%	380	39%	389	37%	293	53%
TP*	**10.60**	**0.13**	**98.8%**	**0.09**	**99.2%**	**0.09**	**99.2%**	**0.02**	**99.8%**	**0.02**	**100%**	**0.02**	**99.8%**
TN	2.11	1.93	9%	1.62	23%	1.37	35%	1.56	26%	1.54	27%	1.50	29%
NO3	0.19	0.15	21%	0.14	26%	0.07	63%	0.06	68%	0.05	74%	0.03	84%
Total NH3	1.04	1.32	-27%	1.18	-13%	1.00	4%	1.22	-17%	1.19	-14%	1.18	-13%
TKN	1.92	1.78	7%	1.48	23%	1.30	32%	1.50	22%	1.49	22%	1.47	43%
TSS	12.0	0.8	93%	2.0	83%	2.0	83%	2.4	80%	2.4	80%	2.4	80%
TDS	500	310	38%	304	39%	280	44%	262	48%	286	43%	192	62%

Test Runs	**Blades**	**RT-Sec**	**Volts**	**Amps**	**VA**	**Watts**
1	Fe	32	28	2.5	70.0	175
2	Fe	32	40	3.5	140.0	490
3	Fe	32	78	7.58	591.2	4481.6
4	Al	32	31	2.2	68.2	150.04
5	Al	32	4	3.2	12.8	40.96
6	Al	32	92	6	552.0	3312

NOTE 1: TP (Total Phosphorous) detectioin limit for this analysis was 0.02

NOTE 2: Lab analysis performed by company's onsite Registered laboratory

FLOWERS CHEMICAL LABORATORIES INC.

P.O. Box 150597, Altamonte Springs FL 32715-0597 | Phone: 407-339-5984 / Fax: 407-260-6110 | E83018 (Main Lab)
571 NW Mercantile Pl. Suite 111, Port St. Lucie FL 34986 | Phone: 772-343-8006 / Fax: 772-343-8089 | E86562 (South Lab)
P.O. Box 1200, Madison FL 32341 | Phone: 850-973-6878 / Fax: 850-973-6878 | E82405 (North Lab)
3980 Overseas Hwy Suite 103, Marathon FL 33050 | Phone: 305-743-8598 / Fax: 305-743-8598 | E35834 (Keys Lab)

Gerber Pumps Intl., Inc.
755 W. SR 434, Suite K
Longwood,FL 32750

PO #: WRF Reuse EFF.
Client Project #: Altamonte Springs
Date Sampled: Oct 22, 2009
Oct 30, 2009; Invoice: 108527

ReUse Water

Analysis Report

Lab #: 108527WW1 **Sampled:** 10/22/09 11:00 AM **Desc:** Raw

Parameter		Result	Units	DF	MDL	PQL	QC Batch	Method	CAS #	Analyzed
Total Phosphorous(as P)	RAW	1.37	mg/L	1.00	0.00200	0.00400	10137223	EPA365.1	7723-14-0	10/30/09

Lab #: 108527WW2 **Sampled:** 10/22/09 11:00 AM **Desc:** EC Run#1

99% Removal

Parameter	Result	Units	DF	MDL	PQL	QC Batch	Method	CAS #	Analyzed
Total Phosphorous(as P)	0.0104	mg/L	1.00	0.00200	0.00400	10137223	EPA365.1	7723-14-0	10/30/09 02:43 PM

Lab #: 108527WW3 **Sampled:** 10/22/09 11:00 AM **Desc:** EC Run#2

Parameter	Result	Units	DF	MDL	PQL	QC Batch	Method	CAS #	Analyzed
Total Phosphorous(as P)	0.0298	mg/L	1.00	0.00200	0.00400	10137223	EPA365.1	7723-14-0	10/30/09 02:44 PM

Lab #: 108527WW4 **Sampled:** 10/22/09 11:00 AM **Desc:** EC Run#3

Parameter	Result	Units	DF	MDL	PQL	QC Batch	Method	CAS #	Analyzed
Total Phosphorous(as P)	0.0210	mg/L	1.00	0.00200	0.00400	10137223	EPA365.1	7723-14-0	10/30/09 02:48 PM

Organics Removal from **St. Johns River**
With **GPi-EC/PW^{tm} ElectroCoagulation**

EC Treated
St. Johns River
Water

Untreated
St. Johns River
Water

St. Johns River Water – Raw and ElectroCoagulation Treatment

<u>Right – Raw</u>

Color:	400 CU
TOC	36.0 mg/l
UVA254 (Organics Indicator):	1.72
Phosphorous:	0.223 mg/l

<u>Left – ElectroCoagulated & 11 micron filtered</u>

Color:	20 CU	**95% Reduction**
TOC	8.77mg/l	**76% Reduction**
UVA254(<u>Organics Indicator</u>):	0.155	**90% Reduction**
Phosphorous:	.0100U mg/l	**95% Reduction**

Advanced Environmental Laboratories, Inc
528 S. North Lake Blvd, Suite 1016
Altamonte Springs, FL 32701
Phone: (407)937-1594
Fax: (407)937-1597

ANALYTICAL RESULTS

Workorder: A1107474 Cloud Lake

Lab ID: **A1107474001**
Sample ID: **Cloud Lake Raw**
Sample Description:

Date Received: 10/06/11 16:00
Date Collected: 10/06/11 12:00
Location:

Matrix: Water

Note that Untreated "Raw" Water had low TP to start

Parameters	Results	Units	Qual	DF	Adjusted PQL	Adjusted MDL	Analyzed	Lab
WET CHEMISTRY								
Analysis Desc: Total Nitrogen,Calculated,Water	Analytical Method: Calculation							
Total Nitrogen	**1.4**	**mg/L**		**1**	0.10	0.10	10/14/2011 16:44	^
Analysis Desc: TKN,E351.2,Water	Preparation Method: Mercuric Sulfate Digestion Analytical Method: EPA 351.2							
Total Kjeldahl Nitrogen	**1.4**	**mg/L**		**1**	0.20	0.10	10/12/2011 10:57	T
Analysis Desc: Total Phosphorus,E365.1,Analysis	Preparation Method: EPA 365.1 Low-Level TP Analytical Method: EPA 365.1 Low-Level TP							
Total Phosphorus (as P)	**0.075**	**mg/L**		**1**	0.0050	0.0010	11/8/2011 10:45	T
Analysis Desc: Total Phosphorus,E365.4,Analysis	Preparation Method: Mercuric Sulfate Digestion Analytical Method: EPA 365.4							
Total Phosphorus (as P)	**0.074**	**mg/L**	**I**	**1**	0.20	0.046	10/12/2011 10:57	T
Analysis Desc: Color,SM2120B,Water	Analytical Method: SM 2120B							
Color	**69**	**Color Units**		**1**	5.0	2.7	10/7/2011 11:54	T
Analysis Desc: Tot Dissolved Solids,SM2540C	Analytical Method: SM 2540C							
Total Dissolved Solids	**330**	**mg/L**		**1**	10	10	10/11/2011 12:59	T
Analysis Desc: Nitrate+Nitrite,SM4500NO3F,W	Analytical Method: SM 4500NO3-F							
Nitrate + Nitrite	**0.048**	**mg/L**	**U**	**1**	0.20	0.048	10/11/2011 14:21	T

ANALYTICAL RESULTS

98.6+% Removed
Below Detection Limits

Workorder: A1107474 Cloud Lake

Lab ID:	**A1107474003**	Date Received:	10/06/11 16:00
Sample ID:	**EC-4**	Date Collected:	10/06/11 12:00
Matrix:	Water		
Sample Description:		Location:	

Parameters	Results	Units	Qual	DF	Adjusted PQL	Adjusted MDL	Analyzed	Lab
Analysis Desc: TKN,E351.2,Water		Preparation Method: Mercuric Sulfate Digestion Analytical Method: EPA 351.2						
Total Kjeldahl Nitrogen	**0.62**	**mg/L**		**1**	0.20	0.10	10/12/2011 10:57	T
Analysis Desc: Total Phosphorus,E365.1,Analysis		Preparation Method: EPA 365.1 Low-Level TP Analytical Method: EPA 365.1 Low-Level TP						
Total Phosphorus (as P)	**0.0010**	**mg/L**	**U**	**1**	0.0050	0.0010	11/8/2011 10:45	T
Analysis Desc: Total Phosphorus,E365.4,Analysis		Preparation Method: Mercuric Sulfate Digestion Analytical Method: EPA 365.4						
Total Phosphorus (as P)	**0.046**	**mg/L**	**U**	**1**	0.20	0.046	10/12/2011 10:57	T
Analysis Desc: Color,SM2120B,Water		Analytical Method: SM 2120B						
Color	**20**	**Color Units**		**1**	5.0	2.7	10/7/2011 11:54	T
Analysis Desc: Tot Dissolved Solids,SM2540C		Analytical Method: SM 2540C						
Total Dissolved Solids	**230**	**mg/L**		**1**	10	10	10/11/2011 12:59	T
Analysis Desc: Nitrate+Nitrite,SM4500NO3F,W		Analytical Method: SM 4500NO3-F						
Nitrate + Nitrite	**0.048**	**mg/L**	**U**	**1**	0.20	0.048	10/11/2011 14:21	T

Orange County Utilities Central Laboratory
9124 Curry Ford Road
Orlando, FL 32825

Phone: (407) 254-9550
Fax: (407) 254-9558
NELAP ID#: E53398

CERTIFICATE OF ANALYSIS

Phosphorous Removal
ElectroCoagulation Testing
ReUse Water: Sand Lake Road WRF

December 20, 2013

Mr. Tim Madhanagopal, P.E.
South Water Reclamation Facility
4760 Sand Lake Road
Orlando, FL 32819

RE: Workorder ID: 1312222
Project ID: SWRF/Special 121013

Dear Tim Madhanagopal, P.E.:

Enclosed are the analytical results for sample(s) received by the laboratory on Wednesday, December 11, 2013. The results in this report relate only to the samples listed on page 2. The chain of custody is included as part of the Certificate of Analysis for the above referenced Workorder ID and should be retained as a permanent record thereof. Estimated uncertainties, in the form of quality control limits, are available in the laboratory's Quality Manual. Precision, in the form of relative percent difference (RPD), is not calculated for results that are less than four times the method detection limit (MDL) and are labeled as 'N/A' (not applicable). If reported, results for radionuclides (Gross Alpha, Radium-226 and Radium-228) were analyzed by NELAP-certified laboratory ID E83033. The results contained in this report meet all requirements of the National Environmental Laboratory Accreditation Conference (NELAC) standards, where applicable.

If you have any questions concerning this report, please feel free to contact me.

Certified By:

Scott Rampenthal, Laboratory Section Manager

Enclosures

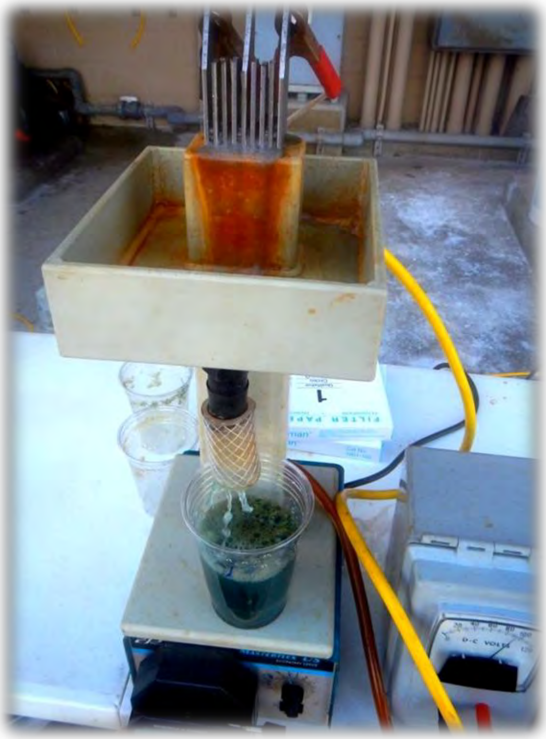
SAMPLE SUMMARY

Workorder: 1312222
Project ID: SWRF/Special 121013

Lab ID	Sample ID	Matrix	Date/Time Collected	Date/Time Received
131222201	Reuse - Raw - N.C	Wastewater	12/10/2013 13:00	12/11/2013 14:55
131222202	EC1 - Fe	Wastewater	12/10/2013 13:00	12/11/2013 14:55
131222203	EC2 - Fe	Wastewater	12/10/2013 13:00	12/11/2013 14:55
131222204	EC3 - Fe	Wastewater	12/10/2013 13:00	12/11/2013 14:55
131222205	EC4 - AL	Wastewater	12/10/2013 13:00	12/11/2013 14:55
131222206	EC5 - AL	Wastewater	12/10/2013 13:00	12/11/2013 14:55
131222207	EC6 - AL	Wastewater	12/10/2013 13:00	12/11/2013 14:55

ElectroCoagulation
ReUse Water Treatment

*E*C Treated / Separation with NO Chemicals or Polymers / 1 L/Min ECpw Lab Unit



EC treated: Fe Blades

EC treated: Al Blades

Phosphorous
Removal Test
ReUse Water

Water Source: ReUse Water
Sand Lake Rd WRF _ Orange County, FL
Test Date: 10Dec2013

		Run #1 Fe		**Run #2 Fe**		**Run #3 Fe**		**Run #4 Al**		**Run #5 Al**		**Run #6 Al**	
Blade Type RT (Sec)	**Before Treatment**	**Fe 60 RT**	**% Red.**	**Fe 30 RT**	**% Red.**	**Fe 25 RT**	**% Red.**	**Al 60 RT**	**% Red.**	**Al 30 RT**	**% Red.**	**Al 25 RT**	**% Red.**
TP*	1.93	**0.017**	**99.1%**	**0.014**	**99.3%**	**0.028**	**98.5%**	**0.003**	**99.8%**	**0.003**	**99.8%**	**0.003**	**99.8%**
Color	15.00	2.00	87%	2.00	87%	2.00	87%	2.00	87%	2.00	87%	2.00	87%
TOC	6.59	4.22	36%	4.37	34%	4.43	33%	4.32	34%	4.41	33%	4.51	32%

Test Runs	**Blades**	**RT-Sec***	**Volts**	**Amps**	**VA**
1	Fe	60	92	2.9	266.8
2	Fe	30	92	2.9	266.8
3	Fe	25	92	2.9	266.8
4	Al	60	92	2.5	230.0
5	Al	30	92	2.5	230.0
6	Al	25	92	2.5	230.0

***RT** is the Retention/Reaction Time (seconds) in the EC Chamber

NOTE 1: **TP (Total Phosphorous) detectioin limit for this analysis was 0.003**

NOTE 2: **Runs #4 - #6 TP was below .003 Detection Limit**

NOTE 3: Lab analysis performed by Orange County Utilities Central Laboratory

ECPW$^{\text{tm}}$ Results

The following results are specific examples of the patented EC/PW$^{\text{tm}}$ and were conducted by a qualified independent laboratory.

CONTAMINANT	BEFORE (mg/L)	AFTER (mg/L)	REMOVAL RATE (%)
Aldrin (pesticide)	0.0630	0.0010	98.40
Aluminum	224.0000	0.6900	99.69
Ammonia *	49.0000	19.4000	60.41
Arsenic	0.0760	<0.0022	97.12
Barium	0.0145	<0.0010	93.10
Benzene	90.1000	0.3590	99.60
BOD	1050.0000	14.0000	98.67
Boron	4.8600	1.4100	70.98
Cadmium	0.1252	<0.0040	96.81
Calcium *	1,321.0000	21.4000	98.40
Chlorieviphos (pesticide)	5.8700	0.0300	99.50
Chromium	139.0000	<0.1000	99.92
Cobalt	0.1238	0.0214	82.71
Copper	0.7984	<0.0020	99.75
Cyanide (Free)	723.0000	<0.0200	99.99
Cypermethrin (pesticide)	1.3000	0.0700	94.60
DDT (pesticide)	0.2610	0.0020	99.20
Diazinon (pesticide)	34.0000	0.2100	99.40
Ethyl Benzene	428.0000	0.3720	99.91
Fluoride	1.1000	0.4150	62.27
Gold	5.7200	1.3800	75.87
Iron	68.3400	0.1939	99.72
Lead	0.5900	0.0032	99.46
Lindane (pesticide)	0.1430	0.0010	99.30
Magnesium *	13.1500	0.0444	99.66
Manganese	1.0610	0.0184	98.27
Mercury	0.7200	<0.0031	98.45
Molybdenum	0.3500	0.0290	91.71
MP-Xylene	41.6000	0.0570	99.86
MTBE	21.5800	0.0462	99.79
Nickel	183.0000	0.0700	99.96
Nitrate	11.7000	2.6000	77.78
Nitrite	21.0000	12.0000	42.86
Nitrogen TKN	1,118.8800	59.0800	94.72
NTU	35.3800	0.3200	99.10
O-Xylene	191.0000	0.4160	99.78
PCB (Arochlor 1248)	0.0007	<0.0001	85.71
Petroleum Hydrocarbons	72.5000	<0.2000	99.72
Phosphate	28.0000	0.2000	99.28
Platinum	4.4000	0.6800	84.55
Potassium **	200.0000	110.0000	45.00
Proptamphos (pesticide)	80.8700	0.3600	99.60
Selenium	68.0000	38.0000	44.00
Silicon	21.0700	0.1000	99.50
Sulfate	104.0000	68.0000	34.61

*pH adjusted needed in order to achieve high % removal rates

**Potassium will not be removed as a salt ion, K^+, but can be removed if associated with other compounds.

CONTAMINANT	BEFORE (mg/L)	AFTER (mg/L)	REMOVAL RATE (%)
Silver	0.0081	0.0006	92.59
Tin	0.2130	<0.0200	90.61
Tolulene	28,480.0000	0.2270	99.99
TSS	1,560.0000	8.0000	99.49
Vanadium	0.2621	<0.0020	99.24

Americium-241	71.9900 pCi/L	0.5700 pCi/L	99.20
Plutonium-239	29.8500 pCi/L	0.2900 pCi/L	99.00
Radium	1093.0000 pCi/L	0.1000 pCi/L	99.99
Uranium	0.1300 mg/L	0.0002 mg/L	99.83

Bacteria	110,000,000.00 cfu	2,700.00 cfu	99.99
Coliform	318,000.0000 cfu	<1.00 cfu	99.99
E coli Bacteria	>2,419.20 mpn	0.00 mpn	99.99
Enterococcus Bacteria	83.00 mpn	<10.00 mpn	82.87
Total Coliform Bacteria	>2,419.20 mpn	0.00 mpn	99.99

CYANOTOXINS Removal

C-43 RESERVOIR

GPI
GerberPumps
international inc.

“CREATIVE TREATMENT SOLUTIONS”

WITH

Powell
Water

ElectroCoagulation

Removal of:
Multiple Contaminants
Simultaneously

Cyanotoxins Toxins Case Study

REPORT: Cyanotoxins Treatment with ElectroCoagulation

Location: Celina, Ohio - Water Treatment Plant

Problem:

Celina Ohio was experiencing excessive cyanotoxin problems in their Grand Lake drinking water source. Powell Water Systems, Inc. (PWS) was contacted to see if the PWS ElectroCoagulation technology could be of benefit to their operations in removal of the excessive cyanotoxins. The level of cyanotoxins in the raw untreated water was 67.1 ug/l.

Background:

There are at least ten different forms of Cyanotoxins which are toxins produced by bacteria called cyanobacteria (also known as blue-green algae). In addition to serious side health side effects, if in large enough concentrations, they can also produce taste and odor issues with potable water from the byproducts of MIBS and Geosims in much smaller concentrations.

ElectroCoagulation technology removes with high efficiency molecules of 6-carbons and longer. MIBS and Geosims are 11 and 12 carbon chains in length and so would respond very favorably to EC treatment. The various cyanotoxins contain many more carbon atoms than either MIBS or Geosims and can be removed effectively with ElectroCoagulation treatment.

ElectroCoagulation treatment:

A PWS Lab Scale 1 LPM EC treatment unit was used for demonstration purposes to confirm that ElectroCoagulation technology can be effective in cyanotoxin removal. The following test results were obtained while performing EC treatment on raw source water form Grand Lake containing cynaotoxins resulting from Planktothrix sp. of blue-green algae.

The raw untreated water from Grand Lake contained 67.1 ug/l of the cyanotoxins. With no dilution of the raw water, reductions of 96.79% and 96.31% were obtained with 60-sec and 15-sec EC chamber HRT (EC chamber Hydraulic Retention/Reaction Time). The PWS EC units are rated for 60-sec HRT. If sufficient treatment results are obtained with lower HRT a smaller ECpw can be utilized at lower capital cost.

EC treatment was also performed with various dilution levels and are recorded as noted in the table following.

Conclusion:

PWS ElectroCoagulation treatment of raw source drinking water can be effective in removing cyanotoxins and their taste and odor byproducts.

Power usage at 15 second residence time would be 2 KWH per thousand gallons EC treated water in a commercial unit. The expected iron blade use would be about 0.2 pounds per 1,000 gallons treated of hot rolled pickled and oiled iron sheet metal. The operating cost with electricity at $0.10 per KWH and 2 KWH per 1,000 gallons treated would be $0.20 per 1,000 gallons treated for electricity. The iron blade cost at $0.50 per pound for iron blades and 0.2 pounds per 1,000 gallons would be $0.10 per 1,000 gallons treated. The combined operating cost for electricity and iron blades would be $0.30 per 1,000 gallons treated.

Removal Rates for Cyanotoxin, Specifically Planktothrix sp.

Using
Powell Water Electrocoagulation

Reported in ug/l
All Amperage Readings were at 100 volts MT
16122 – MT 16125 – Dilution w/DI Water MT
16126 - MT16131 – Dilution w/ Tap Water
Mar. 16, 2016

Sample ID	Description	Amperage	Raw/Dilution Rate	Start	Post EC + 11 Micron Filter	% Reduction
MT 16121	Lagoon Grab Sample		No Dilution	67.1		
MT 16122	EC w/60 sec. residence	~1.0	No Dilution	67.1	2.2	96.76
MT 16123	EC w/15 sec. residence	~1.0	No Dilution	67.1	2.5	96.31
MT 16124	EC w/60 sec. residence	~0.25	4:1	16.7	0.126	99+
MT 16125	EC w/15 sec. residence	~0.25	4:1	16.7	0.164	98.8
MT 16126	EC w/60 sec. residence	Split Chamber 4	50:1	1.34	0.000	99+
MT 16127	EC w/15 sec. residence	Split Chamber 4	50:1	1.34	0.006	99+
MT16128	EC w/60 sec. residence	Split Chamber 3.75	200:1	0.34	0.000	99+
MT16129	EC w/15 sec. residence	Split Chamber 3.75	200:1	0.34	0.000	99+
MT16130	EC w/60 sec. residence	Split Chamber 3.75	400:1	0.16	0.000	99+
MT16131	EC w/15 sec. residence	Split Chamber 3.75	400:1	0.16	0.001	99+

Celina, OH Grand Lake Drinking Water Source

Mono Species of Planktatherix (Neurotoxic Species)

Celina, OH Drinking Water Lab

Raw Water – Start 67.1 ug/l

APPENDIXES

C-43 RESERVOIR

RESEARCH REPORTS & STUDIES

C-43 RESERVOIR

- EPA SITE EC Emerging Technology Summary
- Alum Chemical Composition
- Office of Naval Research: EC Research Study
- USF (University of South Florida)
  (3) Research Projects: Pathogens/Endocrine Disruptors (EDC)/ Nutrients, PCP (Personal Care Products)

United States
Environmental Protection
Agency

EPA/540/S-93/504
September 1993

EPA

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Emerging Technology Summary

Electro-Pure Alternating Current Electrocoagulation

Naomi P. Barkley, Clifton Farrell, and Tracie Williams

The Superfund Innovative Technology Evaluation (SITE) Program was authorized as part of the 1986 amendments to the Superfund legislation. It represents a joint effort between the U.S. Environmental Protection Agency's (EPA) Office of Research and Development and Office of Solid Waste and Emergency Response. The program is designed to assist and encourage the development of waste treatment technologies that would contribute innovative solutions to our hazardous waste problems. Under the Emerging Technology portion of the SITE Program, a 2-yr research effort was conducted by Electro-Pure Systems, Inc., to evaluate the technical and economic feasibility of alternating current electrocoagulation (ACE) for remediation of aqueous waste streams at Superfund sites.

The ACE Technology introduces low concentrations of nontoxic aluminum hydroxide species into the aqueous media by the electrochemical dissolution of aluminum-containing electrodes or pellets. The aluminum species that are produced neutralize the electrostatic charges on suspended material and/or prompt the coprecipitation of certain soluble ionic species, and thereby facilitate their removal.

Electrocoagulation has been demonstrated to enhance the filtration and dewatering rates for solids removed from an effluent; such enhancements are prompted by growth in the mean particle size from typically <0.3 µm in diameter to as much as 150 µm, depending on the degree of electrocoagulation. Significant reductions in the total suspended solids (TSS) loading of particulate slurries and in the concentrations of metals (lead, copper, zinc, chromium), fluorides, and phosphates from aqueous streams can be achieved under certain pH conditions. Treatment does not entail adding chemicals (polymers, metal salts, polyelectrolytes) whose accumulation might inhibit reuse of the effluent as process water. Rather, the insoluble aluminum hydroxide resulting from electrocoagulation may be removed by standard filtration practices.

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the SITE Emerging Technology Program that is fully documented in a journal article (see ordering information at back).

Introduction

Chemical coagulation has been used for decades to destabilize colloidal suspensions and to effect precipitation of soluble metal species as well as other inorganic species from aqueous streams, thereby permitting their removal through sedimentation or filtration. Alum, lime, and/or polymers have been the chemical coagulants used. These processes, however, tend to generate large volumes of sludge with a high bound-water content that can be slow to filter and difficult to dewater. These treatment processes also tend to increase the total dissolved solids content of the effluent, making it unacceptable for reuse within industrial applications.

The ACE Technology was originally developed in the early 1980s to break stable aqueous suspensions of clays and coal fines produced in the mining industry. Traditionally, these effluents were treated with conventional techniques that made use of organic polymers and inorganic salts to agglomerate and enhance the removal of the suspended materials. This ACE Technology was developed to simplify effluent treatment, realize cost savings, and facilitate recovery of fine-grained coal.

ACE Technology is based upon colloidal chemistry principles–principles using alternating electrical power and electrophoretic metal hydroxide coagulation. The basic mechanism for the technology is electroflocculation wherein small quantities (generally <30 mg/L) of aluminum hydroxide species are introduced into solution to facilitate flocculation. Electroflocculation causes an effect similar to that produced by the addition of chemical coagulants such as aluminum or ferric sulfate. These cationic salts destabilize colloidal suspensions by neutralizing negative charges associated with these particles at neutral or alkaline pHs. This enables the particles to come together closely enough to agglomerate under the influence of van der Waals attractive forces. See Figure 1 for the ACE basic process flow.

Although the electroflocculation mechanism resembles chemical coagulation in that cationic species are responsible for the neutralization of surface charges, the characteristics of the electrocoagulated floc differ dramatically from those generated by chemical coagulation. An electrocoagulated floc tends to contain less bound water, is more shear resistant, and is more readily filterable.

Application of an AC electric field to the electrodes induces dissolution of the aluminum and formation of the polymeric hydroxide species. Charge neutralization and particle growth are initiated within the electrocoagulation cells and continue following discharge of the aqueous medium from the apparatus. (In this way, product separation into solids, water, and oils may be achieved.)

The ACE Technology was tested using two designs of the ACE Separator™: (1) a parallel electrode unit in which a series of vertically oriented aluminum electrodes form a series of monopolar electrolytic cells through which the effluent passes and (2) a fluidized bed unit with nonconductive cylinders equipped with nonconsumable metal electrodes between which a turbulent fluidized bed of aluminum alloy pellets is maintained. In the fluidized bed unit, introduction of compressed air into the electrocoagulation cells assists in maintaining the turbulent fluidized bed and in enhancing the aluminum dissolution efficiency by increasing the anodic surface area. Typically, the fluidized bed unit dissolves aluminum at least one order of magnitude more efficiently than does the parallel electrode unit.

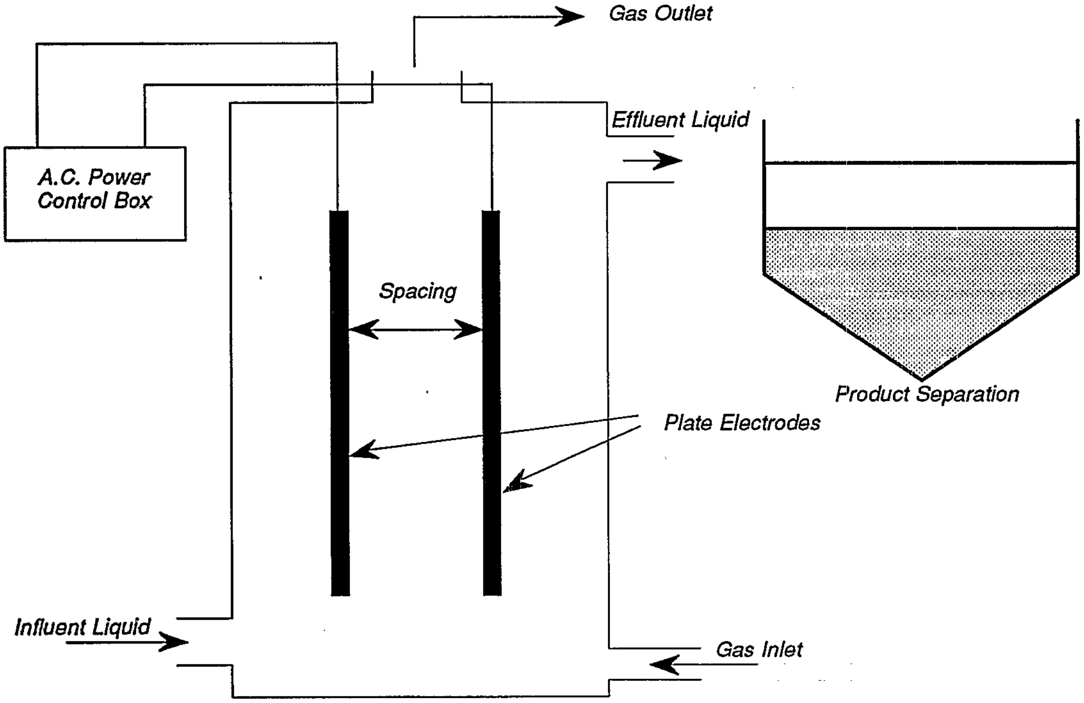


Figure 1. Schematic of an ACE Separator™ used in alternating current electrocoagulation.

Electrocoagulation operating conditions are highly dependent on the chemistry of the aqueous medium, especially conductivity. Other influent characteristics such as pH, particle size, and chemical constituent concentrations will influence operating conditions. Treatment generally requires application of low voltage (<150 VAC) to the electrocoagulation cell electrodes; current usage is typically 1 to 5 amp-min/L. The flow rate of the aqueous medium through an electrocoagulation cell depends on the solution chemistry (conductivity), the nature of the entrained suspension or emulsion, and the extent of electrocoagulation required to achieve the treatment objective. Retention times as short as 5 sec are sometimes sufficient to break a suspension. Electrocoagulation may be accomplished in a single pass or multiple passes (recycle mode). In the fluidized bed unit, a mechanical scrubbing action is created within the electrocoagulation cell–an action that reduces buildup of impermeable oxide coatings on the aluminum pellets and the inherent loss of efficiency that would result. Depending on system configuration, maintenance of the apparatus is limited to periodic replenishment of the aluminum fluidized bed material and/or electrodes. For most applications, pellets for the fluidized bed unit can be produced from recycled aluminum scrap or beverage containers. Where sludge reclamation is the objective, however, the use of higher quality pellets is required to reduce the introduction of impurities into the sludge.

This summary describes the research effort associated with bench- and pilot-scale testing of various surrogate wastewaters for determining the optimum operating conditions, treatment effectiveness, and cost of treatment.

Experimental

EPA's SITE Program research entailed testing the ACE Technology (in both the parallel electrode and fluidized bed system configurations) on various surrogate wastes containing emulsified diesel fuel, metals, and clays. The wastes were prepared to resemble those of leaking, underground storage tanks and soil washing operations. The primary testing objective of such testing was to establish optimum operating conditions for the ACE Separator™ to break the oil/water emulsion and achieve reductions in clay suspended solids and soluble metal pollutant loadings. Experiments were conducted on surrogate wastes prepared by mixing 0.2 to 3.0 wt. % of the -230 mesh (clay and silt) fraction of the EPA's Synthetic Soil Matrix (SSM) with 0.5 to 1.5 wt. % Number 2 diesel fuel, with 0.05 to 0.10 wt. % of an emulsifier (Titon-100X* or Alconox soap), and with from 10 mg/L to 100 mg/L of one or more of the following contaminants: copper, nickel, zinc, orthophosphate, or fluoride. The pH of each surrogate mixture was adjusted with either sodium hydroxide or calcium oxide to the desired value (5, 7, or 9) and the conductivity raised to roughly 1200 microSiemens per centimeter (μS/cm) to 1500 μS/cm with sodium chloride to simulate values expected in nature.

Initially, bench-scale electrocoagulation experiments using the parallel electrode unit were conducted on five aqueous-based systems that included a metals mixture, a clay suspension, a diesel fuel emulsion, a soluble organic solution, and a diesel fuel/soluble organic emulsion. The operating conditions determined during the Year One SITE work effort were used as the conditions for these tests. Optimum treatment time was established by examining the trend in contaminant loadings as a function of treatment time. To compare the results with conventional treatment processes, aliquots of each surrogate stock solution were treated with alum. Sufficient alum was added to give the aluminum equivalent to that introduced in the electrocoagulation experiments.

During the Year Two investigations, operating difficulties, persistent electrode coating and fouling, and low efficiencies of aluminum generation prompted including the alternative, fluidized-bed, electrocoagulation cell design in the remaining bench- and pilot-scale testing program. Three phases of laboratory experiments were undertaken to evaluate both electrocoagulation units: (1) preliminary screening experiments to demonstrate the feasibility of reducing the concentration of each metal, (2) matrix experiments to define the most opportune retention time and current (or current density), and (3) optimization experiments to define other ACE Separator™ operating parameters to achieve the most cost-effective removal conditions. The pH was adjusted to 5, 7, or 9 and the conductivity raised to approximately 1200 μS/cm with sodium chloride. The conductivity of some surrogate wastes was increased to approximately 3000 μS/cm and subjected to electrocoagulation. Surrogate wastes subjected to these experiments included the five aqueous systems described above as well as surrogate wastes containing individual constituents such as nickel, zinc, copper, fluoride, and phosphate.

Pilot-scale tests were performed by using both the parallel and fluidized bed configurations of the ACE Separator™. A 12-hr experiment using the ACE Fluidized Bed Separator™ was conducted on 208-L batches of surrogate waste solution containing 0.2 wt % SSM fines, 0.5 wt % diesel fuel, 0.05 wt % Alconox surfactant, and 10 mg/L each of Cu^{2+}, Zn^{2+}, PO_4^{3-}, F^-, and Ni^{2+}, and whose conductivity and pH had been raised to 1200 μS/cm and 7, respectively. This surrogate was recycled through a 4-in.- diameter, Schedule 80, PVC pipe, 24-in.-high pilot-scale ACE Separator™, which was equipped with two Type 316 stainless-steel electrodes (24 in. high, 2.5 in. wide) and whose interior was filled with 8 to +16 mesh aluminum pellets. The unit was powered at a constant 20 amp, and the voltage was allowed to vary as the electrocoagulation treatment progressed over the 12-hr period. In this experiment, the flow of the surrogate solution through the ACE Separator™ was varied from 1 to 6 gpm and the quantity of compressed air introduced into the solution feed line ranged up to a maximum of 10 psig. Samples of the surrogate solution were collected at various times throughout the experiment to document the rate of aluminum ion generation and the reductions in concentration of the metal contaminants, chemical oxygen demand (COD), and TSS.

In a similar pilot-scale test using the parallel plate unit, the surrogate waste was composed of essentially the same constituents as that for the fluidized bed experiment. The notable changes were that the conductivity of the solution was increased to approximately 3,000 μS/cm and no fluoride salt was added. The other operating parameters were based on results obtained from the bench-scale tests. The aluminum generation and consumption rates and the electrical power required to effect acceptable phase separation as well as contaminant reductions were monitored.

Throughout the various phases of the experimental program, samples of the treated effluent were collected and allowed to settle for 30 min. The supernate was removed and analyzed. The subnate, containing the settled floc, was filtered and the filtrate and filter cake analyzed.

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* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Results and Discussion

Optimum Operating Conditions

Optimum operating conditions for the parallel electrode unit were developed from these studies (Table I). These conditions served as the basis for the subsequent pilot-scale tests.

Optimum operating conditions for parallel electrode unit as a result of bench-scale tests were electrode spacing 0.5 in.; current, 4 amps; retention time, 3 to 5 min; frequency, 10 hertz; and fully submerged.

Similarly, based on the bench-scale testing of the fluidized bed design, the optimum operating conditions established were electrode spacing, 1-in.; aluminum pellets size, 8 to +16 mesh; and, current, 20 amps.

Treatment Effectiveness

Based upon bench-scale experiments conducted on the EPA surrogate wastes, the following summarizes the findings:

- When compared with alum treatment, electrocoagulation provided approximately 83% less sludge volume and a 76% improvement in filtration rate
- For the fluidized bed configuration, aluminum or stainless steel may be used as electrode material in the system, with comparable results
- With both increased frequency for the AC and increased retention time, the agglomerated particles tend to disaggregate.

Pilot-scale tests were conducted with the use of both the parallel and fluidized bed configurations of the ACE Separator™ on a 3% soil slurry containing roughly 50% clays, 1.5% diesel fuel, and 0.1% of a strong surfactant. Electrocoagulation reduced the TSS (222 mg/L to 4.5 mg/L) and total organic carbon (TOC) (130 mg/L to 6.6 mg/L). Copper was reduced by 72%, cadmium by 70%, chromium by 92%, and lead by 88%. No appreciable change in total solids (TS) loadings in the supernate resulted from electrocoagulation.

Table 1. *Optimum Operating Conditions for Parallel Electrode Unit Based on Bench-Scale Tests*

Parameter	*Value*
Current	*4 Ampere*
Electrode Spacing	*0.5 Inches*
Retention Time	*3 to 5 Minutes*
Frequency	*10 Hertz*
Submergence	*Fully Submerged*

Particle size was enhanced by the clay fraction as a result of electrocoagulation. The mean particle diameters of the ACE Separator™ treated particulates, both in the supernate and the filtrate (188 µm and 230 µm, respectively), increased by a factor of approximately 85 and 105, respectively, over that in the original slurry (2.2 µm).

Data obtained from the 12-hr, pilot-scale, fluidized bed test showed that after 30 min of treatment, more than 90% of the metals and phosphates were removed. Aluminum generation rates were highest when the throughput flow rate was <4 gpm. This upper flow limit may reflect compaction of the fluidized bed aluminum pellets against the upper screen of the electrocoagulation cell, thus placing them out of the range of the electrodes. As the emulsion is destabilized, the surrogate solution most likely becomes less resistive to ion mobility and, thereby, improves the operational efficiency of the ACE Separator™.

Filtration time for solids coagulated from particulate suspensions and oily emulsions by electrocoagulation is much less than for solids formed by chemical coagulant addition. Slurries tested were treated with alum addition and with an ACE Separator™. Electrocoagulation improved the filtration rate of titanium oxide by 63%. Other examples (for an oily emulsion and for biological sludge) indicate highly enhanced filtration rates for ACE Separator™ treated waste streams when compared with those of either untreated or alum-treated waste streams.

Shear strength of an electrocoagulation floc is generally much greater than the shear strength of an alum floc. Both sonic treatments (used to evaluate the structural integrity of the floc) and actual filtration tests demonstrated higher shear strength of the electrocoagulation flocs.

Electrocoagulation of metal and phosphate-bearing industrial solutions indicates excellent nickel, copper, and phosphate concentration reductions. More than 90% (concentration basis) of phosphate and copper can be removed from such solutions at low aluminum and electrical power requirements. Reduction in the nickel concentration varies between 75% and 85% (concentration basis).

Electrocoagulation of synthetic laboratory solutions and industrial wastewater also confirmed the feasibility of utilizing electrocoagulation for phosphate removal. Treatment of effluent from a commercial laundry reduced the phosphate concentration from 45 mg/L to 5.4 mg/L after low-intensity electrocoagulation (0.36 kW, 0.75-min retention time). Electrocoagulation of process water from a phosphate mining operation reduced the phosphate level by 91%, from 160 mg/L to 14 mg/L (3.3 kW, 0.17 min). Finally, treatment of dilute phosphoric acid solutions with a nominal 100 mg/L total phosphate concentration and a conductivity of approximately 2000 µS/cm resulted in >95% reductions in soluble phosphate over a range of acidities.

Capital and Operating Costs

As part of this research effort, projected treatment cost estimates were developed. Overall treatment operating costs (electricity, aluminum pellets, operation, and maintenance) will vary upwards from $0.50/1000 gal, depending on emulsion strength, unwanted component concentration(s) (for example, emulsifiers) in the effluent, and its TSS. (It should be noted that, at the outset, we established that operating conditions exceeding $3.00/1000 gal would not be competitive with conventional treatment processes, and thus, they were eliminated from future testing consideration.) Estimates are based on bench- and pilot-scale testing, additional considerations may be involved in full scale operation.

Operator supervision and maintenance would be limited to periodic replenishment of the aluminum pellets, chemical pretreatment systems (for example, salt addition for conductivity enhancement), and electrode replacement. Estimated operating costs are based on laboratory and limited pilot-scale testing of effluents, and currently these costs exceed those for comparable traditional chemical treatment (alum or polyelectrolytes). The lower maintenance and operator supervision required for ACE Separator™ operation and the capability to use ACE Separator™ treated water in closed-loop, zero-discharge applications adds to its attractiveness. Successful commercialization of the technology requires further research to significantly improve aluminum dissolution efficiency. If the ACE Separator™ can be engineered to regularly generate sufficiently high aluminum dissolution concentrations, the technology may be applicable to industrial effluent treatment trains, as well as for some Superfund site remediation activities.

Incorporation of an automated process control system based on influent conductivity and solids loading, or on the discharge solution's supernate turbidity, needs to be engineered. An automated system for addition of replacement aluminum pellets may be justified, although the frequency of pellet addition should be predictable after an initial period of operation. The capital cost for a standard ACE Separator™ with nominal throughput capacity of 50 gpm is estimated at $80,000 and for a 250-gpm unit, $300,000.

Conclusions

ACE offers a promising alternative for treating waste streams containing clays, certain metal constituents, and other soluble pollutants. As an alternative to chemical conditioning, ACE Technology agglomerates the particles without adding any extraneous soluble species (i.e., SO_4^{2-}); the sludge it produces has a lower bound-water content that will filter more rapidly and has a lower susceptibility to filter shear of the coagulated particulates and emulsion droplets.

As a result of the pilot-scale efforts, we compared the effectiveness of ACE Separator™ treatment, alum addition, and polymer coagulation. Conclusions drawn from this comparison for various contaminant parameters were:

- TSS: ACE Separator™ treatment and the polymer treatment yielded equivalent results for the reduction of TSS in the treated supernates. TSS values for alum treatment were four to five times greater than those for ACE Separator™ treatment or polymer treatment.
- COD: ACE Separator™ treatment resulted in the highest COD reductions of the three methods. Removal efficiency for COD was from two to four times higher than removal efficiency for either alum treatment or polymer treatment.
- Lead: ACE Separator™ treatment achieved approximately 66% removal of lead in the high metals runs, whereas polymer treatment showed a slightly higher removal (71%). Because some difficulties were experienced with the alum treatment, these test results were invalidated. Further ACE Separator™ treatments of slurries with low concentrations of metals yielded the highest lead removal (96%).
- Copper: Copper in the supernate achieved dramatic removal by electrocoagulation in both the high (90% reduction) and low (99% reduction) metals concentration experiments. In the former, however, polymer and alum addition achieved greater removal (approximately 100% reduction).
- Chromium: ACE Separator™ treat-ment resulted in good removal for total chromium (87% and 94% reductions for the high and low concentrations). Alum and polymer addition accomplished similar removal.
- Cadmium: Cadmium levels in the supernates dropped as a result of ACE Separator™ treatment: 14% in the high metals runs and 99% in the low metals tests. The inconsistency between these two sets of experiments, as well as the high concentrations remaining in the supernates and filtrates, raises questions about the accuracy of experimental results involving high concentrations of metals. For the low metals tests, the cadmium concentrations in both ACE Separator™ filtrates were much lower than were the concentrations for either alum or polymer treatment.

The following generalization on the effectiveness of the ACE treatment can be made:

- ACE Separator™ treatment consistently reduced the TS and TSS loadings to an equivalent degree and to approximately one-quarter the level achieved through alum addition; and
- Better reductions in soluble metal concentrations are achieved with electrocoagulation treatment than with alum treatment.

In summary, ACE offers a promising technically simple method for achieving solids-liquid separations in aqueous-based waste streams. The majority of the nontoxic, aluminum ionic species introduced will be removed in the coagulated solids phase. The ACE Technology may be particularly suitable for zero-discharge applications in which the addition of chemicals and the buildup of residual concentrations (dissolved solids) would adversely affect effluent quality or inhibit effluent reuse. Other potential applications of the ACE Separator™ include: (1) remediation of groundwater and leachates (metals, COD/BOD removal), (2) enhancement of clay separation from aqueous suspensions/emulsions resulting from soil-washing operations, (3) breakage of oil/water emulsions produced in the pumping of hydrocarbon contaminated groundwater, and (4) removal of TSS from stormwater runoff. Possible industrial applications are fine-grained product recovery (pigments, PVC) and extraction of TSS from waste streams that contribute to high BOD and COD loadings.

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Details of the completed SITE Emerging Technology project are given in a journal article published in Air and Waste, Vol. 43, No. 5, p. 784-789, May 1993. The journal article entitled "Alternating Current Electrocoagulation for Superfund Site Remediation," (Order No. PB93-205 144; Cost: $12.50, subject to change) is also available from:

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Subject: Alum (Aluminum Sulfate) - Chemical Composition

Bert,

As discussed, the active aluminum ion (Al^{+3}) in alum makes up only about 16% of a typical alum molecule. The balance of alum is the sulfate compound which does not precipitate out of the water being treated and adds greatly to additional TDS in the finished treated water which can create discharge water quality issues.

If using sacrificial aluminum plates in our ElectroCoagulation system, only the active Al^{+3} aluminum ion is dissolved into the water, which then acts as a seed for precipitation of suspended solids (TSS) and dissolved contaminants such as phosphorous and nitrogen. The Al^{+3} ion coagulates and flocculates with the TSS and other precipitated compounds and is removed from the EC treated water in the clarification/filtration processes. If using solid iron (mild steel) sacrificial plates, only the $Fe^{+2/+3}$ ions are dissolved into the water and are, likewise, removed from the treated water in the filtration process. There are no additional iron salts introduced into the treated water as with Ferric chloride or Ferric sulfate, both of which typically create higher TDS in the finished water than was in the raw untreated source water.

Below is the percentage breakdown for alum, Aluminum Sulfate, for your reference.

			element in	weight	percentage
Aluminum Sulfate Al2(SO4)3	342.2	g/mole		342.14	100.00%
Aluminum Al	26.98	g/mole	2	53.96	15.77%
Sulfate	32.06	g/mole	3	96.18	28.11%
Oxygen O	16	g/mole	12	192	56.12%

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PRETREATMENT CAPABILITIES AND BENEFITS OF ELECTROCOAGULATION

Michael Mickley

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Boulder, Colorado

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14. ABSTRACT

Bench-scale testing of a commercially available electrocoagulation (EC) technology evaluated the potential of EC for use as pretreatment for membrane systems. Removal capabilities for several contaminants, including oil-water emulsions, silt, silica, arsenic, 14 different metals, pesticides and radionuclides, were examined. The fouling of a polysulfone ultrafiltration membrane by various suspended solids was documented along with the capability of EC removal of these foulants. The most cost-effective application of EC was determined to be as pretreatment to multi-membrane systems such as UF/RO or MF/RO. The potential pretreatment benefits of EC include improved flux of the multi-membrane system, reduced cleaning frequencies, and extension of the applications of the system to high suspended solids waters. Pilot demonstration of the EC/UF/RO processing sequence is recommended.

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The research facilities and staff support of The SeaCrest Group were important in the smooth unfolding and execution of the project.

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CHAPTER 1.

EXECUTIVE SUMMARY

1.0 SUMMARY

The goals of the research project were 1) to demonstrate the removal capabilities of the electrocoagulation (EC) technology and 2) to define the best application of the technology within the context of providing pretreatment to reverse osmosis systems.

EC is the application of electrical potential across electrodes placed in a moving solution to be treated. Above a characteristic voltage dependent on the electrode material, some of the electrode will dissolve (become ionized) in solution. In this way, and only this way, EC resembles chemical coagulation - in that iron or aluminum ions, for instance, may be introduced into the solution to be treated. The EC process goes beyond chemical coagulation in that electrical current moves through the solution and promotes several other mechanisms that influence removal of species from solution. This includes the destabilization of colloids and oxidation-reduction reactions to name just two.

Although EC equipment has been available for several years and significant removal capabilities have been reported, only recently have design improvements made cost-effective and larger volume treatment possible. The application of EC as pretreatment to membrane processes has not been reported in the literature and only one example (EC in front of RO at a car wash) has been identified. The research undertaken was of an applied nature using bench-scale equipment of a commercially available technology.

The research focused on testing an EC device on both mock and real waters over a wide range of contaminants to be removed. The test variables included EC operational parameters as well as solution / water quality variables. Over 100 separate EC runs were made. Early runs involved a lengthy protocol to characterize and document the treatment and its effects. These runs focused on the removal of suspended solids as this was known to be a cost-effective application of EC. Further, the removal of suspended solids was easily and inexpensively characterized through the measurement of turbidity. This allowed for rapid indication of test results and thus a time-efficient approach to study system variables and to refine test protocols. Protocols were later refined and simplified as understanding of the importance and interaction of variables developed.

Over the course of the research, the suspended solids studied included:

- Oil/water emulsions
- Humic acid / tannic acid mixtures
- Latex paint
- Hydrocarbon condensate from a coal-cleaning operation

Although there was no attempt to optimize removal levels, removal efficiencies measured in terms of turbidity were consistently over 99 percent over the entire range of operational and test solution variables.

Later experimental runs studied the removal of metals and semi-metals from solutions. The elements (in solution in ion or complex form) included:

- Al, Ag, As, Ba, Ca, Cd, Cr, Cs, Fe, I, Mg, Na, Si, Sr, and Zn.

Other compounds studied included:

- Nitrate
- Phosphate
- Perchlorate
- DDT
- Chlorpyrifos
- Lindane
- Malathion

The level of removal of these ions and compounds varied considerably. Some ions were removed at high levels regardless of the background solution chemical matrix and operating conditions (Ag, Cd, Cr, Zn, for example) while others varied either dependent on background matrix, operation conditions, or both.

Examination of the literature showed instances of high removal of most of the ions and compounds studied. Clearly, the removal of many items depends on the specific removal situation.

Amperage appears to be the key electrical characteristic necessary for removal. In some systems a threshold of amperage was necessary before any significant removal was attained.

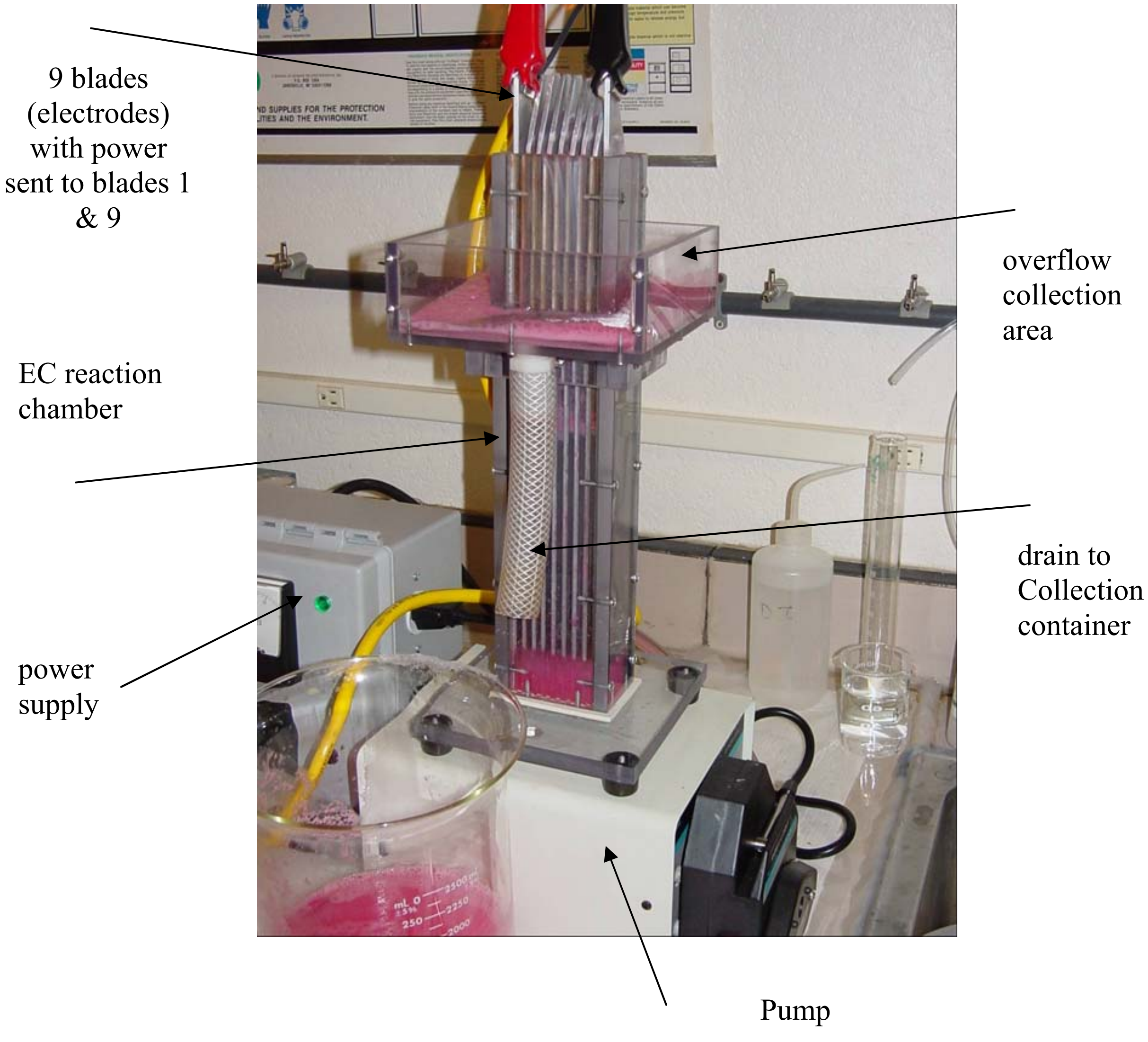
The effective of salinity was minor on removal levels but major on the power required to accomplish the removal. The higher conductivity (lower resistance) of higher salinity solutions allowed a given amperage level to be reached at much lower voltage and thus a lower power.

An emerging trend in membrane technology applications is the use of low-pressure membranes (ultrafiltration and microfiltration) as pretreatment to reverse osmosis units. The low pressure membranes provide a barrier that offers better and more general protection of the reverse osmosis membrane than conventional pretreatment schemes. The low pressure membranes, however, are still susceptible to their own fouling and performance reduction – particularly for treatment of high suspended solids feeds and especially where these feeds have an organic nature.

Due to the excellent EC removal of suspended solids and the simplicity of the EC operation the most promising application of EC in a membrane system was found to be as pretreatment to a multi-membrane system of UF / RO or MF / RO. In this function the EC provides protection of using a simple dead-end flow cell. These studies helped to define the effect of EC on membrane system flux.

3.2.1 Bench-scale EC Test Unit

Due to the many varying parameters and number of tests that were conducted, it was both convenient and necessary to use a small bench-scale EC system. The tests used a 1.0 lpm EC unit manufactured by Powell Water Systems. The test unit is pictured below.



The Power Water System’s 110V bench-scale demonstration EC unit consists of power supply, peristaltic pump, reaction chamber, metal blades sets (iron and aluminum), and supplies.

AC power was transformed to DC power and transmitted from the power supply to the EC electrodes (blades) by cable. Most typically power was connected to the 2 outer blades as shown in the picture. Alternatives to this are discussed below in the power section. At the start of a test run, test solution is pumped into the bottom of the reaction chamber prior to sending

R71	Mg	8	Si	874	8 amp; neutral pH	8	39	8	312	8.65	93	10	**89.25**
R72	Mg	8	Si	874	15 amp; neutral pH	8	70	15	1050	8.65	93	2	**97.85**
R73	Fe	8	Si	874	8 amp; neutral pH	8	43	8	344	8.65	93	3.7	**96.02**
R74	Fe	8	Si	874	15 amp; neutral pH	8	76	15	1140	8.65	93	0.48	**99.48**
R75	Mg	12	Si	1,120	8 amp	8	40	8	320	7	66	3.9	**94.09**
R76	Mg	12	Si	1,120	15 amp	8	76	15	1140	7	66	2.9	**95.61**
R77	Fe	12	Si	1,120	8 amp	8	45	8	360	7	66	9.8	**85.15**
R78	Fe	12	Si	1,120	15 amp	8	80	15	1200	7	66	0.44	**99.33**
R84	Fe	8	Si	874	8 amp; 1 pass	8	40	8	320	7.06	84	10	**88.10**
R85	Fe	8	Si	874	8 amp; 2nd pass	8	34	8	272	7.05	84	0.51	**99.39**
R86	Fe	8	Si	874	15 amp; 1 pass	8	73	15	1095	7.05	84	0.38	**99.55**
R87	Fe	8	Si	874	15 amp; 2nd pass	8	53	15	795	7.05	84	0.13	**99.85**
R88	Mg	8	Si	874	8 amp; 1 pass	8	36	8	288	7.05	84	9.3	**88.93**
R89	Mg	8	Si	874	8 amp; 2nd pass	8	30	8	240	7.05	84	1.7	**97.98**

ALUMINUM & RESIDENCE TIME

RUN #	Blades	Base Solution	Contaminate	Feed TDS	Other Contaminants Special Conditions	Pump Setting	Nominal Voltage	Nominal Amperage	Nominal Power	pH PRE	Conc. PRE	Conc. POST	% REMOVAL
R79	Fe	8	Al	874	4 amp; low flow	4	20	4	80	7	0.41	0.093	**77.32**
R80	Fe	8	Al	874	6 amp; medium flow	6	32	6	192	7	0.41	<0.05	**>87.80**
R81	Fe	8	Al	874	8 amp; low flow	4	40	8	320	7	0.41	0.33	**19.51**
R82	Fe	8	Al	874	8 amp; high flow	8	45	8	360	7	0.41	0.16	**60.98**
R83	Fe	8	Al	874	4 amp; high flow	4	23	4	92	7	0.41	0.096	**76.59**

PERCHLORATE, PHOSPHATE, & NITRATE

RUN #	Blades	Base Solution	Contaminate	Feed TDS	Other Contaminants Special Conditions	Pump Setting	Nominal Voltage	Nominal Amperage	Nominal Power	pH PRE	Conc. PRE	Conc. POST	% REMOVAL
R94	Fe	8	ClO4	874	8 amp	8	50	8	400	7.04	23.7	19.6	**17.30**
R94	Fe	8	PO4	874	8 amp	8	50	8	400	7.04	5.21	<0.20	**>96.16**
R94	Fe	8	NO3	874	8 amp	8	50	8	400	7.04	6.07	5.66	**6.75**
R95	Fe	8	ClO4	874	15 amp	8	89	15	1335	7.04	23.7	21.1	**10.97**
R95	Fe	8	PO4	874	15 amp	8	89	15	1335	7.04	5.21	<0.20	**>96.16**
R95	Fe	8	NO3	874	15 amp	8	89	15	1335	7.04	6.07	5.98	**1.48**

HYDROCARBON CONDENSATE

RUN #	Blades	Base Solution	Contaminate	Feed TDS	Other Contaminants Special Conditions	Pump Setting	Nominal Voltage	Nominal Amperage	Nominal Power	pH PRE	Conc. PRE (NTU)	Conc. POST	% REMOVAL
R96	Al	real water	carbon particulates		nonvisible sign of coagulation	4	100	0.5	50	6	610	---	**---**
R97	Al	real water	carbon particulates		minor coagulation	4	100	3.5	350	6	610	---	**---**
R98	Al	real water	carbon particulates		visible settling after treatment	4	95	8.5	807.5	6	610	---	**---**
R99	Al	real water	carbon particulates		good settling / separation	4	92	12.5	1150	6	610	0.38	**99.94**
R100	Al	real water	carbon particulates		good settling / separation	4	92	17.5	1610	4	610	---	**---**
R101	Al	real water	carbon particulates		good settling / separation	4	98	7	686	4	610	0.28	**99.95**
R102	Al	real water	carbon particulates		good settling / separation	4	100	2	200	5	610	1.84	**99.70**

PESTICIDES*

RUN #	Blades	Base Solution	Contaminate	Feed TDS	Other Contaminants Special Conditions	Pump Setting	Nominal Voltage	Nominal Amperage	Nominal Power	pH PRE	Conc. PRE	Conc. POST	% REMOVAL
R103		DI water	DDT	---	0.5 amp	5	---	0.5	---	7	0.016	0.0026	**83.75**

Strontium	R46	8	15	91.5
Cesium	R43	6	1	13.3
Cesium	R44	6	15	13.3
Cesium	R45	8	1	13.3
Cesium	R46	8	15	13.3
Iodine	R43	6	1	----
Iodine	R44	6	15	8.3
Iodine	R45	8	1	8.3
Iodine	R46	8	15	>91.7

Strontium was removed at relatively high levels (>73%) in all runs. Cesium had a low (13.3%) removal in all runs and the removal of iodine was low except for the higher pH and higher amperage run where it rose significantly to >91.7.

Table 4.4 provides a summary table for the metals removals attained in different studies.

4.1.6 Perchlorate, Phosphate, and Nitrate Removal

All of these contaminants were put in one solution and runs were made at an amperage of 8 (R94) and an amperage of 15 (R95). It is interesting to note that the higher amperage did not improve removal levels. Only phosphate was removed at a high level (>96.16% in both runs). Perchlorate removal was 17.3% and 11.0% for the two runs. Nitrate removal was even less at 6.8% and 1.5% for the two runs.

4.1.7 Pesticide Removal

These runs (R103 to R105) were made by an affiliate of Power Water Systems. The four pesticides, DDT, Chlorpyrifos, Lindane, and Malathion were all present in DI water in the same feed sample. Three different amperages were studied: 0.5, 1, and 2.5. The feed levels of the contaminants ranged from 16 to 81 ppb. The following table shows removal levels attained at the different amperages.

Pesticide	**0.5 amps**	**1.0 amps**	**2.5 amps**
DDT	83.8	86.9	98.1
Chlorpyrifos	30.0	32.5	90.5
Lindane	46.8	49.4	99.0
Malathion	95.9	37.0	>99.0

Either the 95.9% removal of Malathion at 0.5 amp or the 37% removal at 1.0 amp is likely incorrect. Except for this one glitch, removals increase with increasing amperage.

4.1.8 Other Organics and Biologicals

Several challenges arose during considerations of conducting studies on various organic and biological contaminants. First, the study of organics at low levels of concentration meant that, typically, GC-MS analysis was required. For an EC study with multiple runs, this becomes quite

Excerpt from Office of Naval Research
Report by:
Dr. Michael Mickley PhD
Dec. 2004

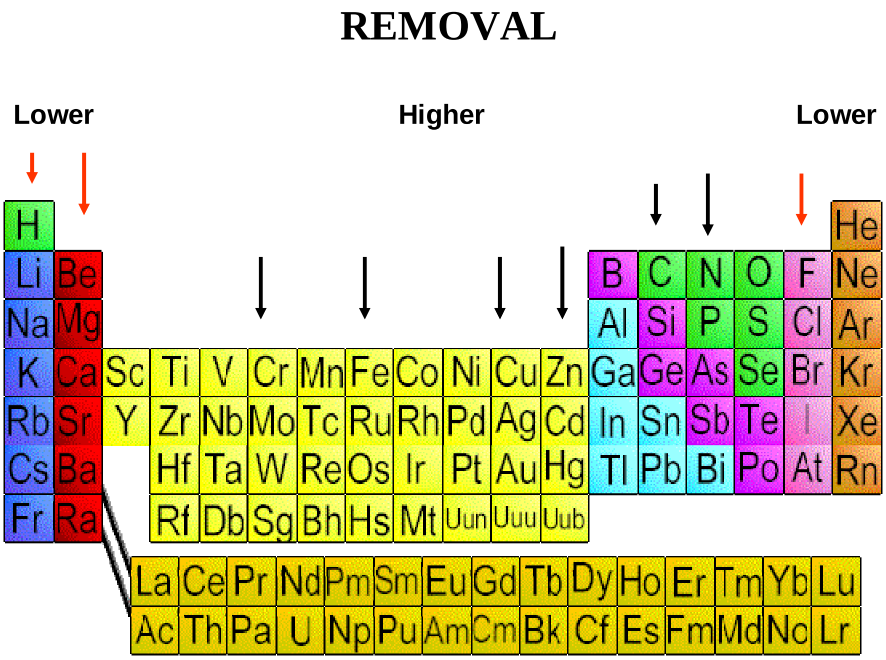


Figure 5.1 Correlation of Removal Levels with Periodic Chart Position

- Amperage – when low amperage did not give significant removal, typically increased amperage helped
- 2nd pass – removal levels increased with running the EC treated solution through the system in a 2nd pass
- pH of feed – in several instances changing of pH had an effect on removal levels
- pH of treated solution – except for high pH feeds, pH increased with EC treatment
- salinity on removal – no direct effect was observed

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August 7, 2010

Dear Mr. Hamilton,

The purpose of this letter is to inform you of the results we have recently obtained from our tests of the Powell Water Systems Electrocoagulation unit for removal of biological pathogens and indicators from sewage.

We performed a trial using a single sample of raw sewage obtained from a municipal wastewater treatment facility in southwest Florida. Samples were tested to determine the abundance of two types of bacteria and four types of viruses before and after treatment with the electrocoagulation unit. The electrocoagulation process resulted in significant decreases in the concentration of all microorganisms tested, and in several cases reduced the concentration of the pathogens to below the detection limits of our assays. Electrocoagulation led to an approximately 4 log reduction in the concentrations of both fecal coliforms and Enterococci (approximately 99.999% decrease). Concentrations of phages (viruses that infect bacteria) infectious for *Eschericia coli* and *Bacillus subtilis* decreased from several thousand plaque forming units (pfu) per milliliter to less than one pful per milliliter. In addition, concentrations of human polyomaviruses were reduced from approximately 10,000 copies per milliliter to below assay detection limits, demonstrating that electrocoagulation removed human pathogenic viruses.

In addition, we determined the efficiency of electrocoagulation for removing *Pepper mild mottle virus* (PMMoV), which is a plant pathogen that has recently been found at extremely high concentrations in human sewage. PMMoV was found in the raw sewage at approximately 60,000 copies per milliliter and electrocoagulation reduced the PMMoV concentrations to below detection limits. This is extremely encouraging since we typically see PMMoV concentrations in excess of 10,000 copies per milliliter in final effluent from most commercial treatment plants.

My laboratory has spent several years studying the types of viruses and bacteria present in raw sewage and treated wastewater, with the goals of identifying pathogens that present a risk to public health as well as effective indicators that can be used for water quality testing. In our preliminary experiment, the Powell Electrocoagulation unit reduced all the tested biological agents (including both bacteria and viruses) with greater efficacy than current wastewater treatment practices.

Thank you for facilitating this trial, and I hope that we can continue to work together in the future to further evaluate this very promising treatment process.

Sincerely,

Dr. Mya Breitbart

water

MDPI

Article

Removal of Six Estrogenic Endocrine-Disrupting Compounds (EDCs) from Municipal Wastewater Using Aluminum Electrocoagulation

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Abstract: Conventional wastewater treatment plant (WWTP) processes are primarily designed to reduce the amount of organic matter, pathogens, and nutrients from the incoming influent. However, these processes are not as effective in reducing the concentrations of micropollutants, including endocrine-disrupting compounds (EDCs), which notoriously evade traditional wastewater treatment technologies and are found even in tertiary-treated effluent. For WWTPs practicing deep-well injection or surface-water discharge, EDCs in the treated effluent are discharged into groundwater or the aquatic environment where humans and wildlife may potentially suffer the effects of chemical exposure. In the current laboratory-scale study, we tested a bench-top electrocoagulation (EC) unit utilizing aluminum blades for the removal of six estrogenic EDCs [estrone (E1), 17β-estradiol (E2), estriol (E3), 17α-ethinylestradiol (EE2), bisphenol-A (BPA), and nonylphenol (NP)]. Samples of municipal wastewater influent and tertiary-treated effluent were spiked with the six EDCs in order to test the removal efficiency of the EC unit. The mean concentration of each EDC component was statistically lower after EC treatment (removal range = 42%–98%). To our knowledge, this is the first study to investigate aluminum electrocoagulation for removal of these specific EDCs, including nonylphenol (without the ethoxylate chain), as well as natural and synthetic estrogens.

Keywords: micropollutant; endocrine disruption; chemical contaminants; pharmaceutical; water treatment; wastewater; estrogen; electrocoagulation

1. Introduction

Micropollutants are chemical contaminants found in the aquatic environment in the μg/L (ppb) or ng/L (ppt) concentration range that are considered to be potential threats to environmental ecosystems [1,2]. Both domestic and industrial wastewaters contain micropollutants, which are not entirely removed by conventional wastewater treatment plant (WWTP) processes and are, therefore, continually discharged into the aquatic environment [3]. The origin of micropollutant contamination is predominantly anthropogenic and the aquatic environment becomes the final resting place for the majority of these chemical compounds [4,5].

Endocrine-disrupting compounds (EDCs) are an important class of micropollutants that are defined as exogenous chemicals, or mixtures of chemicals, that can interfere with any aspect of hormone action [6]. EDCs are a particularly troublesome subset of micropollutants, due to their diverse nature, persistence in the environment, and ability to cause metabolic and reproductive disturbances at very low concentrations. EDCs can enter the aquatic environment directly (e.g., through effluent discharge) or indirectly (e.g., storm-water runoff), but the major transport of EDCs to the aquatic environment is through treated and untreated municipal wastewater discharge to rivers, streams, and surface waters [1,7,8]. Potable water resources, including both surface water and groundwater, can become contaminated through surface-water discharge or deep-well injection of WWTP effluent [4]. Effects of EDCs on wildlife (invertebrates, fish, amphibians, reptiles, birds, and mammals) include: abnormal blood hormone levels, altered gonadal development (e.g., imposex and intersex), induction of vitellogenin gene and protein expression in juveniles and males, masculinization/feminization, hermaphroditism, and decreased fertility and fecundity [9–12].

Estrogenic EDCs specifically target estrogen signaling. These include natural steroidal estrogens, synthetic estrogens, and industrial compounds which mimic estrogen. 17β-estradiol (E2) is the primary natural estrogen and has the greatest potency. Estrone (E1), a metabolite of E2, is a slightly weaker estrogen. Estriol (E3), considered to be the final metabolite, is the weakest natural estrogen, with only 10% of E2's potency. 17α-ethinylestradiol (EE2) is the synthetic steroidal estrogen component of contraceptives [13]. The overall estrogenicity of EE2 in effluent overshadows that of both E1 and E2 combined, due to its high estrogenic potency [14]. Bisphenol-A (BPA) is a monomer used in industry to produce lacquers, food-can liners, and thermal paper [15]. It has high water solubility and enters WWTPs through industrial discharges and leaching from BPA-based products. Nonylphenol (NP) is the persistent and estrogenic final product of the biodegradation of the non-ionic surfactant nonylphenol ethoxylate (NPEO) [16].

Conventional WWTP processes are designed primarily for the removal of organic matter, nitrogen, phosphorus, and pathogens; therefore, it is not surprising that the effluent from conventional WWTPs still contains EDCs at levels ranging from a few ng/L to several μg/L, which are sufficient to cause endocrine disruption in some species [17]. The concentrations of EDCs in WWTP influent vary according to geographic location and population served, while the level of EDC removal during treatment varies according to the WWTP processes employed [18,19]. Monitoring studies have demonstrated that some wastewater treatment processes are more effective than others for reducing EDCs and ultimately a combination of approaches may be necessary to reduce this diverse class of micropollutants. This manuscript focuses solely on the potential of electrocoagulation (EC) for EDC removal in municipal wastewater, since the efficacy of various WWTP processes (e.g., biological treatment with activated sludge, activated carbon treatment, nanofiltration, reverse osmosis, ozonation, and advanced oxidative processes) for reducing EDC concentrations has been reviewed extensively [20–22].

Electrocoagulation technology reduces contaminant levels by passing an electrical current through water, which generates coagulant precursors by electrolytic oxidation of sacrificial anode material—usually aluminum or iron. During the EC process, amorphous insoluble polymeric metal hydroxides and oxides are formed, which adsorb pollutants (particulate and dissolved) during precipitation, making them easily separable [23,24] (Figure 1). The most widely used electrode materials, aluminum and iron, are both inexpensive and effective against a wide range of pollutants, including soluble organic pollutants [25,26]. Patented over a century ago, EC has a long history as a water treatment technology. However, EC was abandoned by the 1930s due to high operation costs, as well as the availablilty of inexpensive chemicals for chemical coagulation treatment [27]. Recent technical and design improvements, combined with a growing need for cost-effective water treatment processes, have led to a re-evaluation of EC technology [27]; however, to our knowledge no studies have tested the efficacy of EC with aluminum blades for reducing EDCs from municipal wastewater. This study therefore sought to determine the removal efficiency of a laboratory-scale electrocoagulation unit with respect to six estrogenic endocrine-disrupting compounds in WWTP influent and tertiary-treated effluent.

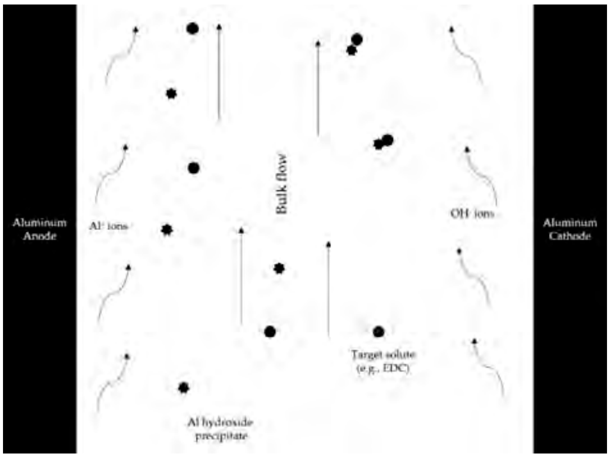


Figure 1. Representative schematic of water flow and interactions inside the reaction chamber. The two black vertical bars represent the electrodes where the power is attached, and the white in between them represents the sample solution flowing past the electrodes. Metal dissolution occurs at the anode which generates aluminum ions. Reduction reactions occur at the cathode which form hydroxide ions. The precipitation reaction occurs when the aluminum and hydroxide ions combine to form aluminum hydroxide (dark circles). The aluminum hydroxides form structures which adsorb contaminants (dark stars), enabling their removal.

2. Materials and Methods

2.1. Electrocoagulation Unit

The EC unit (Figure 2) is a 110-volt demonstration unit manufactured and supplied by Powell Water Systems, Inc. (Centennial, Colorado, USA; United States patent number 7211185 B2). The configuration used in this study has been previously examined for its ability to reduce concentrations of nutrients, personal care products, and microbial pathogens and indicators [28]. The power source is a 110-volt alternating current (AC) to direct current (DC) power converter (allowing direct line voltage to be converted from AC to DC) with voltage control. The pump is a Cole-Parmer®Masterflex Peristaltic Pump System (Vernon Hills, IL, USA) equipped with a 1/20-horsepower unidirectional motor and a separate single-turn speed control. The EC unit chamber (35.6 cm × 5.4 cm × 2.5 cm) is made of a non-conductive acrylic resin and has a total volume of 487.5 mL. Nine aluminum reaction blades (30.5 cm × 2.5 cm × 0.3 cm) were arranged vertically inside the chamber with an electrode gap of 3.18 mm. This vertical arrangement promotes a vertical flow of liquid through the chamber. The volume of one blade is 24.6 cm^3 and the volume of all nine blades equals 221.2 cm^3, leaving a residual chamber volume of 266.3 mL. The EC unit was operated with a three-lead arrangement of electrical connections (power attached to blades 1, 5 and 9; Figure 3) which results in a configuration of two anodes and one cathode. The inflow tube measures 1.2 m.

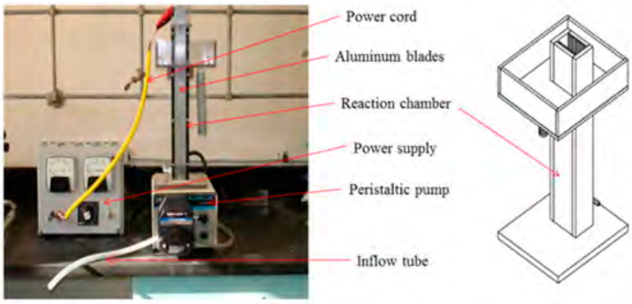


Figure 2. Schematic of laboratory-scale electrocoagulation unit.

Figure 3. Diagram and close-up picture of the nine aluminum blades showing the electrical connections to blades 1, 5, and 9. Anodes are indicated in blue by (+), cathode is indicated in red by (−), and arrows show the flow of electrons.

2.2. Preliminary Tests and Optimization of Parameters

The parameters used for this laboratory-scale study were chosen based upon a series of tests performed to evaluate EDC removal efficiency using different EC conditions and configurations (Supplementary Tables S1 and S2). The optimal parameters used for this study (Supplementary Table S3) were as follows: aluminum blades as the sacrificial electrodes, three-lead arrangement of electrical connections, sample retention time of 2 min/L in the EC reaction chamber, volts held in the range of 85 to 98, and amperes held in the range of 8.5 to 15.5. Inclusion of a precise cleaning step was important in the preliminary testing, as EDCs were found to "stick" to the walls of the unit and tubing. To ensure against cross-contamination between replicates, the EC unit was cleaned in between each run to remove any residual EDCs. The EC unit was cleaned by first removing the blades and rinsing the unit with tap water. The blades were scrubbed with steel wool in order to remove the build-up of the oxidizing layer. The scrubbed blades were then reset and the unit was flushed with 1 L ACS methanol to remove residual EDCs and 2 L deionized (DI) water to rinse the unit of residual methanol. Once the unit was cleaned, DI water laboratory blanks were passed through the unit (no power) to ensure that no EDCs remained in the unit. Polarity reversal of the electrodes was implemented between runs to help prevent the build-up of an oxidizing layer on the blade surface.

2.3. Chemical Standards

Analytical standards E1, E2, E3, EE2, BPA, NP, and 5α-androstanol (internal standard) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Methanol (HPLC grade and Certified ACS) and pyridine (Certified ACS) were purchased from Fisher Scientific (Pittsburg, PA, USA). *N*,*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) with 1% trimethylchlorosilane (TMCS) was purchased from Regis Technologies (Morton Grove, IL, USA). Ultrapure (DI) water was acquired from a US Filter PureLab Plus system.

2.4. Wastewater

Wastewater samples for the experiment were collected from South Cross Bayou Water Reclamation Facility, a tertiary treatment plant located in St. Petersburg, Florida (USA) which serves a population of approximately 260,000. The average wastewater flow per day is 20 million gallons (rated for 33 million gallons per day), and 85% of the wastewater is domestic in origin, while less than 15% is industrial in origin. South Cross Bayou's wastewater treatment processes follow the graphic in Figure 4.

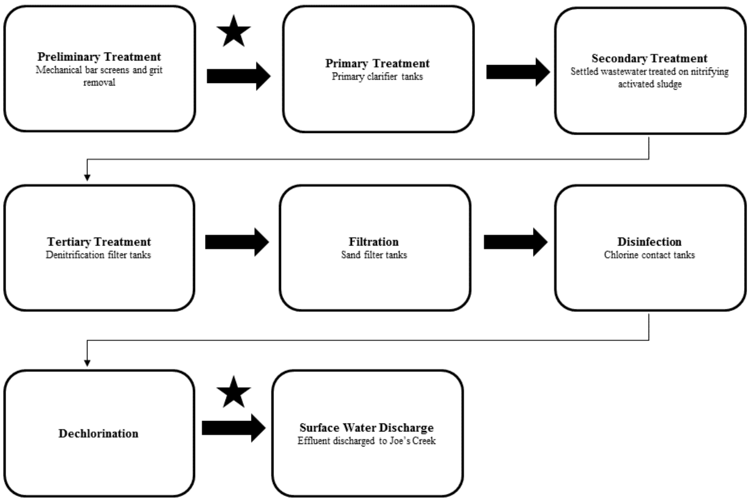


Figure 4. Illustration of the wastewater treatment processes at South Cross Bayou. Stars indicate the points of the raw influent and tertiary-treated effluent samples.

2.5. Blanks

Field blanks were taken at the sample site. Laboratory blanks (DI water spiked with internal standard) were extracted with each batch of samples. Gas chromatography-mass spectrometry (GCMS) instrument blanks (blank solvent injections) were performed every eight samples. All EDCs were undetectable in all the blank samples, including the DI water blanks that were run through the EC unit in between replicate runs, illustrating the effectiveness of the solvent cleaning step performed between runs.

2.6. Experimental Design/Electrocoagulation Processing

Both raw WWTP influent and tertiary-treated effluent were tested in this study in order to determine not only if the effectiveness of EC for reducing EDCs is matrix-dependent, but also to assess the possibility of using EC as a post-treatment addition to traditional WWTPs. Samples were collected the morning of the experiment in methanol-cleaned, 20 L high-density polyethylene carboys. Influent samples were taken at the headworks of the plant while effluent samples were collected after the dechlorination step. After sampling, the carboys were immediately transported to the lab and refrigerated at 4 °C until processing. In the lab, eight spiked-wastewater replicates (outlined below) were created. Half of the spiked-wastewater replicates (n = 4) went straight to analysis (pre-EC) and the other half (n = 4) were processed via electrocoagulation (post-EC). Due to the threat of BPA leaching from the Tygon tubing used in the experiment, BPA removal assays were conducted separately from the remaining EDCs.

Since background concentrations in the WWTP influent and effluent were too low to demonstrate significant removal potential by the EC unit, it was necessary to spike both with EDCs. High concentrations of EDC spikes were used to challenge the efficiency of the EC unit for removal. Stock standards were made up in methanol and, due to the low water solubility of steroids, were added to the pre-EC samples via methanol. Spikes were prepared for the four estrogens (estrone (E1), estradiol (E2), estriol (E3), ethinylestradiol (EE2)) at a concentration of 5 µg estrogen/250 µL methanol. Spikes were also prepared for the two industrial compounds (bisphenol-A (BPA) and nonylphenol (NP)) at a concentration of 20 µg industrial compound/250 µL methanol. Due to their relatively higher concentrations in wastewater, NP and BPA were added at higher levels than the estrogens. Three liters of WWTP influent were spiked with the estrogens and nonylphenol after being filtered through a 1.5 µm pore size, glass microfiber filter (Whatman 934-AH; Fisher Scientific, Pittsburgh, PA, USA). This resulted in a final concentration of 1.7 ppb for the estrogens in wastewater and 6.7 ppb for the industrial compounds in wastewater. Similarly, 3 L of WWTP effluent were spiked with the aforementioned EDCs.

In order to test the removal efficiency of the EC unit, 3 L of spiked WWTP influent ($n = 4$) and effluent ($n = 4$) were separately processed through the EC unit via a recirculation method, where the original sample was passed through the unit, discharged from the unit and then circulated back through the unit. The pump speed was set at eight which corresponded to a retention time of 2 min/L. The voltage fluctuated between 85 and 98 and the ampere readings fluctuated between 9 and 15.5 during EC treatment. Once the sample was collected from the EC unit, it was allowed to sit while coagulation began. After approximately 20 minutes, the EC-treated sample was filtered through two Whatman Grade 1 filters (pore size 11 μm) in order to separate the flocculent (sludge phase) from the treated water (aqueous phase). The final volume captured for analysis was 1 L.

For the BPA experiment, 3 L of WWTP influent ($n = 4$) and effluent ($n = 4$) were spiked with BPA and processed through the EC unit via a one-time flow-through method where the sample would not retouch the Tygon inflow tube (manufactured with BPA). Since the temperature of the EC effluent could get as hot as 69 °C, a one-time flow-through method was essential in order to prevent BPA leaching from the Tygon inflow tube. The pump speed was set at 2.2 which still corresponded to a retention time of 2 min/L. The voltage fluctuated between 94 and 98 and the ampere readings fluctuated between 8.5 and 14.5. The post-EC samples were collected as previously described after the flocculent was separated from the treated water.

2.7. Solid Phase Extraction

In order to determine the concentration of EDCs, the pre-EC and post-EC 1 L samples were processed via solid phase extraction (SPE) within 24 hours and subsequently analyzed via GCMS. An Evolute ABN (Acid, Base, Neutral) column (6 mL/200 mg, Biotage; Charlotte, NC, USA) was conditioned with methanol and equilibrated with DI water. The sample was then loaded onto the column at a flow rate of 15 mL/min using a large volume extraction tank (Biotage, USA) and an SPE vacuum pump. EDCs retained in the column matrix were eluted with 6 mL methanol. The eluate was spiked with 5 μg internal standard and evaporated to dryness under a gentle stream of nitrogen. Recoveries of all compounds were documented and accounted for in the final quantification.

2.8. Determination of EDC Concentrations

Samples were derivatized to their trimethylsilyl ethers by adding 250 μL of BSTFA + 1% TMCS and 250 μL of pyridine, followed by heating in a 60 °C water bath for 40 min in order to drive the derivatization reaction to completion. Samples were then transferred to a 2 mL vial via low volume insert for analysis by GCMS. The GCMS system (Bruker; Fremont, CA, USA) consisted of a Varian 3800 gas chromatograph coupled with a Varian 320 mass spectrometer. The GCMS was equipped with a 30 m × 0.25 mm (internal diameter) ZB-5MS (Phenomenex; Torrance, CA, USA) fused silica capillary column coated with a 5% phenyl arylene/95% dimethylpolysiloxane stationary phase (film thickness 0.25 μm). Helium (high purity) was used as the carrier gas at a flow rate of 1 mL/min. The GC oven temperature was programmed to begin at 150 °C with an initial hold time of 2 min, followed by a temperature ramp of 6 °C/min until reaching 310 °C. The final hold time was 6 min for a total run time of 35 min. The MS was operated in selected ion monitoring (SIM) mode for quantitative analysis using electron impact (EI) ionization at 70 electron volts (eV). The dwell time per atomic mass unit (amu) was 0.5 seconds, and the quantitative and confirmatory ion fragments are outlined in Table 1. Method detection limits (MDLs) were based on standard deviate protocol and were evaluated using GCMS at a signal-to-noise ratio between 5 and 10. Nine replicates were spiked near the detection limit (S/N between 5 and 10) and carried through the entire analytical procedure. Based upon the variability of the replicates, the MDL for each compound was calculated as the standard deviation multiplied by the t-value for nine observations (eight degrees of freedom; t-value = 2.896). MDLs were in the range of 1 to 3 ng/L (Table 1).

Table 1. Characteristics of estrogenic endocrine-disrupting compounds and internal standard.

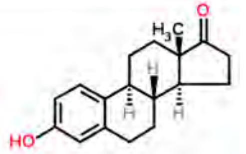
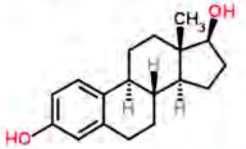
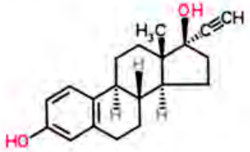
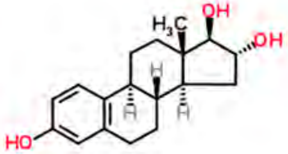
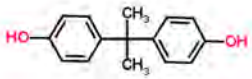
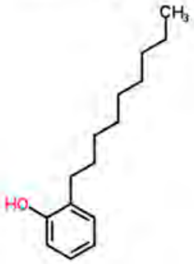
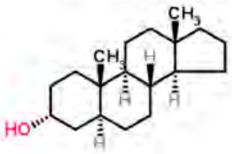
Compound	Type	Retention Time (min)	Quantitative Ion	Confirmatory Ion(s)	Method Detection Limit (ng/L)	Structure
Estrone (E1)	Natural estrogen	21.9	342	218, 257	2	
17β-Estradiol (E2)	Principal natural estrogen	22.4	416	129, 285	1	
17α-Ethinylestradiol (EE2)	Synthetic estrogen	23.8	425	440	1	
Estriol (E3)	Natural estrogen	24.8	504	386	3	

Table 1. *Cont.*

Compound	Type	Retention Time (min)	Quantitative Ion	Confirmatory Ion(s)	Method Detection Limit (ng/L)	Structure
Bisphenol-A (BPA)	Industrial estrogen mimic	16.2	357	358, 372	1	
Nonylphenol (NP)	Industrial estrogen mimic	11.8	179	180, 292	2	
5α-androstanol	Internal standard	18.0	333	258	N/A	

2.9. Statistical Analysis

SAS version 9.4 (SAS Institute Inc.; Cary, NC, USA) was used for statistical analysis of data retrieved from GCMS analysis. All values are reported as mean ± SD. MANOVA was run with four groups (raw influent not treated, raw influent EC-treated, effluent not treated, and effluent EC-treated) with the 6 quantitative variables (E1, E2, EE2, E3, BPA, and NP) using Pillai's Trace statistic. If the MANOVA results showed statistical significance, then *post hoc* testing was run between the raw influent groups (not treated and EC-treated) and between the effluent groups (not treated and EC-treated) for each EDC.

3. Results and Discussion

3.1. Removal of EDCs from Spiked-WWTP Influent by EC

The mean removal achieved for each of the six EDCs from spiked-WWTP raw influent samples is illustrated in Figures 5 and 6. The mean removal efficiency ranged from 56% (estriol, E3) to 81% (nonylphenol, NP). Furthermore, each EDC post-EC had a statistically lower mean concentration than pre-EC (Table 2) obtained from the post hoc test of the statistically significant MANOVA result. NP was removed to the greatest extent (81% removal). Other studies [29,30] have investigated the removal of nonylphenol ethoxylates (NPEOs), but to our knowledge this is the first study to test the removal of the estrogenic breakdown product, NP, by electrocoagulation.

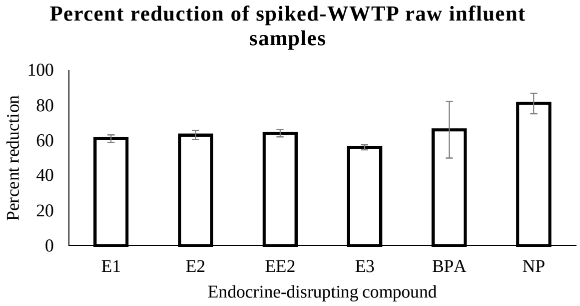


Figure 5. Percent reduction of endocrine-disrupting compounds from spiked-WWTP raw influent samples after electrocoagulation treatment. Error bars are mean +/- standard deviation.

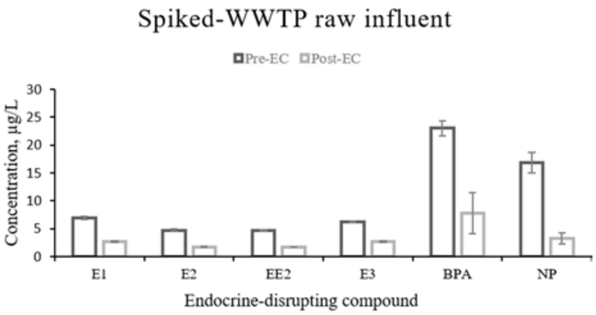


Figure 6. Mean concentrations plus or minus the standard deviation of six endocrine-disrupting compounds in spiked raw influent samples before and after electrocoagulation.

A significant finding was the 64% removal of EE2, which is important for two reasons: (1) this synthetic component of contraceptive products exhibits potent estrogenicity in the environment, with evidence of endocrine disruption at levels around 1 ng/L [10]; and (2) the removal of EE2 by other treatment processes has been historically problematic due to the recalcitrant nature of this compound [14].

Table 2. Percent removal of endocrine-disrupting compounds from spiked-WWTP raw influent samples.

EDC	Mean Pre-EC Conc ± SD (µg/L)	Mean Post-EC Conc ± SD (µg/L)	Test Statistic	*p* Value	% Removal
E1	7 ± 0.3	3 ± 0.1	F = 1194.45	<0.0001	61
E2	5 ± 0.2	2 ± 0.1	F = 954.56	<0.0001	63
EE2	5 ± 0.1	2 ± 0.1	F = 2079.79	<0.0001	64
E3	6 ± 0.2	3 ± 0.1	F = 1021.31	<0.0001	56
BPA	23 ± 1	8 ± 4	F = 85.15	<0.0001	66
NP	17 ± 2	3 ± 1	F = 133.28	<0.0001	81

E3 was removed to a lesser extent (56%) than any of the other compounds, which could be explained by its physico-chemical properties and its lower affinity for sorption onto organic solids. The octanol-water partition coefficient (K_{ow}) describes the partitioning behavior of a compound between water and organic phases. The higher the K_{ow}, the more hydrophobic the compound and the more likely it is to be removed from solution. Most EDCs are hydrophobic compounds with similar log K_{ow} values (e.g., log K_{ow} values of 3.5–4). Since these hydrophobic compounds readily adsorb onto sludge solids, sorption plays an important role in their removal from the aqueous phase [31]. However E3, with its three hydroxyl groups, is only weakly hydrophobic (log K_{ow} = 2.45–2.81) and is, therefore, less apt to bind to sludge [32]. Due to this, E3 likely does not have the same affinity for the flocculent produced during EC treatment. With more E3 in the aqueous phase (*i.e.*, not bound to the EC flocculent), more of it withstands filtration and passes into the EC-treated water sample.

BPA concentrations were reduced by 66%, which is important since BPA is one of the most highly produced chemicals in the world. BPA enters the WWTP at levels in the low ug/L range (concentration can be greatly increased if industrial discharges contribute to WWTP influent). Our findings support those of Govindaraj, *et al.* [33] who achieved 65% removal of BPA from aqueous solutions using aluminum electrocoagulation. Compared with NP, BPA is a more polar compound which explains its lower levels of removal. BPA does not tend to adsorb to sludge particles/sediment as much as NP.

Estrone and estradiol had similar removal levels at 61% and 63%, respectively. Of the natural estrogens, E2 has the greatest potency yet E1 still retains high estrogenicity. For this reason, it is important that both of these natural estrogens are reduced to a significant extent at the level of the WWTP. Since E1 retains estrogenicity and the amount of E1 discharged from WWTPs is more than ten times greater than that of E2, it has been suggested that E1 is the most important natural EDC [3].

3.2. Removal of EDCs from Spiked-WWTP Tertiary-Treated Effluent by EC

The mean removal achieved for each of the six EDCs from tertiary-treated effluent samples is illustrated in Figures 7 and 8. The removal efficiency ranged from 42% (BPA) to 98% (NP), and again each EDC post-EC had a statistically lower mean concentration than pre-EC (Table 3) obtained from the *post hoc* test of the statistically significant MANOVA result.

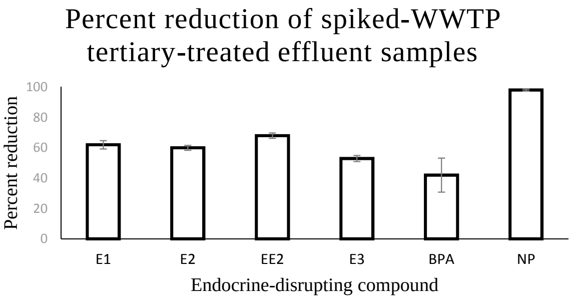


Figure 7. Percent reduction of endocrine-disrupting compounds from spiked-WWTP tertiary-treated effluent samples after electrocoagulation treatment. Error bars are mean +/- standard deviation.

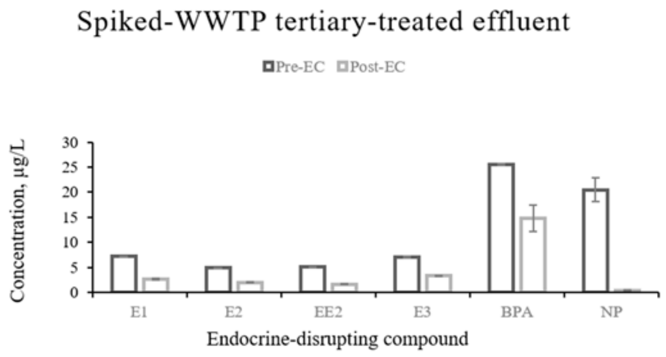


Figure 8. Mean concentrations plus or minus the standard deviation of six endocrine-disrupting compounds in spiked tertiary-treated effluent samples before and after electrocoagulation.

Table 3. Percent removal of endocrine-disrupting compounds from spiked-WWTP tertiary-treated effluent samples.

EDC	Mean Pre-EC Conc ± SD (μg/L)	Mean Post-EC Conc ± SD (μg/L)	Test Statistic	*p* Value	% Removal
E1	7 ± 0.1	3 ± 0.2	F = 1125.53	<0.0001	62
E2	5 ± 0.1	2 ± 0.1	F = 803.89	<0.0001	60
EE2	5 ± 0.1	2 ± 0.1	F = 2304.72	<0.0001	68
E3	7 ± 0.2	3 ± 0.1	F = 984.47	<0.0001	53
BPA	26 ± 0.2	15 ± 3	F = 36.01	<0.0001	42
NP	21 ± 2	0.4 ± 0.1	F = 250.89	<0.0001	98

Higher levels of removal were achieved for NP (98%) in the effluent than in the raw influent samples. However, even with 98% removal, the amount of NP in the final treated sample may still retain estrogenicity. This will be an important question in future testing of EC at environmentally-relevant concentrations. The amount of NP in our post-EC sample, 367 ng, may still be high enough to cause endocrine disruption due to the high initial spike. However, if 98% removal is still achieved at environmentally-relevant concentrations, it will be important to determine if the post-EC concentration is estrogenic or not. *In vitro* bioassays have the advantage of screening for estrogenicity without *a priori* knowledge of the pollutant present, and this will be a useful tool in future EC testing.

EE2 was removed to a high extent (68%) which again is important considering the potent estrogenicity of this compound in the environment as well as its recalcitrant behavior concerning most treatment processes. Estriol was reduced by 53% which is comparable to the raw influent. A lower removal was seen with BPA (42%) than in the raw influent samples. Estrone and estradiol were similarly removed (62% and 60%, respectively) as in the raw influent samples. Since the combination of E1 and E2 contribute largely to the estrogenicity of a sample, their removal is of considerable importance in water treatment processes.

3.3. Implementation Considerations and Concluding Remarks

A detailed comparison of the EDC removal results obtained using EC with typical removal levels achieved using other existing technologies has been presented in Cook *et al.* [34]. While it is clear that additional technologies are needed to reduce micropollutant concentrations, the decision to implement EC treatment requires a cost-benefit analysis, with the main costs of EC being energy consumption [35] and consumable blade materials. EC utilizes fairly simple equipment and can be easily integrated into existing WWTPs without extensive reorganization of the plant's structure and design. The lack of moving parts reduces the required maintenance [23], and the unit can be inserted into any point in the WWTP process, since the effectiveness of EC for reducing EDCs in this study did not depend on the matrix (water) type. For WWTPs that utilize tertiary treatments, like ozonation or filtration, EC could be incorporated as an additional pre-cleaning step before tertiary treatment. The effects of EC (e.g., reducing the amount of metal ions, heavy metals, colloids, oil wastes, dyes, suspended particles, *etc.*) would produce an effluent amenable to tertiary treatment and should reduce the fouling of these latter steps [25,36]. For WWTPs with no tertiary treatment, the EC process could be used to coagulate the raw sewage before going into the existing plant clarification unit. Not only would it reduce levels of chemical oxygen demand, turbidity and many contaminants [37], but it would also have the added benefit of EDC removal. EC can also be used to replace conventional chemical coagulation in plants where that technology is in use, since EC reduces the direct handling of corrosive chemicals and does not produce any secondary pollution caused by added chemical substances [35,37]. Furthermore, EC is a low-sludge producing technique, and the sludge formed tends to be readily settleable and easy to de-water [23].

Future testing should include environmentally-relevant concentrations in WWTP influent and effluent. Since these concentrations, especially for the natural and synthetic estrogens, are on the order of low ng/L, detection limits of analytical instruments used will need to be pushed to the pg/L range. Bioassays will also be an important tool in future testing to determine the final estrogenicity of samples due to the fact that pollutants rarely occur as isolated compounds in environmental matrices, but rather in complex mixtures where pollutants can act synergistically, antagonistically, or additively. Finally, future research should continue to explore the potential synergy of combining EC with additional emerging treatment technologies. For example, a recent study demonstrated that combining electro-enzymatic catalysis with EC results in efficient removal of BPA from water [38].

4. Conclusions

In conclusion, the electrocoagulation of wastewater (WWTP raw influent and tertiary-treated effluent) spiked with six estrogenic EDCs was tested for efficiency of removal using a laboratory-scale unit. EC, with the optimal operating parameters determined in this study, enabled statistically significant removal of all EDCs in both WWTP raw influent (56%–81% removal) and tertiary-treated effluent (42%–98% removal). Although determining the mechanisms responsible for EDC removal is beyond the scope of this study, it is likely that these compounds were removed through sorption onto the amorphous aluminum hydroxide flocs followed by filtration. These flocs, termed "sweep flocs", have large surface areas which promote rapid adsorption of soluble organic compounds [39]. In this study, all samples were spiked with EDCs to challenge the EC instrument with removal of significant quantities of contaminants. Overall, this study demonstrated that aluminum EC can reduce EDC concentrations in municipal wastewater influent and effluent, a property that merits further exploration in anticipation of future regulations regarding EDC discharge into the environment.

Supplementary Materials: The following are available online at www.mdpi.com/2073-4441/8/4/128/s1. Table S1: Preliminary Testing, June 2012; Table S2: Preliminary Testing, November 2012; Table S3: Replicate Experiment for Verification of Optimal Parameters.

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Author Contributions: All authors conceived and designed the experiments; Monica M. Cook, Erin M. Symonds, Bert Gerber and Armando Hoare performed the experiments and analyzed the data; Monica M. Cook wrote the paper; Monica M. Cook, Erin M. Symonds, Bert Gerber, Armando Hoare, Edward S. Van Vleet and Mya Breitbart edited and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

WWTP	Wastewater treatment plant
EDC	Endocrine-disrupting compound
EC	Electrocoagulation
E1	estrone
E2	17β-estradiol
E3	estriol
EE2	17-ethinylestradiol
BPA	bisphenol-A
NP	nonylphenol
NPEO	nonylphenol ethoxylate
BSTFA	N, O-bis(trimethylsilyl)trifluoroacetamide
DI	deionized
GCMS	gas chromatography-mass spectrometry
MDL	method detection limit
TMCS	trimethylchlorosilane
EI	(electron impact)

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Reduction of nutrients, microbes, and personal care products in domestic wastewater by a benchtop electrocoagulation unit

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To preserve environmental and human health, improved treatment processes are needed to reduce nutrients, microbes, and emerging chemical contaminants from domestic wastewater prior to discharge into the environment. Electrocoagulation (EC) treatment is increasingly used to treat industrial wastewater; however, this technology has not yet been thoroughly assessed for its potential to reduce concentrations of nutrients, a variety of microbial surrogates, and personal care products found in domestic wastewater. This investigation's objective was to determine the efficiency of a benchtop EC unit with aluminum sacrificial electrodes to reduce concentrations of the aforementioned biological and chemical pollutants from raw and tertiary-treated domestic wastewater. EC treatment resulted in significant reductions ($p < 0.05$, $\alpha = 0.05$) in phosphate, all microbial surrogates, and several personal care products from raw and tertiary-treated domestic wastewater. When wastewater was augmented with microbial surrogates representing bacterial, viral, and protozoan pathogens to measure the extent of reduction, EC treatment resulted in up to 7-$\log_{10}$ reduction of microbial surrogates. Future pilot and full-scale investigations are needed to optimize EC treatment for the following: reducing nitrogen species, personal care products, and energy consumption; elucidating the mechanisms behind microbial reductions; and performing life cycle analyses to determine the appropriateness of implementation.

In order to protect public and environmental health, innovative technologies are needed to reduce the concentrations of emerging microbes[1] and chemicals[2] from domestic wastewater prior to discharge into the environment and/or water reuse. Fecal-borne pathogens, encompassing known and emerging bacteria, helminths, protozoa, and viruses, substantially contribute to human disease and mortality worldwide[1,3]. Furthermore, it has been postulated that the input of personal care products (PCPs; a chemically diverse group of over-the-counter medications, insect repellents, antibiotics, and disinfectants) into aquatic environments or the drinking water supply could negatively affect wildlife and humans, respectively[4,5]. Finally, it is well-understood that the removal of nutrients, principally nitrogen and phosphorus, from domestic wastewater is necessary to prevent the eutrophication of surface waters exposed to treated wastewater discharge. While many different wastewater treatment options exist, adequate reduction of all chemicals and microbes is extremely complex due to their great physical and structural diversity[1,6]. It is therefore important to evaluate treatment technologies for their ability to remove a diverse range of contaminants, since a combination of approaches will likely be required to ensure safe discharge of treated effluent and/or water reuse.

Electrocoagulation (EC) has become increasingly popular over the last 25 years to treat a wide-variety of wastewaters as technological advances have made this technique more cost- and energy-efficient[7–10]. The EC process applies electricity to sacrificial electrodes (typically aluminum or iron), which generates coagulants (e.g. aluminum hydroxide for an aluminum anode), destabilizes contaminants, enhances the suspension of particulates, and disrupts emulsions. Contaminants are either directly broken down or aggregated to form flocs that become buoyant as they associate with the gases generated by the concurrent electrolysis of water. Following EC, the floc is separated from the treated water via sedimentation and/or filtration. EC may be an advantageous treatment option as it does not require a constant supply of chemicals[7–10] and consequently, may be more easily implemented in a developing-country context where such chemicals are not readily available[7]. It has also been suggested that EC technology could be an effective decentralized drinking water treatment technology[11] and easily deployed as portable equipment for use in remote locations or in the event of emergencies[12].

The efficacy of EC to reduce various biological and chemical constituents found in water and wastewater under normal and emergency conditions has been investigated in several prior studies. When evaluating EC technologies for their use in treating potable water, Vik et al. determined significant removal of humic substances with EC treatment of surface waters[13] and Zhu et al. ascertained effective removal of MS2 bacteriophages from synthetic freshwater[14]. In another study, even though the use of iron electrodes in EC treatment reduced MS2 bacteriophage by up to 6.5-$\log_{10}$ in synthetic freshwater, natural levels of organic matter present in surface waters limited virus reductions to as little as 1.0-$\log_{10}$[15]. Consequently, the use of aluminum electrodes was suggested to prevent the complexation of organic matter and iron ions that inhibit adequate flocculation and subsequent virus removal. Furthermore, EC treatment of surface waters is both technically and economically effective for the removal of algae[16] and greatly reduces concentrations of fecal indicator bacteria[17]. In a recent laboratory study, EC decreased concentrations of the antibiotic tetracycline by nearly 99% in laboratory-made aqueous solutions[18]. With respect to the treatment of industrial wastewater, EC has also been extensively used, primarily with aluminum, iron, and steel electrodes, to reduce chemical oxygen demand (COD) as well as the concentrations of arsenic, fluoride, food and oil waste, heavy metals, nitrate, organic matter, phenolic and polymeric wastes, suspended particles, textile dyes, and refractory organic pollutants[6,7,9,19–21].

Unlike industrial wastewater, the application of EC to treat domestic wastewater has yet to be as thoroughly investigated. To date, several studies have shown that EC treatment of domestic wastewater (natural and synthetic) can greatly reduce turbidity by more than 90%, COD by up to 75%, and provide up to 'complete disinfection' per the absence of fecal coliforms in treated effluents[17,22–28]. Additionally, Ozyonar et al. observed phosphorus removal efficiencies as great as 98% with EC treatment of domestic wastewater and determined that aluminum electrodes provided the greatest removal of phosphorus, as well as COD and turbidity[28]. The incorporation of EC as a tertiary or polishing treatment has also been suggested as it can greatly reduce phosphate concentrations in domestic wastewater after secondary treatment via anaerobic digestion or activated sludge treatment[23,29].

The application of EC to treat domestic wastewater represents a potential alternative and/or addition to traditional treatment due to cost effectiveness, ease in operation, design simplicity, and its successful use to treat other waters; however, the full potential of EC to reduce multiple types of microbes, PCPs, and nitrogen species from domestic wastewater has yet to be fully understood[7,30]. The primary objective of this study was to determine the efficiency of a benchtop EC unit, equipped with aluminum electrodes, to reduce nutrients (nitrate + nitrite, nitrite, ammonium, and phosphate), a suite of 18 PCPs, and six types of microbes from both raw and tertiary-treated domestic wastewater in order to further understand the potential of EC as a principal or polishing treatment, respectively. The PCPs assessed in this study represent those identified as potential threats to environmental and/or human health and routinely studied in U.S. Environmental Protection Agency (US EPA) Clean Water Act programs[31]. To investigate the potential of EC treatment to reduce microbial contaminants, several commonly used microbial surrogates were chosen to represent bacterial, parasitic protozoan and viral pathogens as well as to allow for culture- and molecular-based analyses.

Results and discussion

Nutrients. Significant (>95%; $p < 0.0003$, $\alpha = 0.05$) reductions in phosphate were observed upon EC treatment of both raw wastewater and tertiary treated wastewater (Table 1). These results corroborate previous findings demonstrating up to 100% removal using aluminum sacrificial electrodes and further suggest that EC may be an especially useful treatment technology to achieve enhanced phosphorus reductions from domestic wastewater[28,29,32]. Despite the consistent reduction of phosphate by EC, the extent of reduction for the other nutrients differed for raw wastewater compared to tertiary-treated wastewater (Table 1).

Significant decreases in nitrate + nitrite were observed (48.35%; $p = 0.0007$, $\alpha = 0.05$) during the treatment of tertiary-treated wastewater; however, no significant reduction in nitrate + nitrite was achieved during the treatment of raw wastewater. Additionally, even though significant increases in nitrite and ammonium were observed during EC treatment of tertiary-treated wastewater, significant reductions (>14%; $p < 0.0087$; $\alpha = 0.05$) were observed after EC treatment of raw wastewater. Previous studies on nitrate reduction from ground and surface water for potable water treatment have shown that EC with iron and aluminum blades is more efficient than chemical coagulation; however, the extent of nitrate reduction depended upon the EC conditions (e.g. current density applied, electrode connections) and the characteristics of the water under treatment (e.g. pH, initial nitrate concentration, total dissolved solids)[33,34]. Since up to 89.7% nitrate removal from aqueous solutions has been observed by Malakootian et al.[34], future research is necessary to identify the optimum EC conditions for reduction of various nitrogen species from domestic wastewater and treated effluent.

Microbes. Six commonly used microbial surrogates were analysed using a combination of molecular- and culture-based techniques. The double-stranded DNA human polyomavirus (HPyV) and single-stranded RNA pepper mild mottle virus (PMMoV) were measured as surrogates for DNA and RNA viruses in wastewater, respectively,

Table 1 | Mean +/− standard deviation of nutrient concentrations before and after EC treatment of raw wastewater and tertiary-treated wastewater with the benchtop unit. A negative t-statistic signifies an increase in nutrient concentrations after EC treatment. When a two-tailed student's t-test (t) or Wilcoxon Rank Sum test (S) revealed a positive, significant difference ($\alpha = 0.05$) between pre- and post- EC treatment concentrations, the mean percent reduction was calculated

		Mean concentration +/− standard deviation (μM)			
Wastewater Sample	Nutrient	Pre-EC treatment	Post-EC treatment	Two-tailed student's t-test results	% Mean reduction
Raw	Nitrate + Nitrite	11.20 +/− 0.79	10.63 +/− 0.31	t = 1.36, p = 0.2218	N/A
	Nitrite	0.52 +/− 0.07	0.33 +/− 0.06	t = 3.83, p = 0.0087	64.48
	Ammonium	1349.34 +/− 10.88	1155.76 +/− 63.67	t = 5.99, p = 0.0079	14.35
	Phosphate	62.76 +/− 20.17	2.65 +/− 0.42	t = 19.93, p = 0.0003	95.79
Tertiary-treated	Nitrate + Nitrite	2.88 +/− 0.22	1.49 +/− 0.38	t = 6.34, p = 0.0007	48.35
	Nitrite	0.11 +/− 0.03	0.41 +/− 0.02	t = −15.87, p < 0.0001	N/A
	Ammonium	3.08 +/− 0.19	4.78 +/− 0.29	t = −9.74, p < 0.0001	N/A
	Phosphate	3.95 +/− 0.20	0.15 +/− 0.02	t = 37.87, p < 0.0001	96.33

using molecular techniques[35–38]. Fecal-indicator bacteria (FIB; fecal coliforms and *Enterococcus* spp.) were measured as surrogates for wastewater-related bacteria using culture-based techniques as well as molecular techniques for *Enterococcus* spp.[3,39]. To quantify the extent of microbial reduction, the EC unit was used to treat domestic wastewater augmented with the aforementioned bacteria and viruses as well as two other commonly used microbial surrogates that are not typically found in wastewater at high concentrations: male-specific (F+) bacteriophages (MS2)[40] and *Bacillus subtilis* spores (surrogate for wastewater-related, protozoan parasites; i.e *Cryptosporidium*[3]). Both MS2 bacteriophages and *B. subtilis* spores were analysed using culture-based techniques.

EC treatment resulted in significant reductions ($p < 0.0286$, $\alpha = 0.05$), ranging from 81.567% to >99.999998%, of all microbial surrogates tested in all domestic wastewater samples (Table 2). These results suggest that EC with aluminum electrodes is an effective treatment for the wide-range of pathogen types present in domestic wastewater. Furthermore, EC treatment resulted in a greater than 4-$\log_{10}$ reduction for all microbial surrogates in augmented domestic wastewater. Although this study does not attempt to discern the mechanisms behind "the observed reductions after" EC treatment, previous studies on synthetic freshwater and wastewater have suggested that the primary microbial removal mechanism during EC is due to the enmeshment of microbes to flocs and subsequent separation of flocs from treated water by filtration[12]. It is also possible that the oxidants produced during EC (e.g. $HO\cdot$, O_3, H_2O_2) provide additional microbial reductions via disinfection as a result of cell/capsid membrane damage[15,17]. The effective reduction of FIB observed (as great as 7-$\log_{10}$) in this study supports the results of previous investigations on EC treatment of domestic wastewater, which cite reductions as high as 4-$\log_{10}$[17,22,23,25]. Finally, this is the first study to our knowledge to demonstrate that EC can significantly reduce concentrations of viral and parasitic protozoan surrogates in domestic wastewater.

Personal care products. EC treatment of raw domestic wastewater significantly ($p < 0.05$, $\alpha = 0.05$) reduced concentrations of the following PCPs: acetaminophen, DEET, gemfibrozil, ibuprofen, iopromide, salicylic acid, triclocarban, and triclosan (Table 3). While the initial concentrations of many PCPs in tertiary-treated wastewater were below the process limit of detection (pLOD), EC treatment of tertiary-treated wastewater significantly ($p < 0.05$, $\alpha = 0.05$) decreased concentrations of iopromide, sulfamethoxazole, and thiabendazole (Table 3). Although this study does not attempt to discern the EC removal mechanisms associated with the different PCPs, it is likely that PCP adsorption to flocs was a major removal mechanism[41], particularly for compounds with higher octanol-water partition coefficient (K_{ow}) values (e.g. gemfibrozil, ibuprofen, triclocarban, and triclosan). It is also possible that compounds with lower K_{ow} values (e.g., acetaminophen, DEET, iopromide, salicylic acid, sulfamethoxazole, and thiabendazole) were removed by the destabilizing effects of EC, which result in charge neutralization, decreased solubility, and ultimately, enhanced aggregation to flocs[42].

The differences in PCP removal by EC treatment observed for raw wastewater and tertiary-treated wastewater are likely the result of chemical differences between the two water types (e.g. total suspended solids, which differed on average by two orders of magnitude that influence chemical adsorption to flocs[7–10,41,42] (195 mg/L and 1 mg/L in raw wastewater and tertiary-treated wastewater, respectively; courtesy of South Cross Water Reclamation Facility)). Since it has been previously reported that current intensity greatly influences the extent of tetracycline (a common antibiotic) removal from aqueous solutions during EC with aluminum electrodes[18], it is possible that the current intensity was suboptimal for maximizing PCP removal during this study. Future research is need to optimize the EC treatment process for removal of a wide-range of PCPs from domestic wastewater after various primary and secondary treatments in order to understand the full potential of EC to reduce PCP concentrations.

Conclusions

This study demonstrates that a benchtop EC unit outfitted with aluminum electrodes can concomitantly reduce concentrations of phosphate, microbial surrogates representing several major pathogen types (DNA/RNA viral, bacterial, protozoan parasite), as well as several PCPs in domestic wastewater. By providing the first information about the ability of EC to reduce concentrations of viral and parasitic protozoan surrogates, as well as PCPs, this study enhances previous assertions that EC is a promising sustainable wastewater treatment technology for domestic wastewater[7,12,30]. While these collective results highlight the potential of EC for domestic wastewater treatment, further research is needed to address a number of outstanding issues. First, future work should attempt to discern the mechanisms behind the observed reductions as well as to optimize EC configurations and conditions to enhance the removal of PCPs and nitrogen species from domestic wastewater. Secondly, it will be necessary to optimize the EC treatment conditions to minimize energy consumption and the incorporation of renewable energy sources[43]. Future pilot-scale and full-scale studies assessing the effectiveness of EC treatment of domestic wastewater are needed to fully understand the feasibility of this treatment option with respect to removing nutrients, microbes, and PCPs both from raw wastewater as a stand-alone treatment or as a polishing technology for refining tertiary-treated wastewater from standard wastewater treatment plants. Additionally, full life-cycle assessments are needed in order to understand the appropriateness of EC technologies as an option for decentralized and/or centralized domestic wastewater treatment prior to their implementation.

Methods

Benchtop electrocoagulation unit. The demonstration, benchtop EC unit (United States patent number 7211185 B2 by Powell Water Systems, Inc.; Centennial, CO, USA) evaluated in this study was comprised of a non-conductive, acrylic-resin chamber (35.6 × 5.4 × 2.5 cm) with nine aluminum plates (each 36.8 × 2.5 × 0.3 cm) vertically arranged and spaced 0.3 cm apart such that they occupied approximately 45% of the chamber volume (Figure 1). A 110-volt AC to DC power converter, set to 98 volts, was used to supply electricity to the unit via three electrical connections to the first, fifth, and ninth blade, resulting in two anodes and one cathode. During EC treatment, the actual current delivered ranged from 8.5–15.0 amps for raw domestic wastewater and 12.0–15.5 amps for tertiary-treated domestic wastewater. A peristaltic pump (Cole-Parmer® Masterflex Peristaltic Pump System 77910; Vernon Hills, IL, USA) was used to pump wastewater up through the unit chamber, which recirculated wastewater throughout the benchtop unit at a rate of 0.94 L/min. Wastewater was recirculated for 1 min per every liter of wastewater being treated. The resulting flocculant was removed from the EC unit effluent via filtration with paper filters that retain 11 μm particles (Whatman Qualitative Grade Plain Circles Grade 1; GE Healthcare Bio-Sciences, Pittsburgh, PA, USA). Since the aluminum blades become oxidized over time, they were cleaned with a sandblaster after every 12 L of wastewater treated by the EC unit to physically remove the oxidized portion of the aluminum blade.

Experimental design. Raw influent (post-grit removal) and tertiary-treated (dechlorinated) effluent were collected in sterile, plastic HDPE carboys from South Cross Bayou Water Reclamation facility (activated sludge plant with tertiary treatment) in St. Petersburg, Florida, USA. The tertiary-treated domestic wastewater received the following treatment prior to collection: grit removal, primary clarification, secondary treatment with an activated sludge system, and finally tertiary treatment with sand filtration, chlorination, and de-chlorination. Carboys were stored at 4°C in the dark and all experiments were conducted within 12 h of collection. Given the large number of analytes and logistical limitations, twice the minimum anticipated number of trials ($n = 4$) were collected before and after EC treatment in order to test the reduction efficiency of the EC unit. Four trials were executed with both raw wastewater and treated effluent, with each trial requiring an 18-L sample. From each sample, 6.1 L were isolated before treatment and the remaining volume was treated with the EC unit and filtered as described above. The EC unit was cleaned with 1 L analytical grade methanol and rinsed with 5 L DI water after each trial. Process controls, consisting of DI water that was recirculated through the EC unit, were collected after the second and fourth trial to ensure no cross-contamination between trials. All pre- and post-

Table 2 | Mean +/− standard deviation (n = 4 unless indicated otherwise; [a] n = 2 and [b] n=3) of bacteria and virus concentrations, two-tailed student's t-test (t) or Wilcoxon Rank Sum test (S) results, and mean percent reduction from domestic wastewater before and after EC treatment. Analyte concentrations are described as less than the process limit of detection (<pLOD) when undetected: [c]0.01 fecal indicator bacteria cfu/ml, [d]2.08×10^{2} HPyV targets/ml, [e]1.09×10^{2} PMMoV targets/ml, [f]0.1 MS2 bacteriophage pfu/ml, and [g]1.00×10^{3} *Enterococcus* spp. targets/ml with IC-NASBA. For molecular analyses, analyte concentrations are considered positive but below the process limit of quantification (+BLOQ) when at least one replicate is +BLOQ: [h]5.00×10^{3} *Enterococcus* spp. targets/ml (qPCR), [i]2.00×10^{3} *Enterococcus* spp.targets/ml (IC-NASBA), and [l]2.19×10^{2} PMMoV targets/ml

		Mean concentration +/− standard deviation per milliliter			
Wastewater Sample	Analyte	Pre-EC treatment	Post-EC treatment	Test statistic and p-value	% Mean reduction
Raw	*Enterococcus* spp. (cfu)	4.701×10^{2} +/− 1.50×10^{2}	<pLOD[c]	S = 26.00, p = 0.0286	>99.998
	Fecal coliform (cfu)	1.95×10^{2} +/− 2.29×10^{2}	< pLOD[c]	S = 26.00, p = 0.0286	>99.995
	HPyVs (qPCR target)	2.69×10^{3} +/− 8.16×10^{2}	< pLOD[d]	S = 26.00, p = 0.0286	>92.252
	PMMoV (qPCR target)	5.47×10^{4} +/− 1.64×10^{4}	<pLOD[e]	S = 26.00, p = 0.0286	>99.800
Tertiary- treated	*Enterococcus* spp. (cfu)	5.43×10^{-2} +/− 2.54×10^{-2}	<pLOD[c]	S = 26.00, p = 0.0286	>81.567
	Fecal coliform (cfu)	7.40×10^{1} +/− 4.05×10^{1}	< pLOD[c]	S = 26.00, p = 0.0286	>99.986
	HPyVs (qPCR target)	<pLOD[d]	< pLOD[d]	N/A	N/A
	PMMoV (qPCR target)	<pLOD[e]	<pLOD[e]	N/A	N/A
Spiked raw	*Bacillus subtilis* (cfu)	3.80×10^{6} +/− 3.74×10^{5}	3.00×10^{0} +/− 1.41×10^{0} [a]	S = 26.00, p = 0.0286	>99.99996
	Enterococcus spp. (cfu)	1.25×10^{8} +/− 1.56×10^{7}	2.15×10^{0} +/− 4.12×10^{0}	S = 26.00, p = 0.0286	>99.999998
	Enterococcus spp. (qPCR target)	1.37×10^{6} +/− 1.40×10^{5}	+BPLOQ[h]	S = 26.00, p = 0.0286	>99.507
	Enterococcus spp. (NASBA target)	1.15×10^{6} +/− 1.72×10^{5}	<pLOD[g]	S = 26.00, p = 0.0286	>99.913
	Fecal coliform (cfu)	1.22×10^{6} +/− 2.61×10^{5}	8.13×10^{-1} +/− 9.10×10^{-1} [b]	t = 9.33, p = 0.0026	>99.99993
	HPyVs (qPCR target)	6.29×10^{5} +/− 2.00×10^{5}	< pLOD[d]	S = 26.00, p = 0.0286	>99.967
	PMMoV (qPCR target)	6.38×10^{6} +/− 2.35×10^{6}	<pLOD[e]	S = 26.00, p = 0.0286	>99.998
	MS2 bacteriophage (pfu)	3.72×10^{4} +/− 3.82×10^{3}	<pLOD[f]	S = 26.00, p = 0.0286	>99.9997
Spiked tertiary- treated	*Bacillus subtilis* (cfu)	3.60×10^{6} +/− 3.69×10^{5}	7.45×10^{2} +/− 6.43×10^{2} [a]	t = 20.23, p = 0.0003	>99.989
	Enterococcus spp. (cfu)	1.44×10^{6} +/− 1.03×10^{5}	5.67×10^{1} +/− 7.03×10^{1}	t = 27.88, p = 0.0001	>99.996
	Enterococcus spp. (qPCR target)	1.68×10^{6} +/− 1.40×10^{5}	+BPLOQ[h]	S = 26.00, p = 0.0286	>99.702
	Enterococcus spp. (NASBA target)	1.56×10^{6} +/− 1.04×10^{5}	+BPLOQ[i]	S = 26.00, p = 0.0286	>99.872
	Fecal coliform (cfu)	1.47×10^{6} +/− 6.24×10^{4}	3.38×10^{1} +/− 4.59×10^{1}	t = 47.05, p < 0.0001	>99.998
	HPyVs (qPCR target)	7.69×10^{5} +/− 2.81×10^{5}	< pLOD[d]	S = 26.00, p = 0.0286	>99.973
	PMMoV (qPCR target)	1.24×10^{7} +/− 6.26×10^{6}	+BPLOQ[l]	S = 26.00, p = 0.0286	>99.998
	MS2 bacteriophage (pfu)	2.98×10^{4} +/− 5.34×10^{3}	<pLOD[f]	S = 26.00, p = 0.0286	>99.9996

Table 3 | Mean +/− standard deviation of personal care product concentrations before and after EC treatment of raw and tertiary-treated wastewater with the benchtop unit (n = 4, unless otherwise noted). Any undetected analytes are listed as less than the reported process limit of detection (<pLOD). When a two-tailed student's t-test (t) or Wilcoxon Rank Sum test (S) revealed a positive, significant difference ($\alpha = 0.05$) between pre- and post- EC treatment concentrations, the mean percent reduction was calculated. Results that exceeded the calibration range but did not saturate the instrument detector are indicated with an ^{E}. Results that were likely underestimations (laboratory control sample spike below the control limit) are indicated with*

	Raw wastewater				Tertiary-treated wastewater			
	Mean concentration +/− standard deviation (ng/L)		Test statistic and p-value	% Mean reduction	Mean concentration +/− standard deviation (ng/L)		Test statistic and p-value	% Mean reduction
Analyte	Pre-EC treatment	Post-EC treatmet			Pre-EC treatment	Post-EC treatment		
Acetaminophen	55750 +/− 28000^E	28000 +/− 4243^E	S = 26.00, p = 0.0286	49.78	<pLOD	<pLOD	N/A	N/A
Caffeine	31250 +/− 3202^E	26250 +/− 4787^E	S = 23.00, p = 0.1714	N/A	<pLOD	72 +/− 3	N/A	N/A
Carbamazepine	130 +/− 16	125 +/− 6	S = 20.00, p = 0.6564	N/A	165 +/− 6	178 +/− 10	N/A	N/A
DEET	4075 +/− 263	3400 +/− 424^E	t = 2.70, p = 0.0354	16.56	29 +/− 1	68 +/− 12	N/A	N/A
Gemfibrozil	2700 +/− 13	2350 +/− 82^E	t = 4.58, p = 0.0038	12.96	<pLOD	<pLOD	N/A	N/A
Ibuprofen	12000 +/− 817^E	9950 +/− 900^E	t = 3.37, p = 0.0150	17.08	<pLOD	<pLOD	N/A	N/A
Iopromide	4600 +/− 653*	3325 +/− 619^{*,E}	S = 26.00, p = 0.0286	24.77	505 +/− 31	350 +/− 26	t = 7.67, p = 0.0003	31.00
Meprobamate	655 +/− 48	660 +/− 82^E	t = 0.11, p = 0.9193	N/A	588 +/− 24^E	645 +/− 44^E	N/A	N/A
Naproxen	11250 +/− 500^E	11250 +/− 500^E	S = 18.00, p = 1.0000	N/A	<pLOD	<pLOD	N/A	N/A
Phenytoin	<pLOD	130 +/− 0 (n=2)	N/A	N/A	183 +/− 15	208 +/−15	N/A	N/A
Primidone	<pLOD	<pLOD	N/A	N/A	<pLOD *	<pLOD *	N/A	N/A
Salicylic Acid	32500 +/− 5568	9425 +/− 961^E	S = 26.00, p = 0.0286	71.00	61 (n=1)	78 +/−15	N/A	N/A
Sulfamethoxazole	1925 +/− 310	1700 +/− 548^E	t = 0.72, p = 0.5013	N/A	24 +/− 5	< RL	S = 26.00, p = 0.0286	58.76
Thiabendazole	<pLOD	15 +/− 1	N/A	N/A	20 +/− 1	18 +/− 1	t = 3.00, p = 0.0240	10.00
Triclocarban	728 +/−200	113 +/− 75	t = 5.77, p = 0.0012	84.54	<pLOD	<pLOD	N/A	N/A
Triclosan	1350 +/−238	248 +/− 89	t = 8.68, p = 0.0001	81.67	<pLOD	<pLOD	N/A	N/A
Trimethoprim	488 +/− 54	508 +/− 48^E	t = 0.56, p = 0.5986	N/A	<pLOD	<pLOD	N/A	N/A
Warfarin	<pLOD	<pLOD	N/A	N/A	<pLOD	<pLOD	N/A	N/A

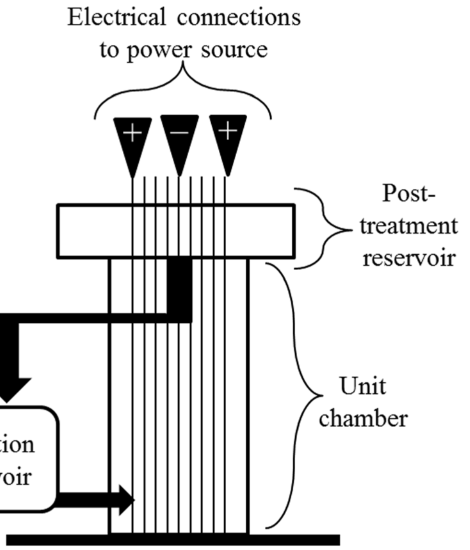

Figure 1 | The benchtop electrocoagulation unit with nine aluminum blades arranged vertically in the unit chamber. Electrical connections on the first, fifth, and ninth blades were connected to a 110-volt AC to DC power converter. A peristaltic pump re-circulated wastewater up through the unit chamber, into the post-treatment reservoir, and into the collection reservoir.

treatment samples, as well as process controls, were analyzed for nutrients, microbes, and PCPs.

In order to quantify the reduction efficiency of microbes, 1-L wastewater influent and effluent samples were augmented separately with concentrated surrogates for bacteria (*Enterococcus faecalis* ATCC-29212™ and *Escherichia coli* strain C600), viruses (JC HPyV ATCC-VR-1583™, PMMoV (obtained from Scott Adkins; USDA), and MS2 bacteriophages), and parasitic protozoa (*B. subtilis* spores) (see Supplementary Information). Four trials were executed for both the raw wastewater and tertiary-treated effluent. Twenty-milliliter and 120-ml aliquots of the spiked-wastewater were collected prior to treatment with the EC unit for samples augmented with bacteria and viruses, respectively. The remaining volume was treated with the benchtop EC unit as described above. The EC unit was cleaned between each trial and one process control was collected upon completion of the fourth trial.

Nutrient analyses. Four sets of pre- and post-EC treatment samples of raw wastewater and tertiary-treated wastewater samples, along with two process controls, were analyzed in duplicate by the Oceanic Nutrient Laboratory at the University of South Florida, College of Marine Science for nitrate + nitrite, nitrite, ammonium, and phosphate. Due to the high nutrient concentrations in raw wastewater, pre-EC treatment raw wastewater samples were diluted to 2.4% final concentration with deionized water prior to analysis. The analytical methods used for nitrate + nitrite, nitrite, ammonium, and phosphate followed the recommendations of Ref. 44 and were analyzed using a five-channel Technicon Autoanalyzer II (SEAL Analytical, Mequon, WI, USA) upgraded with new heating baths, proportional pumps, colorimeters, improved optics, and an analog to digital conversion system (New Analyzer Program v. 2.40; Waters Corporation, Milford, MA, USA). To extend the dynamic range to 30 µM, the ammonium technique was modified by decreasing the flow rates for the nitroprusside, hypochlorite, phenolate, citrate, sample, air bubble, and waste draw to 50 µl, 50 µl, 50 µl, 320 µl, 600 µl, 160 µl, and 1200 µl per minute, respectively.

Nutrient standards were run in triplicate before and after analysis, as well as a check standard in the middle of the run to correct for any drift in sensitivity. The detection limits for nitrate + nitrite, nitrite, ammonium, and phosphate were 0.22 µM, 0.02 µM, 0.38 µM, and 0.09 µM, respectively. All method blanks were negative. Process controls for both experiments had low levels of nitrate + nitrite, nitrite, ammonium, and phosphate; however, the concentrations were less than the standard deviations for replicate samples.

Microbial analyses. *Human polyomavirus (HPyV) and pepper mild mottle virus (PMMoV).* All samples were processed as previously described[45]. Briefly, 12 ml of sample were 0.45-µm filtered and concentrated to 200 µl using Amicon Ultra-15 centrifugal filter units (EMD Millipore, Billerica, MA, USA). Viral concentrates were stored at 4°C overnight and DNA and RNA were simultaneously purified within 24 h of the experiment using the QIAmp MinElute Virus Spin Kit (Qiagen, Valencia, CA, USA), following manufacturer's instructions and eluting with 50 µl molecular grade water. cDNA was immediately generated by reverse transcription from RNA templates using random hexamers and Superscript III First Strand Synthesis for RT-PCR (Invitrogen, Carlsbad, CA, USA) per manufacturer's instructions. Extraction blanks, containing only the kit reagents, were also processed to ensure no cross-contamination among samples. RNA was stored at −80°C and DNA and cDNA were stored at −20°C.

Using previously published assays, quantitative PCR (qPCR) was used to determine the concentrations of HPyV[36] and PMMoV[35] following the established guidelines for qPCR[46] (see Supplementary Information). The lowest standard dilution within the linear dynamic range of the standard curve was considered the limit of quantification (LOQ) and was 500 and 100 target gene copies per reaction for HPyV and PMMoV, respectively. When no fluorescence was detected, the concentration of HPyV and PMMoV was considered 'less than the limit of detection' (<LOD). If fluorescence was detected at levels less than the LOQ, then the concentration was reported as positive but below the LOQ (+BLOQ). All extraction blanks and no-template controls were negative and PCR inhibition was only observed in one process control for the HPyV assay. All process blanks were negative for HPyV. For PMMoV, the process blanks were all negative except those that were +BLOQ for the experiments executed with augmented wastewater. Mean virus-target concentrations were back-calculated to reflect all sample dilutions (nucleic acid purification through qPCR detection) and the original sample volume concentrated. The process limit of quantification (pLOQ), an ideal estimation assuming 100% recovery, was 417 targets/ml for HPyV qPCR and 219 targets/ml for PMMoV RT-qPCR. The process limit of detection (pLOD) was assumed to be half the pLOQ for both assays.

Fecal indicator bacteria. To determine the concentrations of fecal indicator bacteria (FIB) in all natural and augmented domestic wastewater samples before and after EC treatment as well as in all process controls, multiple dilutions of each sample were filtered onto gridded, 0.45-µm-pore size nitrocellulose filters (Millipore, Billerica, MA, USA) in triplicate. Fecal coliforms were cultured on mFC agar[47], with incubation at 44 ± 0.5°C for 24 h. All blue colonies were considered fecal coliforms and used to enumerate total concentrations of fecal coliforms. Enterococci were enumerated on mEI agar, with incubation at 41 ± 0.5°C for 48 h[39]. Resulting bacterial colonies with a blue halo were recorded as enterococci. The maximum volume filtered was 100 ml; therefore, the theoretical process limit of detection (pLOD) was 1 colony forming unit (cfu)/100 ml. No FIB colonies grew on method blanks or process controls.

The concentration of enterococci in the augmented domestic wastewater samples was also determined using qPCR following standard methods[48] and internal control nucleic acid based sequence amplification (IC-NASBA) (see Supplementary Information). Briefly, 1 ml volumes of augmented domestic wastewater before and after EC treatment were filtered onto 0.45-µm-pore size HV polyvinylidene difluoride filters (Millipore, Billerica, MA, USA) within 24 h of collection. RNA was purified from filters designated for IC-NASBA analysis using the RNeasy® Mini Kit (Qiagen, Valencia, CA, USA). DNA was purified from filters designated for enterococci qPCR using the DNeasy® Blood & Tissue Kit (Qiagen, Valencia, CA, USA). RNA and DNA were eluted using 50 µl and 100 µl of nuclease-free water, respectively. All samples were analyzed in triplicate. The LOQ for the qPCR and IC-NASBA assays was 100 cells per reaction and results were reported as +BLOQ or <LOD, as previously described for HPyV and PMMoV. The pLOQ was 5,000 cells/ml for the qPCR analysis and 2,000 cells/ml for the IC-NASBA analysis. The pLOD was assumed to be half the pLOQ for both assays. All extraction blanks and no-template controls were negative and no PCR inhibition was observed. All process blanks were negative.

Bacillus subtilis spores. All augmented pre-and post-EC treatment samples and process controls were incubated at 50°C for 20 min to kill other non-spore forming bacteria and then maintained in the dark at 4°C. Within 48 h of the experiment, aliquots of each sample were spread-plated in triplicate (all pre-EC treatment samples were diluted 1 : 10,000) onto tryptic soy agar and incubated at 36.5 ± 1°C for 24 h. The resulting viable *B. subtilis* colonies (i.e. opaque in color and rough appearance) were enumerated and concentrations were back-calculated to account for dilutions. Since the maximum sample volume plated was 500 µl, the pLOD was 2 cfu/ml. No colonies grew on method blanks. While no colonies were present in the process control for the experiments with raw wastewater, the average *B. subtilis* concentration in the process control for the experiment with the tertiary treated wastewater was 39 cfu/ml.

MS2 bacteriophage. Since the wastewater samples were augmented with an MS2 bacteriophage culture prior to EC treatment, MS2 bacteriophage concentrations were quantified using the single-agar layer (SAL) protocol using *E.coli* Famp ATCC-700891™ for post-EC treatment samples and the double-agar layer (DAL) protocol for pre-EC treatment samples that had been diluted four-fold[40]. Per US EPA method 1602, each pre-EC treatment sample was analyzed using the DAL protocol in triplicate and each post-EC treatment sample was analyzed in replicates of ten using the SAL protocol. All method blanks were negative. The pLOD was 1 plaque forming unit (pfu)/10 ml for the SAL protocol and 2,000 pfu/ml for the DAL protocol. The average concentrations of MS2 bacteriophage in the process controls were less than the pLOD.

Personal care products. Four raw and four tertiary treated wastewater samples as well as two process controls were analyzed before and after EC treatment by Test America (a NELAP accredited laboratory; Sacramento, CA, USA) following US EPA method 1694 for the following PCPs (with pLOD for all samples except the raw wastewater prior to EC treatment indicated in parentheses): acetaminophen (20 ng/L), caffeine (51 ng/L), carbamazepine (10 ng/L), DEET (25 ng/L), gemfibrozil (25 ng/L), primidone (250 ng/L), salicyclic acid (50 ng/L), thiabendazole (10 ng/L), triclocarban (10 ng/L), triclosan (50 ng/L), warfarin (20 ng/L), ibuprofen (25 ng/L), iopromide (50 ng/L), meprobamate (10 ng/L), naproxen (50 ng/L), phenytoin (100 ng/L), sulfamethoxazole (10 ng/L), and trimethoprim (10 ng/L)[31]. For the analysis of raw wastewater prior to EC treatment, the LOD was an order of magnitude greater for all analytes.

No PCPs were detected in the two process controls collected during the experiment with tertiary-treated wastewater. However, low concentrations of acetaminophen (22 ng/L), caffeine (83 ng/L), DEET (180 ng/L), and salicylic acid (76 ng/L) were detected in the process controls collected during the experiment with raw wastewater. Since the detected concentrations of these analytes in the process controls are less than the standard deviations observed for raw wastewater samples before and after EC treatment, it is unlikely that the observed contamination influenced the results of this study.

Statistical analyses. Statistical analyses were executed in SAS v.9.3 (SAS Institute Inc.; Cary, NC, USA) to identify significant ($\alpha = 0.05$) differences in the concentrations of all nutrients, microbes, and PCPs before and after EC treatment. If the data had normal distributions, a two-tailed t-test was performed with either the pooled method (for equal variances) or the Satterthwaite approximation (for unequal variances). If the data were not normally distributed, then the non-parametric Wilcoxon Rank Sum test was performed. For a given analyte, if a significant difference in pre- and post-EC treatment concentrations was determined with 95% confidence, then the average percent reduction was calculated. If concentrations were +BLOQ or <LOD, then the pLOQ or pLOD, respectively, were used to conservatively test for statistical differences and to calculate the average percent reduction.

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Author contributions

This study was designed by E.M.S., M.M.C., E.S.V.V. and M.B., with assistance from J.O.L. E.M.S., M.M.C., S.M.M., R.M.U. and R.O.S. executed the experiments with input from J.O.L. Microbial analyses were executed by R.O.S. (MS2 bacteriophage), S.M.M. (fecal indicator bacteria, *B. subtilis* spores, and HPyV), R.M.U. (fecal indicator bacteria), and E.M.S. (*B. subtilis* spores and PMMoV). The *B. subtilis* spores were provided by J.O.L. Statistical analyses were executed by E.M.S., with assistance from M.M.C. The manuscript text as well as tables and figures were written and prepared by E.M.S., with subject relevant contributions from all authors. All authors reviewed the manuscript.

Additional information

Supplementary information accompanies this paper at http://www.nature.com/scientificreports

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Comparison of ElectroCoagulation to conventional Lime Softening for Silica removal - study done for a major US oil company.

Note: Conclusion was that EC over a 20-yr basis **cost only 20% as much** as Lime Softening due to low O&M costs and no chemicals needed.

EVALUATION OF LIME SOFTENING VS ELECTROCOAGULATION FOR TREATMENT OF PRODUCED WATER

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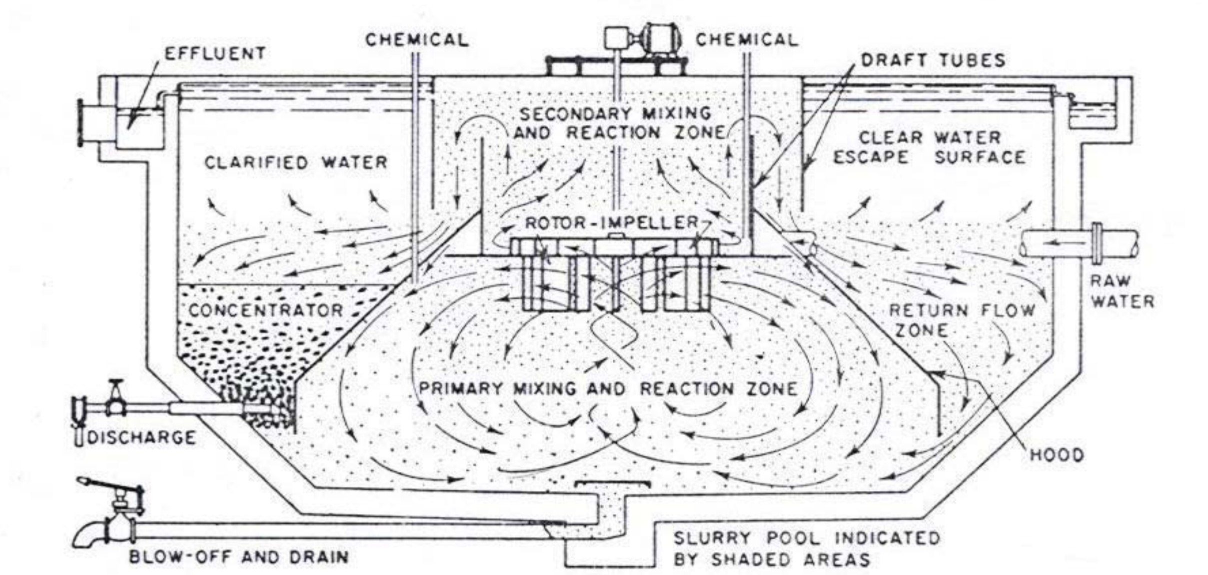
MARCH 2009

INTRODUCTION

The following is an appraisal level economic evaluation comparing the cost of reducing the silica level in produced water by lime softening as compared with electrocoagulation.

Lime Softening



Lime softening removes hardness (calcium + magnesium) from water by adding lime to precipitate these constituents as calcium carbonate and magnesium carbonate.

$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$

$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + MgCO_3 + 2H_2O$

The hardness present in the water in proportion to the alkalinity (HCO_3) in the water is called carbonate hardness. Lime addition alone will remove only the carbonate hardness. Hardness remaining in the water in excess of the carbonate hardness is called noncarbonate hardness. If this additional hardness needs to be removed, then soda ash (Na_2CO_3) must be added to the water along with lime. The soda ash adds more alkalinity to the water and allows more hardness to be precipitated. This reaction is called lime-soda softening.

The reactions shown above proceed until all alkalinity in proportion to the hardness has been exhausted from the water. Each of the subsequent reactions with the noncarbonate hardness compounds will have a slightly different reaction. For instance, in the case of magnesium sulfate, the lime first reacts with the magnesium sulfate as follows:

$MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4$

The calcium sulfate then reacts with soda ash:

$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$

Lime softening is also one of the most common methods for removing silica from water supplies such as makeup to cooling towers. When magnesium hydroxide precipitates, it forms a large floc particle that adsorbs or entraps silica particles in the water. Every pound of silica to be removed from the water requires the precipitation of 1 pound of magnesium hydroxide. If sufficient magnesium is not present in the makeup water, then additional magnesium must be fed in proportion to the amount of additional silica to be removed. This is the mechanism for removal of silica in a lime-soda softening system.

The dynamic nature of the sludge layer in a lime softener does not support frequent shutdowns and startups which are typical of a dispatched generating station. Once the sludge blanket is lost, it can take up to a day to get it re-established and place the system back on line and integrated with the other wastewater treatment blocks.

Pros:

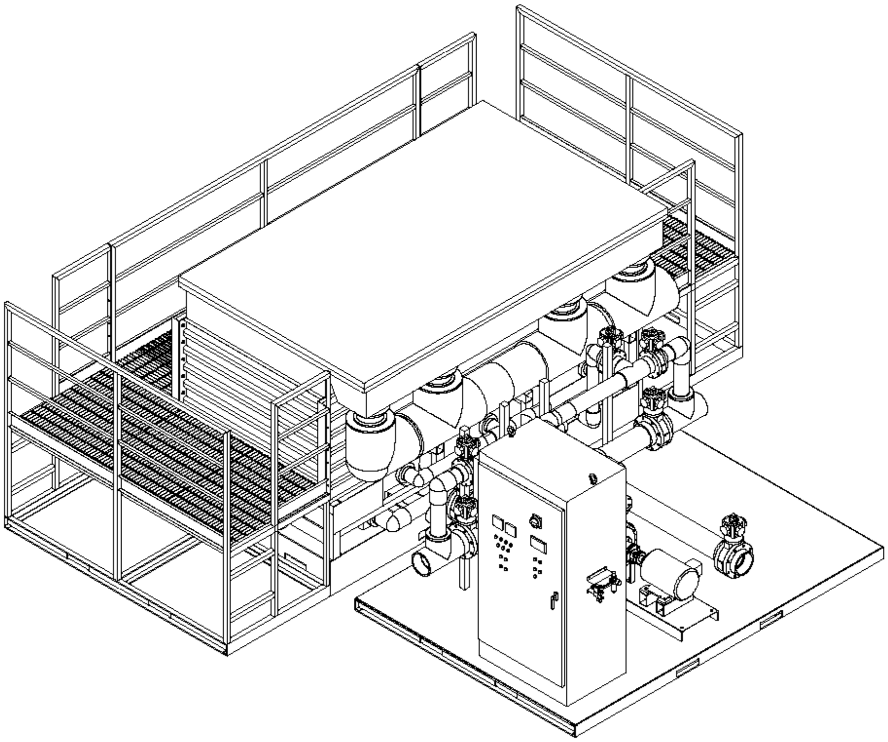
- Well established technology
- Able to remove a broad range of contaminants
- Not subject to irreversible damage by accidental operation

Cons:

- Uses large amounts of chemicals and generates large volumes of waste
- Can be upset by rapid variations in feed water flow
- Manpower intensive operation

Electrocoagulation

The electro-coagulation (EC) process removes contaminants by passing an electrical current through water to induce oxidation and reduction reactions in the water that is being treated. Electrocoagulation systems have been in existence for years (Dietrich, patented 1906), using a variety of anode and cathode geometries. But it has been only in recent years that an efficient industrial grade unit has been developed. A primary advantage of the process is high removal (98% to 99%) of many contaminants with no chemical additions, minimum waste produced, low power requirements, and nominal manpower requirements.



The reaction chamber contains a series of flat metal blades placed parallel to each other. Typically, aluminum and steel blades are used in the process. The water to be treated is introduced into the bottom of the chamber and is dispersed evenly as it moves upward through the blades. Direct current is applied to the blades by attaching positive (+) and negative (-) leads to the first and last blade in the chamber. The liquid then becomes a conductor, allowing the DC current to pass across all the blades in the chamber.

Electrical consumption is typically 4 kwh /1000 gal. The metal blades react to the current by releasing charged metal ions into the water at a rate of 0.20 pounds per 1,000 gallons. The flooding of electrons into the water neutralizes charged colloidal particles allowing them to coalesce and settle. The metal ions tend to form metal oxides that electromechanically attract to the contaminants that have been destabilized. The reaction chamber includes an air purge system to keep debris from accumulating inside the chamber and polarity reversing is applied to extend blade life and prevent contaminants from coating the blades.

Pros:

- Uses no chemicals
- High reliability and easy to operate (minimal manpower requirements)
- Minimal waste volume (<2%)since sludge contains no added chemicals
- High recovery (>98%) for critical dissolved constituents such as silica
- Largely insensitive to variations is feedwater flow and quality
- Low power consumption (4 kw-hr/1000 gal)

Produced Water Treatment Comparison
Lime Softening vs Electrocoagulation

LEVELIZED COSTS								CAPITAL COSTS
Option	Debt	Electricity	O&M	Chemicals	Consumables	Sludge Disposal	TOTAL	
Lime Softening	$732,501	$525,624	$1,312,420	$1,455,399	$295,388	$508,791	$ 4,830,124	$ 6,876,730
Electrocoagulation	$689,229	$140,166	$109,368	$0	$58,324	$36,900	$ 1,033,987	$ 6,470,489

CONCLUSIONS

1. The results of the economic evaluation indicate that a 500 gpm lime softening system has about the same capital cost as a 500 gpm electrocoagulation system. The estimated cost presented for the lime softening system indicates it to be slightly higher than a 500 gpm electrocoagulation system, but essentially the same within the accuracy of the evaluation
2. The results of the economic evaluation indicate the levelized cost of a 500 gpm electrocoagulation system to be about one-fifth the levelized cost of a comparable 500 gpm lime softening system. This difference is realized by lower operating costs across the board.
3. Operating data from operating facilities, projections, and published data indicate both lime softening and electrocoagulation should be able to reduce the silica level in the design water analysis from 218 ppm to 10 ppm.
4. The same data bases indicate neither lime softening or electrocoagulation can reduce the silica level in the design water analysis from 218 ppm to 1 ppm. Electrocoagulation could probably reduce the silica level to 1 ppm if a two pass configuration was provided.
5. Increasing the allowable effluent silica concentration from 10 ppm to 20 ppm would have no impact on the capital or levelized cost of the electrocoagulation system. Increasing the allowable effluent silica concentration from 10 ppm to 20 ppm would reduce the amount of magnesium chloride fed to the lime softener slightly. But outside of that, there would be no impact on the capital cost and only minimal reduction of the levelized cost.

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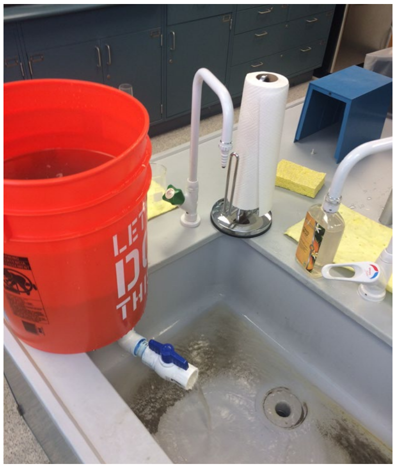
C-43 RESERVOIR

- Slow Rate Sand Filter Lab Test
- Colloidal EC Treatment
- SoilTain Slurry Dewater System

Slow Rate Sand Filter – Lab Test



Solids after 1 hour

Surface water was treated with ElectroCoagulation and filtered thru a slow rate sand filter.

Solids formed after 1 hour and thick solid layer cracked after 2 days.

Solids 2 days

Solids 44 days

“Colloidal Fines Coagulation”

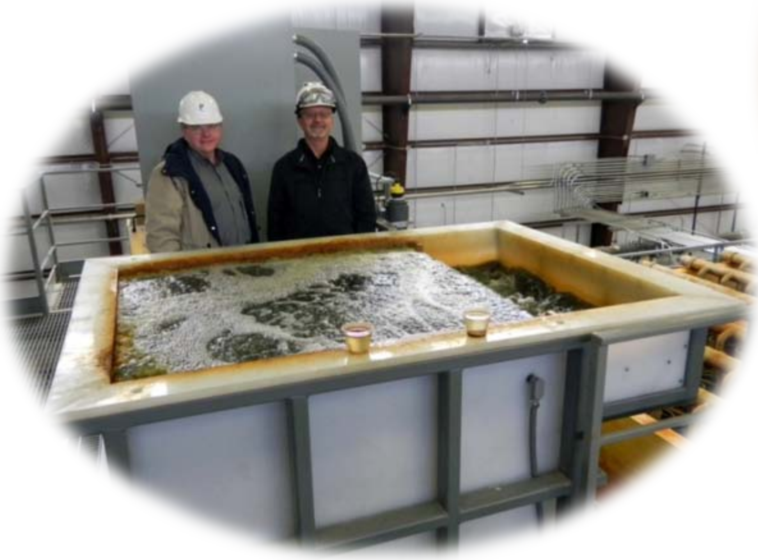
Powell Water

Electro***C***oagulation (**ECpw**^{tm}), the passing of electrical current through water, **REMOVES Colloidal Solids** **WITHOUT** chemicals.

4,300 PPM TDS
16,000 PPM TSS

Suspended Particles Smaller than 11 microns

Separation with No Chemicals



500 GPM EC-PW

GPI
GERBERPUMPS
international inc.

Contact:
Bert Gerber, PE
bert@gerberpumps.com
407.834.9104

Colloidal Clay from Mining Operations

Total Dissolved Solids	4,300	mg/l
Total Suspended Solids	16,000	mg/l
Total Solids	20,300	mg/l
Very low conductivity		

SoilTain® Dewatering

High-Flow Sludge Dewatering System

HUESKER

Ideas. Engineers. Innovations.

State-of-the-art sludge disposal

Sludge is generated by processes in a variety of economic sectors and often poses major challenges: sediments can obstruct navigation channels; industrial and mining operations generate large amounts of sludge that require eco-friendly disposal; enormous quantities of sewage sludge are produced every day across the globe, with disused sewage sludge lagoons in particular posing a problematic legacy.

As a general rule, all types of sludge require dewatering as part of any treatment process. This can be achieved by a variety of procedures:

SoilTain®	Spoil area	Chamber filter press
Belt filter press	Centrifuge	Direct removal

By providing a fast and economical means of sludge dewatering, **SoilTain® dewatering tubes** can provide the ideal solution. The large-format tubes offer high process capacity and dewatering performance while occupying relatively little area. The tubes can also be used for the permanent containment of the dewatered sludge cake.

Problems posed by sludge

SoilTain® sludge dewatering applications

The direct removal of waterlogged sediments and residues from mines, industrial plants, construction sites and sewage works often involves high cost and effort. It therefore tends to be more economical to dewater the sludge prior to any disposal operation.

SoilTain® tubes offer a fast and cost-effective dewatering solution that is suitable for many different sludge types.

Sediments

Sediments, which comprise a mixture of mineral and organic material, are often polluted by TBT, PCB and heavy metals such as Mercury or Lead.

Mining residuals

Mining operations continuously generate large volumes of sludge which, depending on the constituents, may pose an environmental hazard.

Industrial sludge

Industrial processes also produce mineral and organic sludges that are easier to store, transport or dispose of in a cake form.

Infrastructural sludges

These types of sludge typically arise on construction sites where often there may be little space available for storage.

Sewage sludge

Sewage sludge is the product of biological waste water treatment processes. Small treatment plants frequently have no mechanical dewatering equipment.

The SoilTain® process

Dewatering with SoilTain®

1. Extraction

The first step is to remove the sludge. Sediments, for instance, can be extracted by a suction dredger. Other sludges may be continuously produced as a by-product.

Benefits of SoilTain®

- Extremely high hourly processing rates
- Handling without the need for any interim storage
- System mobility

2. Conditioning

The sludge is conditioned through the addition of a flocculating agent. This causes the particles suspended in the water to agglomerate together into larger flakes, so-called flocs.

Benefits of SoilTain®

- Low mechanical loads acting on flocs
- Low plant requirement (only one machine needed)

3. Dewatering

The gravity drainage process ensures the steady removal of water from the sludge in the technical textile tube. The specific opening size of the high-performance woven textile ensures retention of the solid fraction of the sludge while allowing the water to escape from the tube.

Benefits of SoilTain®

- Recirculation of water is possible
- Very high filling volume capacity
- Stackability of tubes
- Flexible extension (through addition of tubes)

4. Disposal

Through the steady process of consolidation, the water content in the tubes decreases until it can be tipped, incinerated or otherwise used for a particular purpose.

Benefits of SoilTain®

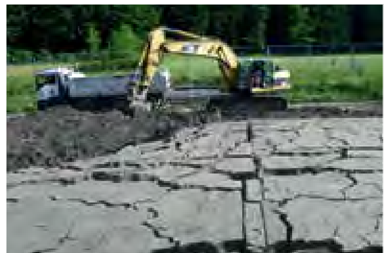
- Sludge encapsulation prevents rewetting
- Tubes are also suitable for permanent containment
- Low area requirement

The ideal solution
SoilTain® Dewatering Tubes

SoilTain® tubes offer a fast and economical means of sludge dewatering. The large-format tubes offer high process capacity and dewatering performance while taking up relatively little space. This helps to speed up progress on site.

The tubes, which are made of purpose-developed, high-performance woven technical textile material, can be stacked to increase storage capacity still further. Cost savings are also achieved by the lower machinery and associated power and fuel demands for dewatering and transportation of the sludge from the site. The tubes can be used for permanent containment of the dewatered and consolidated material. There is no risk of rewetting, e.g. by rainwater, even where the tubes are in use for longer periods. As a result, a higher quantity of dry solid residue is achievable than by spoil area dewatering. SoilTain® not only acts as a reliable, long-term containment system, it also minimizes the odour emissions from the sludge.

SoilTain® offers a state-of-the-art solution to sludge dewatering.



HIGH EFFICIENCY

- **Rapid dewatering within a short period**
- **Flexible filling capacity through variation of tube size and tube number**
- **High resource efficiency (low energy, capital and labor requirement)**
- **High dry residue quantity**
- **Flexible use for temporary project-specific or continuous dewatering processes**

SoilTain® range

Standard tube sizes from 26.2 ft (8 m) circumference and 32.8 ft (10 m) length to 91.8 ft (28 m) circumference, 213.3 ft (65 m) length providing a 2093 yd^3 (1,600 m^3) storage capacity. Tube sizes can also be customized to meet project-specific requirements. HUESKER employs a unique weaving process in conjunction with special stitching techniques and sewing machines in order to optimized the seam layout and achieve high tensile strengths at the seams. The tubes are typically supplied on steel cored rolls. The product has been successfully tested for environmental soundness. HUESKER operates a quality management system and has been certified to ISO 9001.

HUESKER SoilTain® service

- Engineering support for customized tube design
- Placement planning and area calculation
- Optimization of tube sizes and numbers
- Custom-manufacture of tubes to meet project requirements
- Recommendation of local specialist operators

SoilTain® – large sludge volumes rapidly dewatered at comparatively low costs

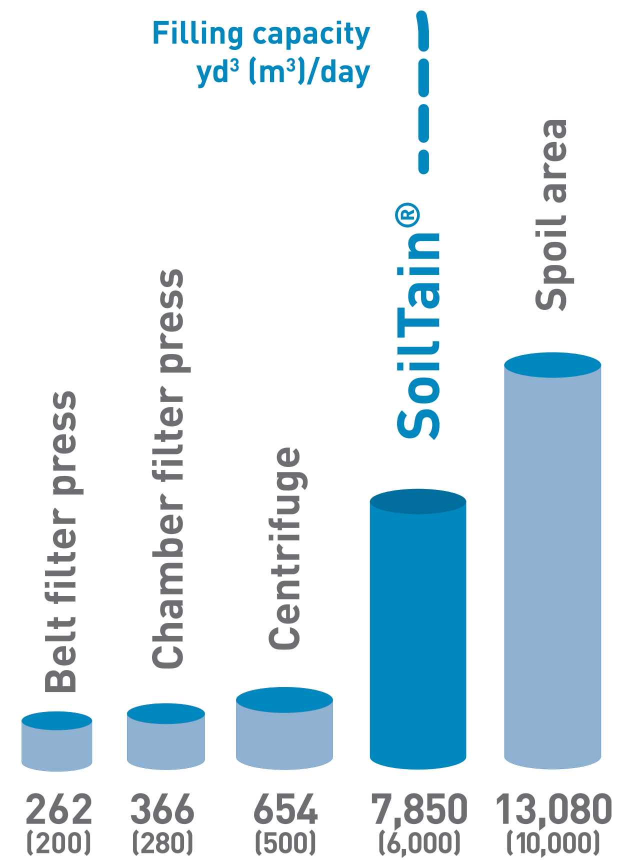
SoilTain® strengths

Three crucial factors

Various factors require consideration when choosing the best system for a particular sludge dewatering and disposal application.

Decision-making criteria include the necessary dewatering capacity and speed, water quality, mobility, available space and maintenance requirement, and, not least, the associated investment. Experience has shown that system efficiency is ultimately the decisive factor on the majority of projects. It is important to remove the sludge from the problem zone as rapidly as possible and quickly reduce its volume to facilitate disposal while at the same time helping to minimize the overall project costs.

The three crucial factors are illustrated by the following example of a project with 130,800 yd^3 (100,000 m^3) in-situ sludge with a dredged volume of 451,240 yd^3 (345,000 m^3).



Filling capacity

This denotes the sludge volume that can be fed to the dewatering medium within a predetermined period (here, within one day or ten working hours). This step entails the highest process costs due to the required expenditure on labor and plant. The faster the sludge is removed, the lower the costs for the overall dewatering operation.

Process time

Total cost

Process time

In addition to the filling operation, the dewatering process also includes the subsequent volume reduction phase. The cake, i.e. dry mass, remaining at the end of this process is then suitable for disposal. The short process time achieved by SoilTain® could only be matched by mechanical means through the use of some 12 centrifuges, 22 chamber filter presses or 30 belt filter presses.

The diagram presents a comparison based on the use of a single centrifuge or press.

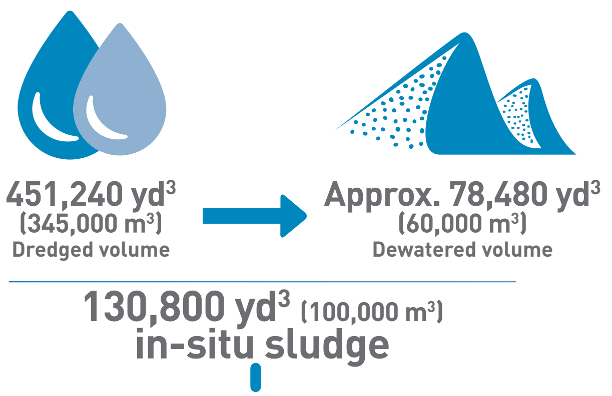
SoilTain®
Approx. 4 months

Spoil area
Approx. 2 years

Centrifuge
Approx. 2 years

Chamber filter press
Approx. 3.5 years

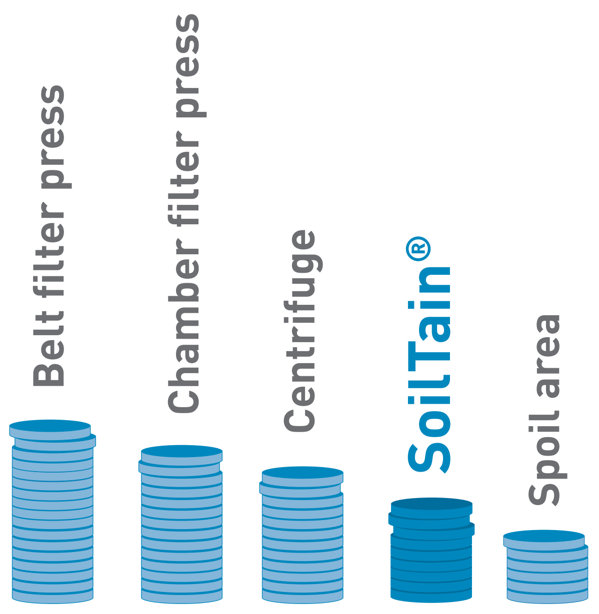
Belt filter press
Approx. 4.5 years



Project costs

Even the most efficient system still has to add up financially. The cost of labor, plant, ancillaries and consumables needed for the different systems varies substantially. To facilitate project cost estimation, HUESKER can provide transparent, illustrative cost comparison calculations upon request.

Source: HUESKER cost simulation tool



SoilTain® – high-flow sludge dewatering

Application example: Sediments
Dockside maintenance dredging

Tributyltin (TBT) was banned worldwide in 2003. It had previously been used as an anti-fouling agent in many ship hull coatings to prevent the growth of marine organisms. As a result, the sediments at Husum docks in northern Germany had been heavily polluted by the toxic chemical.

The maintenance dredging operations involved the extraction of 65,400 yd^3 (50,000 m^3) of polluted dock silt by cutter-suction dredger. To optimize the use of the small area available for dewatering, the SoilTain® Dewatering Tubes were stacked two layers high. The tubes served both to dewater and permanently encapsulate the sediments.

FACTS

- **Disposal of 65,400 yd^3 (50,000 m^3) of TBT-polluted sediments**
- **Tubes stacked in two layers to save space**
- **Simultaneous dewatering and encapsulation**

Application example: Infrastructural sludge
Sludge removal from pit base

An excavation pit in Neuhof in the German Federal State of Hesse contained a 3 ft (1 m) layer of sludge topped by 13 ft (4 m) of water. The sludge had to be pumped off to allow the pouring of an underwater concrete foundation. For excavation stability reasons, casting had to take place prior to removal of the water.

As no large areas were permanently free for sludge dewatering, the sludge was placed in custom-manufactured SoilTain® Dewatering Tubes that fitted to the available space. After dewatering, the sludge cake was removed from the site.

FACTS

- **Disposal of infrastructural sludge**
- **Small area available for dewatering**
- **Use of custom-manufactured SoilTain® Dewatering Tubes**

Application example: Sewage sludge
Filtration and dewatering at sewage plant

A bioreactor at the ETE Uberabinha sewage plant in Brazil produces waste water containing organic particles in suspension. The particles had previously been removed by means of a flotation process, with the floated sludge being returned to the bioreactor. However, the chemicals used in this method slowed down the reaction process.

SoilTain® Dewatering Tubes proved to be the most straightforward and cost-effective alternative. The waste water is now treated with a flocculating agent and filtered by the tubes. The drained water is then readily available for reuse in the bioreactor while the dewatered sewage sludge is later disposed of at a landfill site.

FACTS

- **Filtration of continuously produced waste water**
- **Dewatering and consolidation of sewage sludge**
- **Reuse of filtered water for bioreactor process**

Application example: Mining residuals
Removal of gypsum sludge from open-cast mine

Nickel and zinc are mined near the Finnish village of Kajaani at Talvivaara. The mine has a production capacity of some 10 million tons of ore per year. Previously, the large quantities of gypsum sludge arising during the mining operations had been deposited in lagoons.

A leak in one of the lagoons prompted the trial application of SoilTain® Dewatering Tubes. The tests proved so successful that the tubes are now used for the disposal and permanent containment of all gypsum sludge generated at the mine. As the tubes are stacked in a five-layer pyramidal arrangement, the site space requirement is greatly reduced compared to the original lagoon storage concept used.

FACTS

- **Dewatering of large quantities of gypsum sludge**
- **Safe permanent containment of sludge cake**
- **Following successful trials, system now used for entire production**

Technology Information Request Outline
C43 Water Quality Feasibility Study
April 14 2020

I. Treatment Process

A. Process Flow Diagram - Included

B. Flow Equalization - (Temporary detention of water volume or reduction in flow rate required to implement the treatment process using storage tanks, basins, or other means). Flow can be pumped into a tank to feed two EC units at 3600 GPM each; total 7200 GPM or directly into the EC units from the pumps feeding the C43 water to the EC system.

C. Distribution – the EC treated water will receive solids separation treatment and then the water can be blended together with the untreated water as the total flow is directed to the river.

D. Pre-Treatment Processes – 1/32” screening required which can be by a convex outward shaped self-cleaning screen.

E. Treatment

1. Provide information demonstrating prior pilot/project capability to achieve the project water quality criteria – Lake Jesup Study for SJRWMD and others

2. Treatment chemicals and/or media required for the process will be described Clean-In-Place (CIP) acids required: Sulfuric, Hydrochloric, or Phosphoric

F. Post-Treatment Processes – Solids will need to be separated from the treated water via conventional clarifiers, disk filters, or Heuesker SoilTain bags (see Appendix). Slow rate sand filters also may be an option sized at three (3) units at 465’ square.

G. Collection – Feed water for EC treatment to come from C43 reservoir.

H. Chemical Supply – CIP acids as noted above

II. Residuals Process – This aspect is undefined at the present time. A good estimate of the volume of generated sludge is given.

A. Collection or Removal

B. Volume Reduction/Dewatering

C. Storage – need further discussions with Jacobs and SFWMD regarding disposal of solids generated. Approximately 32,000 lbs/da DMB of solids will be generated. The TP and TN of the solids will be in the range of 3% for TP and 2.5% for TN. The iron % will also be in the 25% range.

D. Transfer

E. Disposal Process and Location

F. Centrate Management

III. Land Area (total)

A. Treatment Facility (including process tanks or basins, chemical storage, electrical system, buildings)

B. Supporting Facilities (Vehicle Access Roads, Fencing, Security, Equipment Garage, Storage, Parking, and Administration)

C. Residuals Handling and Solids Storage

D. Stormwater Management

IV. Power (annual) – given in the report under Executive Summary and O&M Spread sheets section

A. Process requirements

B. Site requirements

C. Monitoring

V. Fuel Consumption (annual)

A. Chemical Supply, Storage, and Transport

B. Site Vehicle Operation

C. Residuals Transport and Disposal

VI. Other Beneficial Attributes – Features and Benefits defined in the proposal

A. Additional Vendor Provided Information

VII. Capital Cost (2020 Dollars) – Included in the Budget Cost section

A. Process Facility (including components described under Items I and II)

B. Land (including components under Item III)

VIII. Operations and Maintenance (Annual) – O&M costs for power and sacrificial plates is included in O&M section.

A. Labor

B. Materials

1. Acquisition

2. Management

3. Disposal

C. Residuals

D. Power

E. Fuel

F. Monitoring or Other

HWTT

HYBRID WETLAND TREATMENT TECHNOLOGY
C-43 WEST BASIN STORAGE RESERVOIR TREATMENT PROJECT

Prepared By:
Watershed Technologies, LLC

May 2020

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Executive Summary

Watershed Technologies, LLC (WTLLC) is pleased to submit this proposal for use of the patented Hybrid Wetland Treatment Technology (HWTT) for the C-43 West Basin Storage Reservoir (WBSR) project. HWTT has proven be an effective method for the removal of phosphorus (P), nitrogen (N) and other pathogens in waters of the State of Florida with ten systems operating across the State for over twelve years for several sites. The HWTT facilities have relatively low-cost benefit values compared to other technologies and high reduction rates for both P and N. Several of the sites have replaced non-performing projects, can be located within small areas of land, require minimal infrastructure, and can successfully treat varying qualities of water in an environmentally sound manner. Other existing HWTT systems are used to provide necessary hydration of downstream wetlands. The technology has also shown that it can be rapidly implemented, and there is no lag in treatment performance upon initiation of pulse flows after long periods of no flows or droughts. Multiple HWTT facilities have been permitted by the Florida Department of Environmental Protection (FDEP), two Water Management Districts, municipalities, and counties. Construction, performance, and operational reports are reviewed by these agencies on a regular basis.

The cost benefit values have been calculated for this proposal based upon the projected costs, stated water quality specifications and other assumptions. The projected Cost Benefit is $83 per pound of P removed; $13 per pound of N removed; and $11 per pound for P and N combined. Total projected capital costs are $21,190,929 excluding land (686 acres required), and projected annual Operations & Maintenance is $7,185,860.

HWTT projects can be accessed via a proprietary Dashboard system, allowing real-time, on-line internet access to all HWTT sites. The program includes flow treated, chemical dosing levels, and system status (on-line, off-line, partial). Facility diagrams, statistics, and history are presented, and live camera views are also displayed. Several favorable articles have been written regarding HWTT; samples are included in the Other Beneficial Attributes Section of this Report.

I. Treatment Process

A conceptual treatment process was established to achieve the effluent water quality targets established in the request for vendor information. Those water quality targets include a 50% reduction in total phosphorus (TP) (target of 0.08 mg/L) and Total Suspended Solids (TSS) (10 mg/L) together with a 33% reduction in total nitrogen (TN) (target of 1.0 mg/L). It was assumed that these targets must be met at all times and are not to be considered annual average efficiencies. Removal efficiencies were based on performance of other HWTT facilities currently being operated throughout the state of Florida. A description of the treatment process elements is provided below.

A. Process Flow Diagram

A conceptual process flow diagram was established assuming an ideal site geometry with no constraints (for example, wetlands) which would require an increase in the area requirement for the project. The facility treatment process would consist of two identical treatment trains. Figure I-1 illustrates the single treatment train configuration with proposed raw water inflow locations. Note that the stated flow rates represent the total flow at those injection points when accounting for the sum between the two treatment trains. Figure I-1 is a scaled diagram which shows conceptually the location of each of the primary facility features.

B. Flow Equalization

No flow equalization is required as part of the HWTT facility due to the ability for chemical dosing rates to be adjusted quickly based on changing volumes and water chemistry. It is assumed that major changes in flow from the reservoir would be relatively predictable and would be coordinated with the water quality component to maximize performance of the facility.

C. Distribution

One of many benefits of HWTT technology is the ability to distribute flows from one treatment element using gravity flow alone. Once water is delivered to the site from the reservoir, either by gravity or with an inflow pump station, no additional pumping is needed to complete the process except due to head conditions wherein water would be pumped offsite following the treatment process. Following intake into the facility, water is routed between treatment ponds using standard corrugated metal culverts, and water levels are controlled through the use of riser structures.

D. Pre-Treatment Processes

No pre-treatment is expected for this facility based on available water quality data. Minor modifications to the site may be necessary once the water quality impacts associated with storage within the reservoir are better identified. This pretreatment would consist of a limerock berm, which could be implemented using a small area and would only be required if Alkalinity of the water discharged from the reservoir is ultimately lower than values currently expected based on available data.

E. Treatment

HWTT technology is well established throughout Florida and is currently being implemented in different watersheds, treating water with a wide range in water quality characteristics. All projects implemented to date have demonstrated the ability for the technology to decrease effluent concentrations for a variety of water quality parameters (for example, Total Phosphorus, Total Nitrogen, Total Suspended Solids, and Fecal Coliform Bacteria).

The treatment process uses either Aluminum Sulfate (alum) alone or in conjunction with Polyaluminum Chloride (PAC) depending on the Alkalinity and pH of the raw water being treated. Based on available data, alum alone should be sufficient for this facility; although, the impacts on water quality associated with storage within the reservoir cannot be quantified at this time.

Following chemical dosing, water is routed through settling ponds where longer residence times and slower flow velocities allow floc to settle out of the water column. The settling ponds remove the vast majority of the floc material; however, following the settling ponds, additional treatment is provided by a series of natural wetland systems. These wetlands consist of both Floating Aquatic Vegetation (FAV) and Submerged Aquatic Vegetation (SAV) to provide additional physical removal of floc, which may have been too buoyant to be removed in the settling ponds, through adsorption and removal of dissolved nutrients from direct assimilation of nutrients by the vegetation. The species of vegetation selected and the potential use of Emergent Aquatic Vegetation (EAV) is dependent on site specific conditions and actual water quality characteristics of the WBSR inflow, which would be determined through the initial optimization process.

F. Post-Treatment Processes

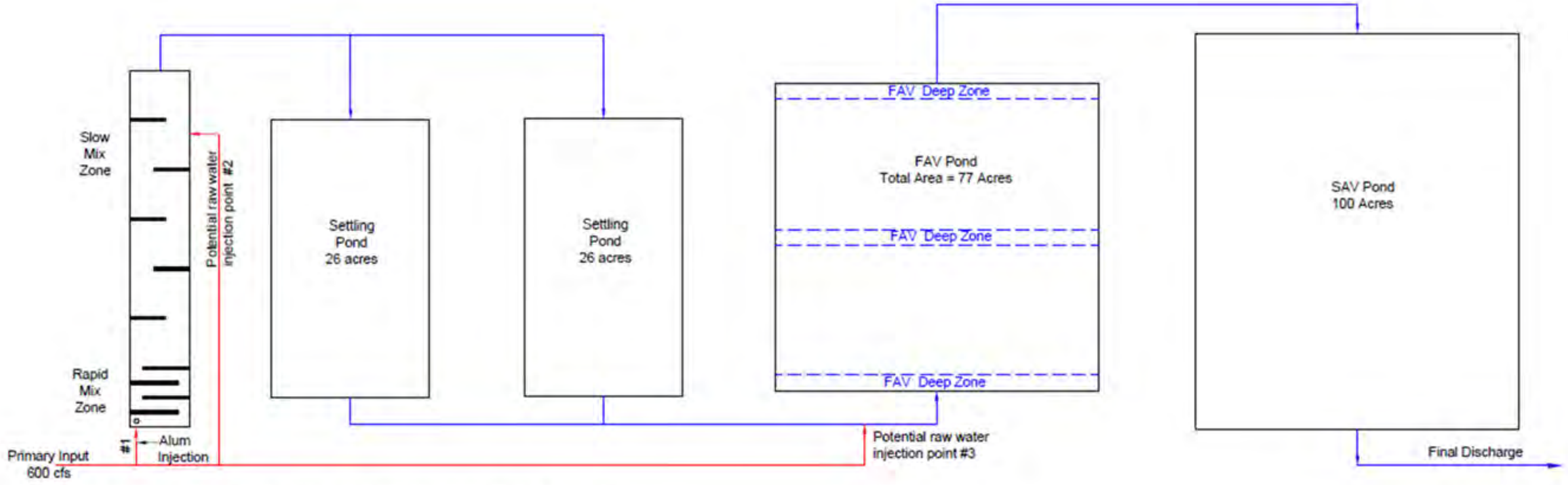
Similar to pre-treatment processes, no post-treatment is expected for this facility. Depending on actual water quality characteristics, a limerock berm may be incorporated into the back end of the SAV ponds to add Alkalinity to the water prior to discharging back to the C-43 Canal. HWTT technology has proven to be effective at removing chemicals added at the beginning of the treatment process before discharging back to the receiving water body thereby preventing the need for extensive post-treatment processes.

G. Collection

Following treatment through the parallel treatment trains, water will be discharged via gravity to a common final collection canal at the location of the outflow pump station intake.

H. Chemical Supply

Alum is available in sufficient quantities to allow the facility to treat the anticipated volumes of water to the target effluent water quality limits. A bulk chemical price has been obtained from a local supplier and those prices are incorporated into the operations and maintenance costs presented in subsequent chapters of this document.

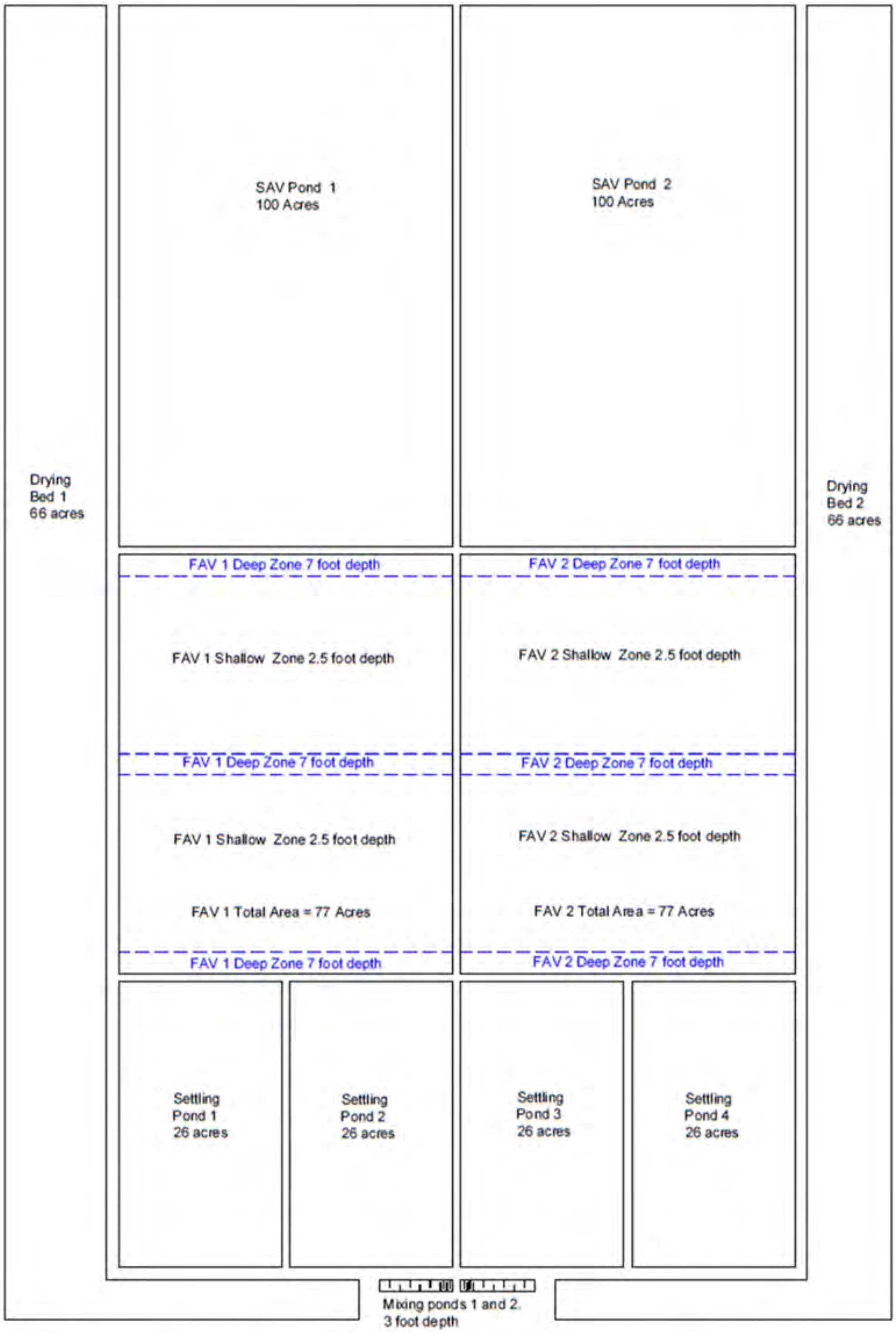


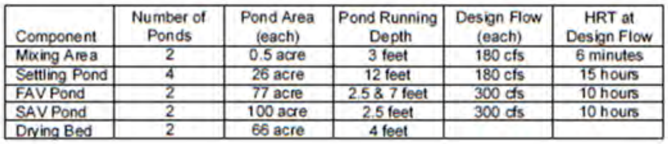
For pond sizing the following assumptions were made:

Input #1 + Input #2 = 360 cfs

Input #3 = 240 cfs

Figure I-1. Process flow diagram for one of two treatment trains. Flows represent the estimated total flow injected at depicted locations when considering both treatment trains at full capacity.





Component	Number of Ponds	Pond Area (each)	Pond Running Depth	Design Flow (each)	HRT at Design Flow
Mixing Area	2	0.5 acre	3 feet	180 cfs	6 minutes
Settling Pond	4	26 acre	12 feet	180 cfs	15 hours
FAV Pond	2	77 acre	2.5 & 7 feet	300 cfs	10 hours
SAV Pond	2	100 acre	2.5 feet	300 cfs	10 hours
Drying Bed	2	66 acre	4 feet		

Figure I-2. Process flow diagram depicting primary HWTT facility infrastructure for WBSR.

II. Residuals Process

A. Collection or Removal

Alum is mixed with the reservoir discharge at the front end of the system to facilitate flocculation in the facility. The four (4) settling ponds are used to collect solids by slowing water velocities and promoting settling prior to discharge to the FAV and SAV treatment ponds. Solids which accumulate at the bottom of each of the settling ponds are in a state where they can be removed via pumping. Floc pumps installed with intakes at the base of each of the settling ponds will be used to periodically remove solids.

B. Volume Reduction/Dewatering

Dewatering of the treatment residual happens passively through the use of drying beds incorporated in both of the treatment trains. The drying beds are sized based on the anticipated accumulation rate of solids and are large enough to store sufficient water from the settling ponds in an effort to completely remove the solid material during a settling pond cleanout phase. The passive dewatering/volume reduction allows for minimal operating and maintenance expenses associated with this component of the treatment process.

C. Storage

No storage other than what is provided within the drying beds is required for solids that are produced by the treatment process. As solids dry, consolidation will occur therefore increasing the available storage volume within the drying beds for subsequent removal of solids from the settling ponds. Once solids are sufficiently dried and have accumulated to a point where insufficient storage volume exists within the drying beds, they are transported and disposed of based on the procedures outlined below.

D. Transfer

Transfer of dewatered solids from the drying beds will occur after the water content has decreased to a satisfactory level. A front-end loader or other readily available equipment can be used for excavating the material from the drying bed for transfer to one of two locations within the site, as described below.

E. Disposal Process and Location

Accumulated solids have been demonstrated to have additional potential for binding nutrients and can therefore be recycled within the system to continue providing a treatment benefit under HWTT. Typically, the solids material will be excavated and spread throughout an FAV cell during the routine maintenance period for those ponds. An additional disposal method exists if or when the neighboring reservoir dries out, which would be infrequent but likely to occur some years during project implementation. During dry-out conditions, solids material could be spread throughout the reservoir to the extent possible or alternatively transported to a disposal facility. Similar to disposal in the FAV ponds, this process would allow for quick and efficient disposal of the material, but more importantly, the method would assist in the binding of nutrients during the refilling of the reservoir. Such binding would reduce the degree of nutrient resuspension that typically occurs when these conditions exist.

F. Centrate Management

No centrate will be produced as part of the HWTT facility. The solids material will be naturally dewatered through passive processes and the water content will be lost via seepage and evapotranspiration.

III. Land Area (Total)

The total projected land area for the WBSR HWTT Treatment proposal is 668 acres (Table III-1). The treatment portion is comprised of 459 acres; supporting facilities are 77 acres; and residuals and solids storage consist of 132 acres.

Table III-1. WBSR HWTT Land Area Requirements in Acres.

Description	Total Area (ac)
Mixing Chambers	1.0
Settling Ponds	104.0
FAV Ponds	154.0
SAV Ponds	200.0
Drying Beds	132.0
Supporting Facilities	
Internal Embankments	33.6
Partial Bypass Canal	10.8
Perimeter Buffer	25.0
Miscellaneous (staging area, storage, parking, etc.)	7.6
TOTAL	668.0

A. Treatment Facility

The treatment area utilizes 459 acres, consisting of two treatment trains with multiple treatment ponds in series. The mixing zone where chemical is mixed with the incoming raw water from the reservoir will require approximately one (1) acre of land in total. From there, four (4) settling ponds will be constructed to allow for floc to settle out followed by FAV and SAV ponds. The estimated total acreage for the settling, FAV and SAV ponds is 104 acres, 154 acres and 200 acres, respectively, for a total pond treatment land area of 459 acres.

B. Supporting Facilities

Supporting facilities are considered as areas required for access (that is, internal access roads, perimeter access road, and embankments), chemical storage/dosing facilities, and miscellaneous areas such as those used for storage, parking, pump station pads, and other similar uses. The total land area for supporting facilities for the C43 HWTT facility is anticipated as being approximately 77 acres.

C. Residuals Handling and Solids Storage

Solids will be pumped to the drying beds after accumulating in the settling ponds. The drying beds allow for passive dewatering of the solids material that is a biproduct of the treatment process through evapotranspiration and seepage. The drying beds are sized based on an assumed solids accumulation rate in the settling ponds. Based on the anticipated flows to be treated, two beds will be required sized at 66 acres each. The total land area for residuals handling and solids storage is therefore 132 acres.

D. Stormwater Management

No additional land area is required for management of runoff resulting from onsite rainfall. All runoff will be directed towards onsite ponds used in the treatment process except for runoff from the site perimeter buffer, which will be graded towards onsite drainage swales. This area is included in the acreage for supporting facilities above.

IV. Power (Annual)

After raw water is dosed with chemical at the beginning of the treatment process, all subsequent elements rely on gravity and natural processes for treatment; therefore, the power requirement for the technology is minimal. Power is required for operating the chemical storage building and the associated equipment (for example, chemical dosing pumps and monitoring equipment). Power for operating the floc recycling pumps is also required.

It is assumed that inflow and outflow pump stations are to be excluded from this proposal; accordingly, the power requirements associated with those features are not included.

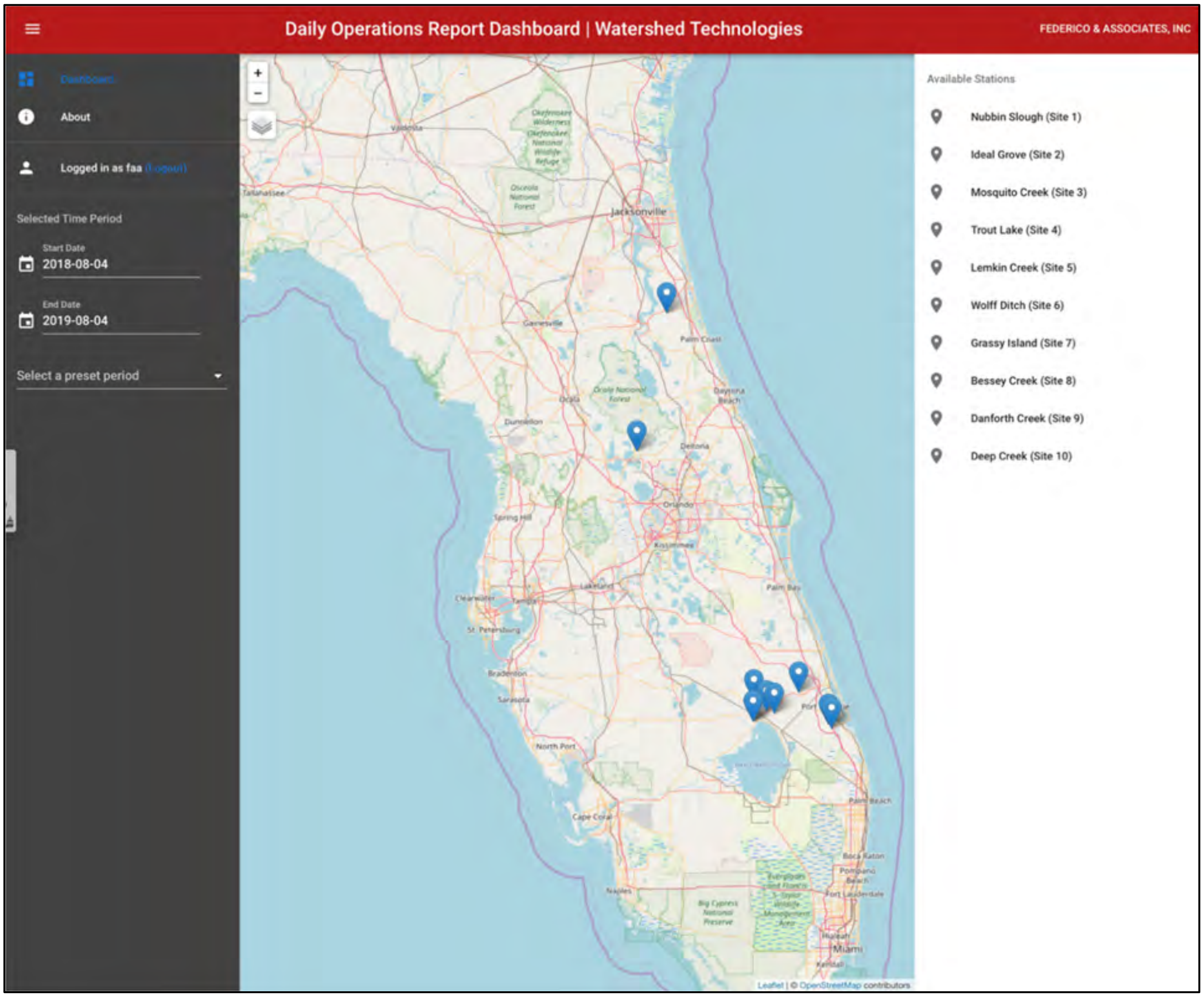
V. Fuel Consumption (Annual)

All permanent infrastructure requiring power within the HWTT facility is based on electric power. It is assumed that inflow and outflow pump stations are to be excluded from this proposal; accordingly, the power requirements associated with those features are not included. The fuel requirements are, therefore, minimal, and it is assumed that only one personnel vehicle will require fuel for operating the site. Fuel is required for operating machinery used in the periodic tilling process and is included in the unit cost for tilling in the Operations and Maintenance budget.

VI. Other Beneficial Attributes

Hybrid Wetland Treatment Technology (HWTT) Description

All ten HWTT projects are operational and assist the State in achieving the Total Maximum Daily Load (TMDL) for four impaired water bodies as part of the Best Management Action Plans (BMAPs). Assistance is provided through the successful removal of P and N for over 12 years at several sites. A significant level of performance data has been analyzed and reported for the ten HWTT sites since their inception. Reports and performance data are reviewed on an on-going basis by the Florida Department of Agriculture and Consumer Services (FDACS) and by multiple agencies and municipalities (South Florida Water Management District, St. Johns Water Management District, FDEP, Martin County, St. Johns County, Lake County, and the City of Eustis). The FDACS review also includes monthly operational reports for all sites, semi-annual presentations, and annual reports. An online Dashboard provides real-time data and operational statistics for all facilities.



Daily Operations Report Dashboard | Watershed Technologies

Logged in as faa

Selected Time Period

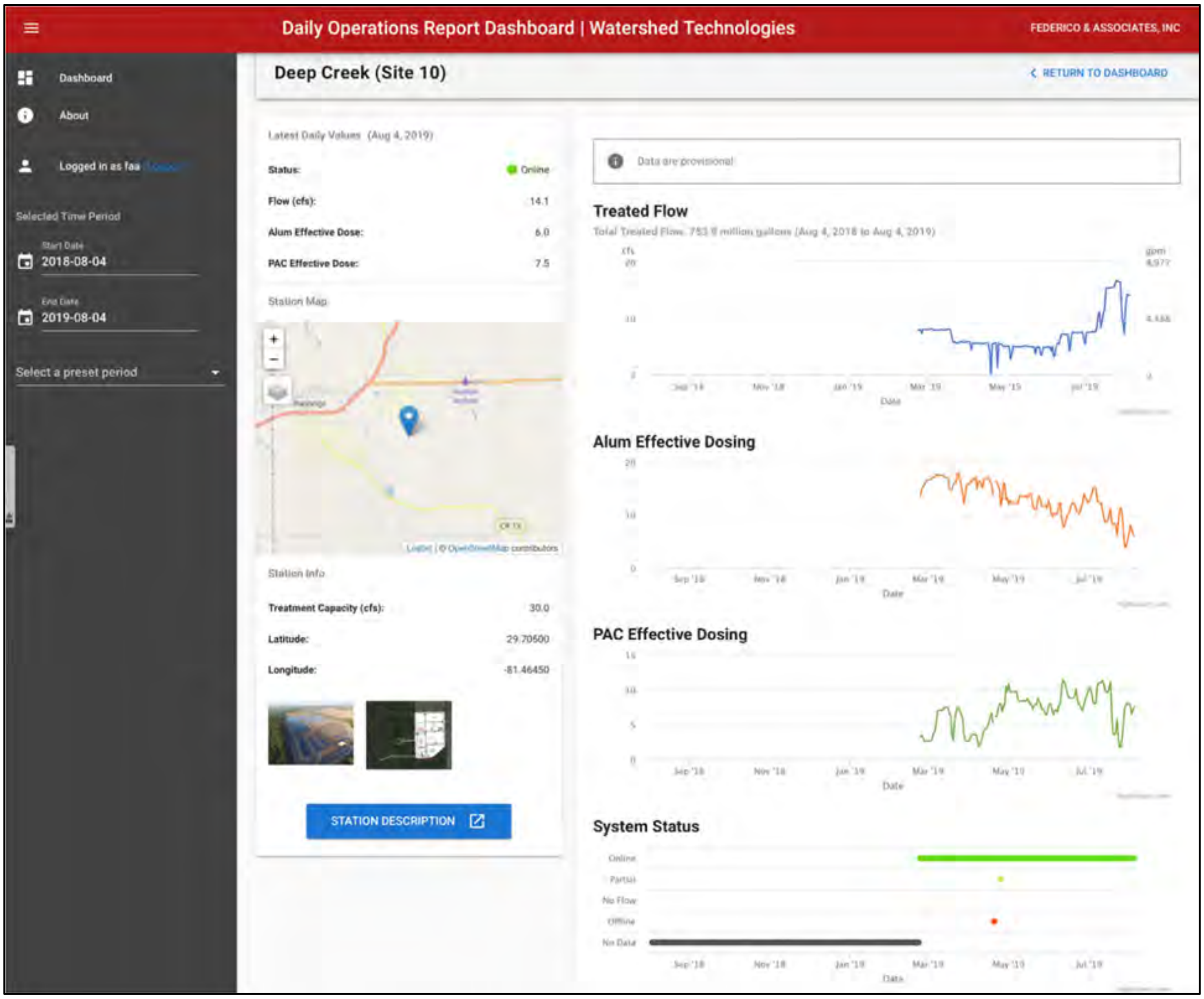
Start Date 2018-08-04

End Date 2019-08-04

(http://104.131.127.240/dor/). Login credentials are:

username: guest

password: jacob



Deep Creek (Site 10)

Selected Time Period

Start Date: 2018-08-04

End Date: 2019-08-04

Latest Daily Values (Aug 4, 2019)

Status:	Online
Flow (cfs):	14.1
Alum Effective Dose:	6.0
PAC Effective Dose:	7.5

Station Info

Treatment Capacity (cfs):	30.0
Latitude:	29.70500
Longitude:	-81.46450

Treated Flow

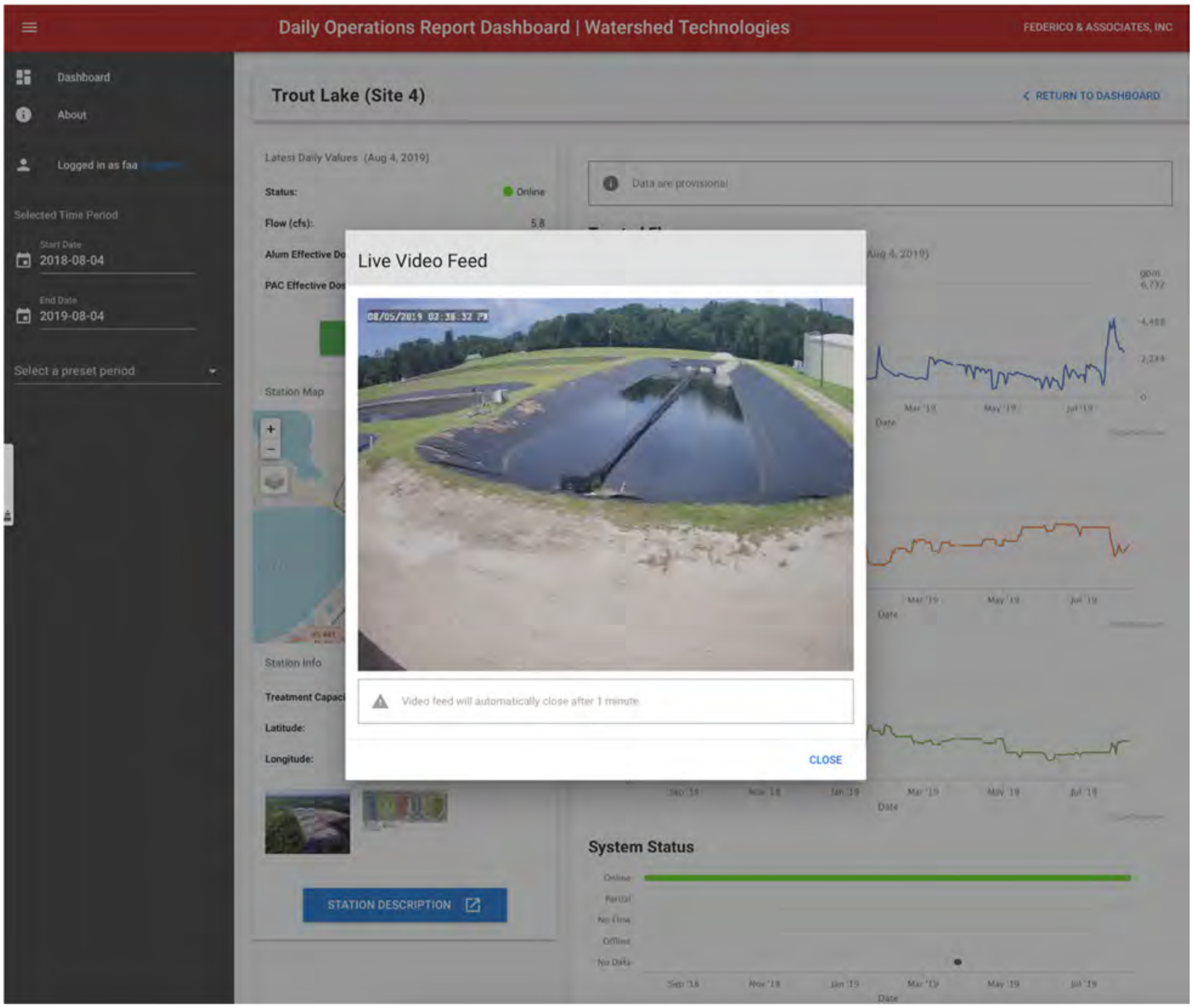
Total Treated Flow: 753.8 million gallons (Aug 4, 2018 to Aug 4, 2019)

Alum Effective Dosing

PAC Effective Dosing

System Status

("No Data" represents the period prior to implementation of telemetry.)



Logged in as faa

Selected Time Period

Start Date: 2018-08-04

End Date: 2019-08-04

Select a preset period

Latest Daily Values (Aug 4, 2019)

Status: Online

Flow (cfs): 5.8

Alum Effective Do

PAC Effective Dos

Data are provisional

Video feed will automatically close after 1 minute

Treatment Capaci

Latitude:

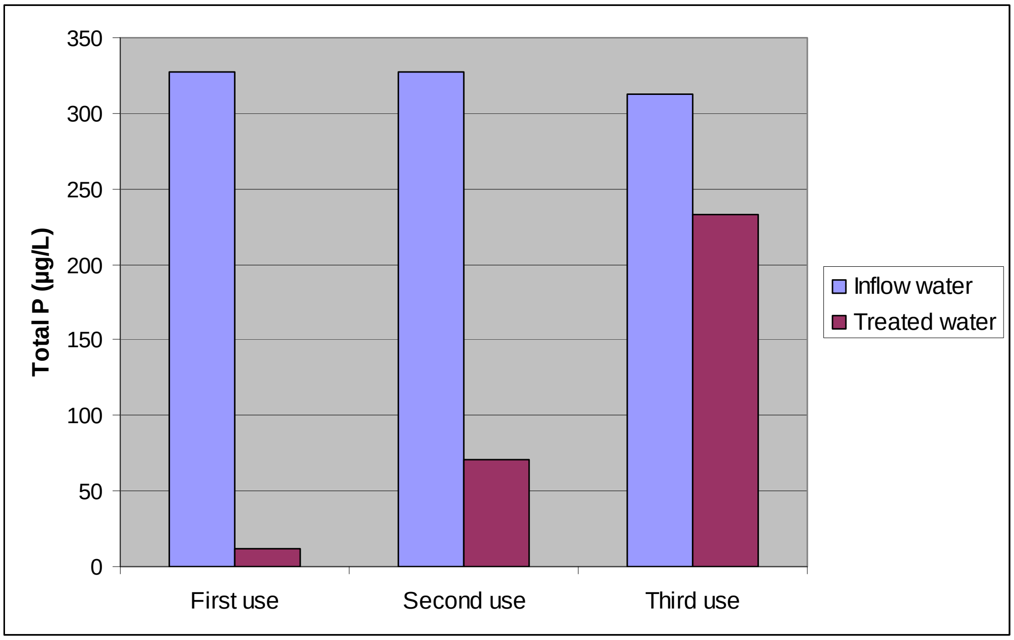
Longitude:

HWTT Performance

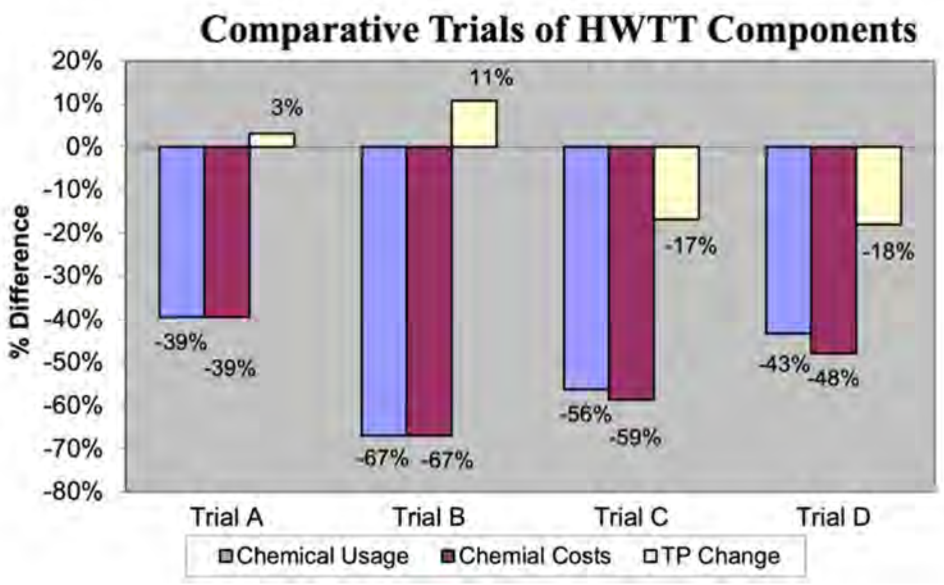
The HWTT technology includes pre-existing intellectual property represented and covered by and in three US Patents (7,014,776; 7,179,387; and 7,510,660) as well as other patents and patent applications (both allowed and pending) and related proprietary know-how and other intellectual property, including software and works of authorship noted below (collectively, the "HWTT," "HWTT Technology," or "HWTT systems") owned by Watershed Technologies, LLC. The FAVT technology includes pre-existing intellectual property represented and covered by and in three US Patents (7,074,330; 7,556,735; and 7,632,407) as well as other patents and patent applications (both allowed and pending) and related proprietary know-how and other intellectual property, including software and works of authorship noted below (collectively, the "FAVT," "FAVT Technology," or "FAVT systems") owned by Water & Soil Solutions, LLC.

HWTT uses an extremely cost-effective and highly reliable approach to treatment, demonstrating an average P removal rate of 86% with the larger sites exceeding 90% P reduction. The technology is also highly successful in the removal of N (up to 68%), and other pathogens and has replaced systems that were not performing. Key attributes are described below:

- The treatment system is comprised of chemical additives (alum) combined with vegetated and non-vegetated aquatic zones. Years of testing have shown that the use of alum does not introduce metal contamination as could the use of other chemical coagulants (for example, iron). The water discharged from the treatment site has been tested for over ten years at multiple locations and has been demonstrated to FDEP to be non-toxic to standard bioassay organisms.
- The floc produced in the treatment process is dried on-site.
- In zones with floating aquatic vegetation (FAV), ideal coverage is usually achieved by periodic harvesting; however, since FAV are predominantly water, removal is costly and inefficient. Floating Aquatic Vegetative Tilling (FAVT) overcomes these constraints in the following manner: (1) the FAV wetland assimilates additional nutrients and can grow to a high density; (2) the wetland is drained during the dry season, thereby stranding the FAV on the soil of the shallow zones to naturally desiccate; (3) if there is sufficient dried floc the material can be spread across the shallow zones (4) the plant material and floc is then tilled into the soil; (5) the wetland is reflooded; and (6) FAV that is stored in deeper zones are used to repopulate the marsh for the subsequent growth period. There are several operational treatment wetlands that have successfully implemented this approach.
- During periods when parts of the WBSR are dry, the dried floc can opportunistically be distributed over the area and tilled into the soil. The incorporated floc will assist in reducing the reflux of nutrients from the land as the reservoir is reflooded.
- The technology can be rapidly implemented.
- No lag in treatment performance upon initiation of pulsed flows or prolonged periods of no-flow or drought.
- The technologies demonstrate cost-effective phosphorus and nitrogen removal.
- Provides the effectiveness and reliability of chemical treatment systems for P and N removal (up to 96% and 68%, respectively) while minimizing chemical use through the reuse of the residual nutrient removal capability of alum flocs.



- Significant reductions in chemical use are accomplished with intermittent dosing, internal floc recycling, and other strategies.
- Relative to conventional alum-based systems, HWTT facilities enabled a 39% to 67% reduction in chemical use in full-scale comparative trials.

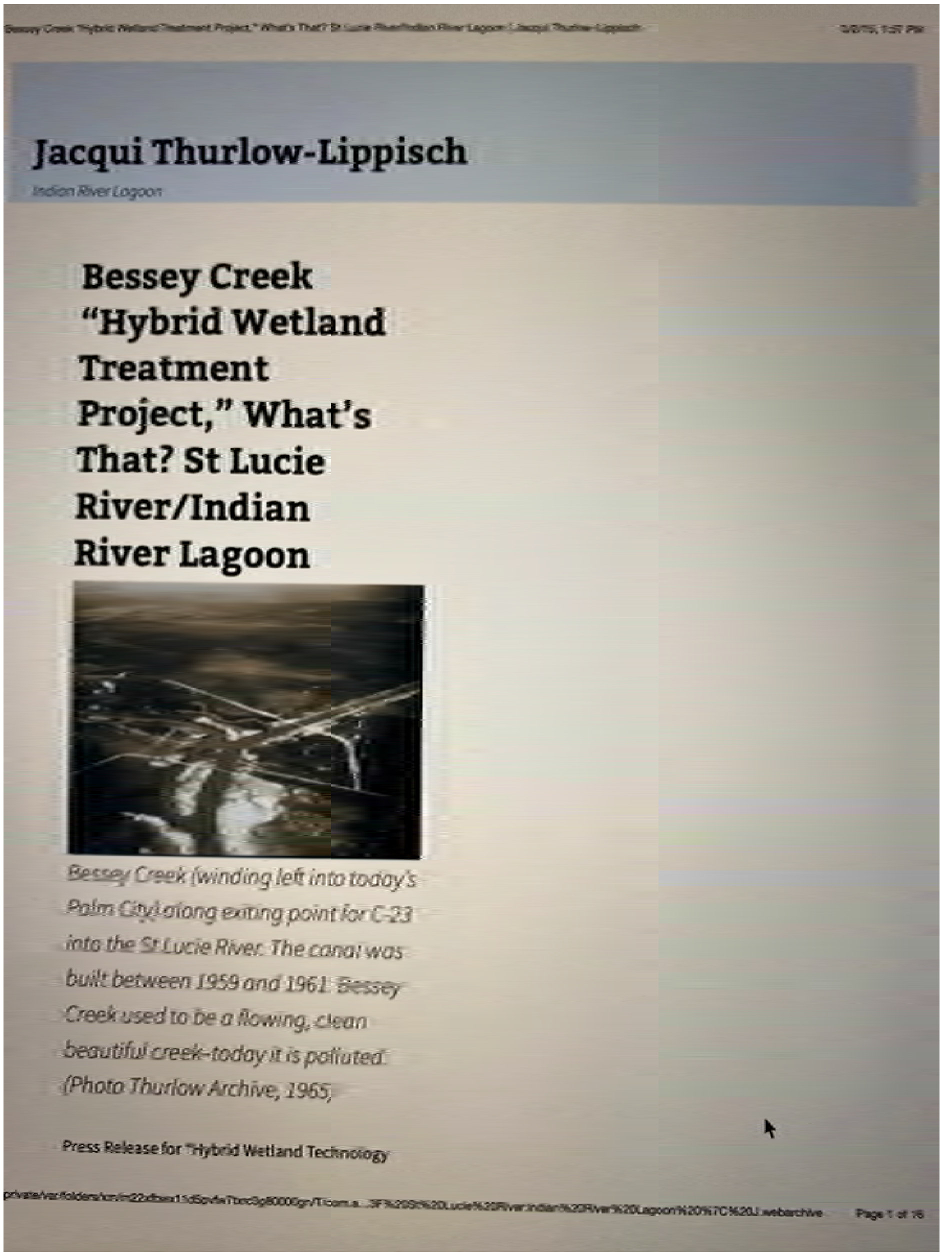


- Compared to traditional wetland treatment systems, there is a significant reduction in land footprint.
- The facility has minimal infrastructure.
- Assists in achieving restoration goals.
- Provides environmental benefits via wetland and wildlife habitat restoration and creation.
- Utilizes appropriate sequences and configurations of wetland unit processes to transform/remove additional contaminants and pathogens.

HWTT News Articles

Several articles have been written regarding the HWTT technology and projects. A compilation is provided below with links to the articles.

(Article Available in Submission)



Jacqui Thurlow-Lippisch

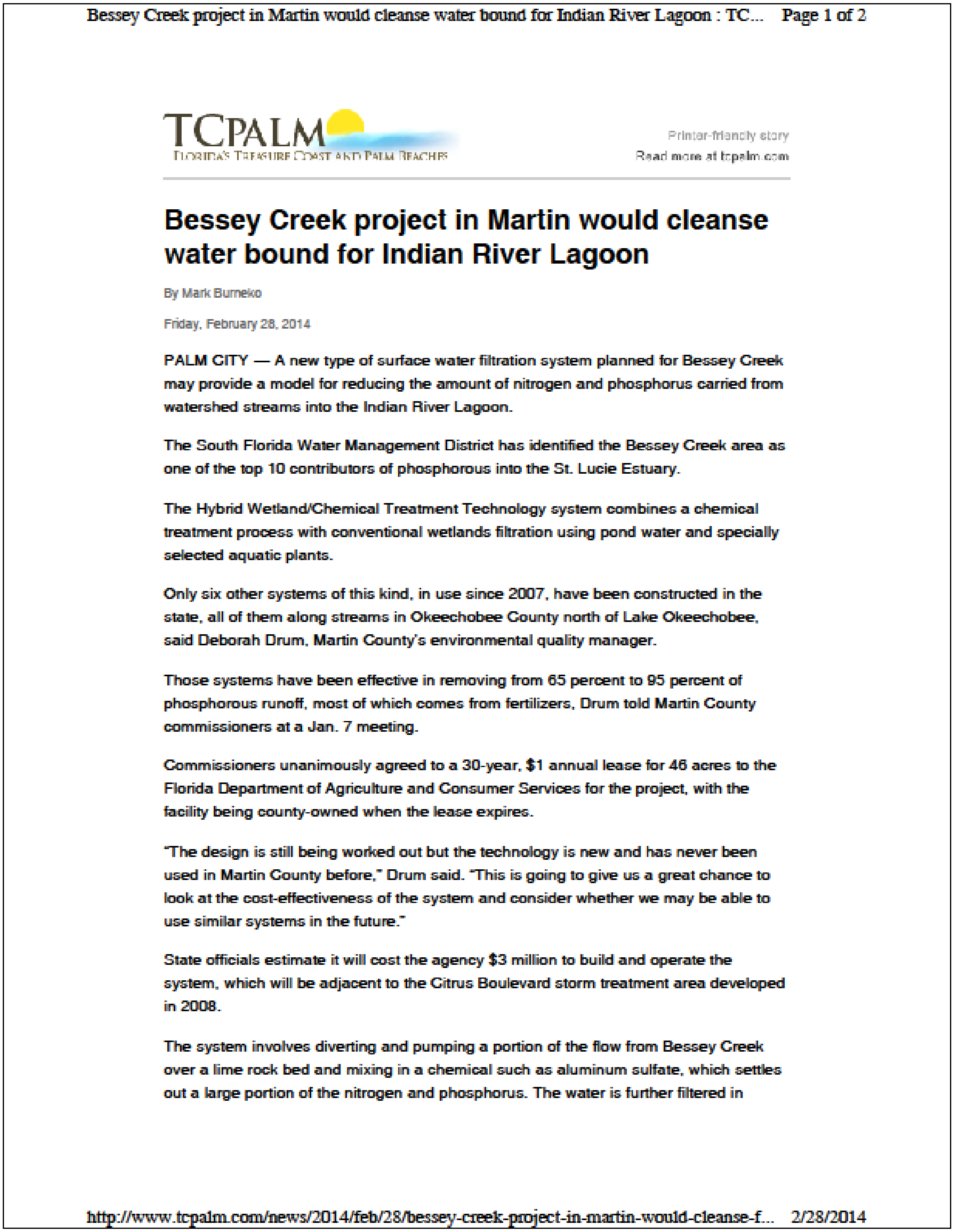
Indian River Lagoon

Bessey Creek "Hybrid Wetland Treatment Project," What's That? St Lucie River/Indian River Lagoon

Bessey Creek (winding left into today's Palm City) along exiting point for C-23 into the St Lucie River. The canal was built between 1959 and 1961. Bessey Creek used to be a flowing, clean beautiful creek–today it is polluted. (Photo Thurlow Archive, 1965)

Press Release for "Hybrid Wetland Technology

(Double Click to Access Article)



Bessey Creek project in Martin would cleanse water bound for Indian River Lagoon : TC... Page 1 of 2

TCPALM
FLORIDA'S TREASURE COAST AND PALM BEACHES

Printer-friendly story
Read more at tcpalm.com

Bessey Creek project in Martin would cleanse water bound for Indian River Lagoon

By Mark Burneko

Friday, February 28, 2014

PALM CITY — A new type of surface water filtration system planned for Bessey Creek may provide a model for reducing the amount of nitrogen and phosphorus carried from watershed streams into the Indian River Lagoon.

The South Florida Water Management District has identified the Bessey Creek area as one of the top 10 contributors of phosphorous into the St. Lucie Estuary.

The Hybrid Wetland/Chemical Treatment Technology system combines a chemical treatment process with conventional wetlands filtration using pond water and specially selected aquatic plants.

Only six other systems of this kind, in use since 2007, have been constructed in the state, all of them along streams in Okeechobee County north of Lake Okeechobee, said Deborah Drum, Martin County's environmental quality manager.

Those systems have been effective in removing from 65 percent to 95 percent of phosphorous runoff, most of which comes from fertilizers, Drum told Martin County commissioners at a Jan. 7 meeting.

Commissioners unanimously agreed to a 30-year, $1 annual lease for 46 acres to the Florida Department of Agriculture and Consumer Services for the project, with the facility being county-owned when the lease expires.

"The design is still being worked out but the technology is new and has never been used in Martin County before," Drum said. "This is going to give us a great chance to look at the cost-effectiveness of the system and consider whether we may be able to use similar systems in the future."

State officials estimate it will cost the agency $3 million to build and operate the system, which will be adjacent to the Citrus Boulevard storm treatment area developed in 2008.

The system involves diverting and pumping a portion of the flow from Bessey Creek over a lime rock bed and mixing in a chemical such as aluminum sulfate, which settles out a large portion of the nitrogen and phosphorus. The water is further filtered in

http://www.tcpalm.com/news/2014/feb/28/bessey-creek-project-in-martin-would-cleanse-f... 2/28/2014

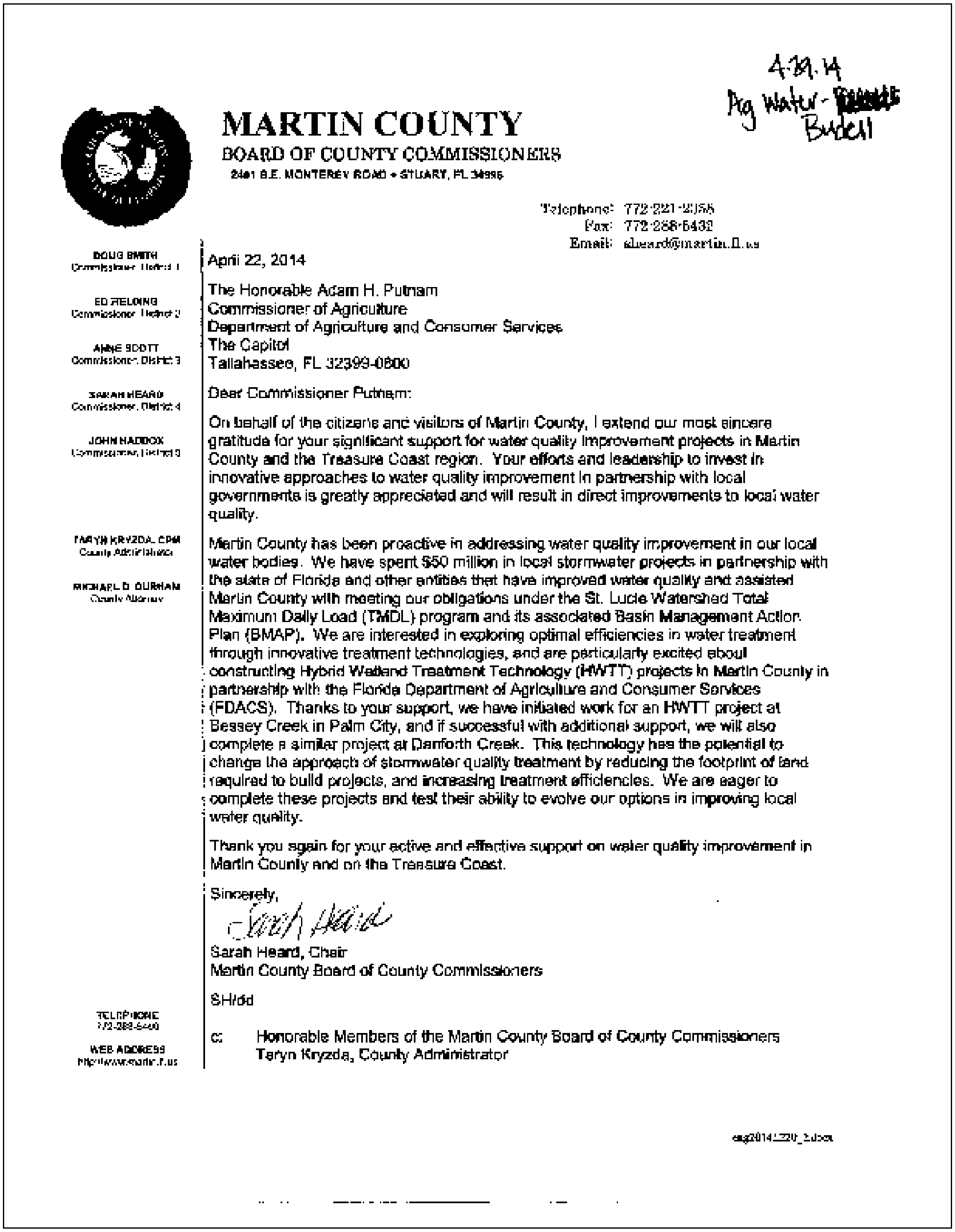
(Double Click to Access Article)

Hybrid wetland treatment projects help reduce Trout Lake nutrient levels

By PRAKASH GANDHI

Florida Specifier June 2017

(Double Click to Access Article)



4.29.14
Ag Water- Budell

MARTIN COUNTY
BOARD OF COUNTY COMMISSIONERS
2401 S.E. MONTEREY ROAD • STUART, FL 34996

Telephone: 772-221-2358
Fax: 772-288-5432
Email: sheard@martin.fl.us

April 22, 2014

The Honorable Adam H. Putnam
Commissioner of Agriculture
Department of Agriculture and Consumer Services
The Capitol
Tallahassee, FL 32399-0800

Dear Commissioner Putnam:

On behalf of the citizens and visitors of Martin County, I extend our most sincere gratitude for your significant support for water quality improvement projects in Martin County and the Treasure Coast region. Your efforts and leadership to invest in innovative approaches to water quality improvement in partnership with local governments is greatly appreciated and will result in direct improvements to local water quality.

Martin County has been proactive in addressing water quality improvement in our local water bodies. We have spent $50 million in local stormwater projects in partnership with the state of Florida and other entities that have improved water quality and assisted Martin County with meeting our obligations under the St. Lucie Watershed Total Maximum Daily Load (TMDL) program and its associated Basin Management Action Plan (BMAP). We are interested in exploring optimal efficiencies in water treatment through innovative treatment technologies, and are particularly excited about constructing Hybrid Wetland Treatment Technology (HWTT) projects in Martin County in partnership with the Florida Department of Agriculture and Consumer Services (FDACS). Thanks to your support, we have initiated work for an HWTT project at Bessey Creek in Palm City, and if successful with additional support, we will also complete a similar project at Danforth Creek. This technology has the potential to change the approach of stormwater quality treatment by reducing the footprint of land required to build projects, and increasing treatment efficiencies. We are eager to complete these projects and test their ability to evolve our options in improving local water quality.

Thank you again for your active and effective support on water quality improvement in Martin County and on the Treasure Coast.

Sincerely,

Sarah Heard

Sarah Heard, Chair
Martin County Board of County Commissioners

SH/dd

c: Honorable Members of the Martin County Board of County Commissioners
Taryn Kryzda, County Administrator

TELEPHONE
772-288-5400

WEB ADDRESS
http://www.martin.fl.us

VII. Capital Costs (2020 Dollars)

Capital costs for this conceptual design of the proposed WBSR HWTT Treatment system are summarized in Table VII-1 by categories specified in the project specifications. Projected costs for detailed components are presented in Table VII-2 in 2020 dollars. The Land Area items shown below relates to the components identified in the specifications and does NOT refer to the cost of the land. (Rounding differences occur in the calculations.)

Table VII-1. WBSR HWTT Projected Capital Costs by Category

WATERSHED TECHNOLOGIES, LLC		
PROJECTED WBSR HWTT CAPITAL COSTS BY CATEGORY*		
I. Treatment Process	Distributon (I.C.)	$ 1,050,671.46
	Treatment Processes (I.E.)	$ 2,940,137.69
	Post-treatment Processes (I.F.)	$ 2,716,195.74
	Sub-total	$ 6,707,004.89
II. Residuals Process	Residual Collection (II.A.)	$ 6,388,481.81
	Residual Storage (II.A,B,C.)	$ 2,956,242.81
	Residual Transfer (II.D.)	$ 505,577.17
	Sub-total	$ 9,850,301.79
III. Land Area	Supporting Facilities (III.A.)	$ 1,597,351.63
	Treatment Facility (III.A.)	$ 1,588,622.86
	Supporting Facilities (III.B.)	$ 438,555.79
	Sub-total	$ 3,624,530.27
Other	Mobilization	$ 605,455.11
	Survey/Geotech	$ 403,636.74
		$ 1,009,091.85
	Total	$ 21,190,929.00
*See Assumptions		

Table VII-2. C-43 WBSR HWTT Projected Capital Costs in 2020 dollars

PROJECTED WBSR HWTT TREATMENT CAPITAL COSTS*

Process Facility	Category	Item	C43 Quantity	Unit	Cost (in 2020 Dollar
Supporting Facilities (III.B.)	Erosion Control	staked silt fence (temporary)	125000	lf	$ 84,803.01
Supporting Facilities (III.B.)	Erosion Control	staked turbidity barriers (temporary)	1200	lf	$ 4,537.23
Supporting Facilities (III.B.)	Erosion Control	floating turbidity barriers (temporary)	320	lf	$ 2,592.70
Supporting Facilities (III.B.)	Erosion Control	Construction Entrance	1	ls	$ 19,229.22
Erosion Control	Erosion Control				$ 111,162.16
Treatment Processes (I.E.)	Contact Chamber	clearing/grubbing (strip and pile field topsoil)	1.0	ac	$ 972.26
Treatment Processes (I.E.)	Contact Chamber	pond liner installation	1	ls	$ 4,321.17
Treatment Processes (I.E.)	Contact Chamber	inflow piping (6 x 72" CMP, materials and installation	600	lf	$ 129,635.17
Treatment Processes (I.E.)	Contact Chamber	inflow structure installation: set box, grout pipe connections, install grating, internal baffle, and slides gates	1	ls	$ 129,635.17
Treatment Processes (I.E.)	Contact Chamber	outflow piping (8 x 72" CMP, materials and installation)	2600	lf	$ 994,301.77
Contact Chamber	Contact Chamber				$ 1,258,865.55
Residual Collection (II.A.)	Settling Pond	clearing/grubbing (strip and pile field topsoil; berm footprint only)	6.52	ac	$ 7,778.11
Residual Collection (II.A.)	Settling Pond	excavation (pond)	1876977.778	cy	$ 6,083,058.42
Residual Collection (II.A.)	Settling Pond	embankment (berms and bench)	23387	cy	$ 37,897.58
Residual Collection (II.A.)	Settling Pond	spread topsoil over finished surfaces (berm top, interior & exterior slopes)	31546	sy	$ 13,935.78
Residual Collection (II.A.)	Settling Pond	Hydroseeding (berm top, interior & exterior slopes)	31546	sy	$ 16,357.65
Residual Collection (II.A.)	Settling Pond	outflow structures (8x72" CMP w/ 96" risers, materials and installation)	600	lf	$ 229,454.25
Settling Pond	Settling Pond				$ 6,388,481.81

PROJECTED WBSR HWTT TREATMENT CAPITAL COSTS*

Process Facility	Category	Item	C43 Quantity	Unit	Cost (in 2020 Dollar
Treatment Processes (I.E.)	FAV Pond	clearing/grubbing (strip and pile field topsoil; berm footprint only)	4.31	ac	$ 3,889.06
Treatment Processes (I.E.)	FAV Pond	excavation (pond)	496907	cy	$ 1,610,414.53
Treatment Processes (I.E.)	FAV Pond	embankment (berm)	15456	cy	$ 25,045.70
Treatment Processes (I.E.)	FAV Pond	spread topsoil over finished surfaces (berm top, interior & exterior slopes)	20848	sy	$ 9,506.58
Treatment Processes (I.E.)	FAV Pond	Hydroseeding (berm top, interior & exterior slopes)	20848	sy	$ 10,810.42
Distributon (I.C.)	FAV Pond	outflow structures (8x96" CMP w/ 120" risers, materials and installation)	600	lf	$ 229,454.25
Treatment Processes (I.E.)	FAV Pond	vegetation stocking: import FAV from approved source and stock pond	1	ls	$ 21,605.86
FAV Pond	FAV Pond				$ 1,910,726.40
Post-treatment Processes (I.F.)	SAV Pond	clearing/grubbing (strip and pile field topsoil; berm footprint only)	7	ac	$ 7,562.05
Post-treatment Processes (I.F.)	SAV Pond	excavation (pond)	806667	cy	$ 2,614,309.30
Post-treatment Processes (I.F.)	SAV Pond	embankment (berm)	25059	cy	$ 40,607.32
Post-treatment Processes (I.F.)	SAV Pond	spread topsoil over finished surfaces (berm top, interior & exterior slopes)	33801	sy	$ 14,583.96
Post-treatment Processes (I.F.)	SAV Pond	Hydroseeding (berm top, interior & exterior slopes)	33801	sy	$ 17,527.25
Distributon (I.C.)	SAV Pond	outflow structures (8x96" CMP w/ 120" risers, materials and installation)	600	lf	$ 229,454.25
Post-treatment Processes (I.F.)	SAV Pond	vegetation stocking: import SAV from approved source and stock pond	1	ls	$ 21,605.86
SAV Pond	SAV Pond				$ 2,945,649.99

PROJECTED WBSR HWTT TREATMENT CAPITAL COSTS*

Process Facility	Category	Item	C43 Quantity	Unit	Cost (in 2020 Dollar
Residual Storage (II.A,B,C.)	Floc Recycling	floating booms	1	ls	$ 10,802.93
Residual Storage (II.A,B,C.)	Floc Recycling	floating boom installation (incl. anchor materials)	1	ls	$ 2,160.59
Residual Storage (II.A,B,C.)	Floc Recycling	clearing/grubbing - drying bed (strip and pile field topsoil; berm footprint only)	15.87	ac	$ 17,284.69
Residual Storage (II.A,B,C.)	Floc Recycling	excavation - drying bed	851840	cy	$ 2,760,710.62
Residual Storage (II.A,B,C.)	Floc Recycling	embankment - drying bed (berm and bottom area)	56951	cy	$ 92,285.84
Residual Storage (II.A,B,C.)	Floc Recycling	spread topsoil over finished surfaces - drying bed (berm only)	76818	sy	$ 33,165.00
Residual Storage (II.A,B,C.)	Floc Recycling	Hydroseeding - drying bed (berm only)	76818	sy	$ 39,833.14
Distributon (I.C.)	Floc Recycling	Overflow Sturcture (for each drying bed)	2	ea	$ 43,211.72
Residual Transfer (II.D.)	Floc Recycling	Floc pumps, piping, valves, and appurtenances (materials and installation)	4	ea	$ 505,577.17
Floc Recycling	Floc Recycling				$ 3,505,031.70
Supporting Facilities (III.B.)	Roads and Drainage	baserock access road (8" compacted baserock, 15' wide)	2680	lf	$ 41,591.28
Supporting Facilities (III.B.)	Roads and Drainage	baserock access road (8" compacted baserock, 15' wide) - 1 ac parking/misc area and one shell rock road that runs length of site (internal)	12524	lf	$ 192,940.35
Supporting Facilities (III.B.)	Roads and Drainage	grading - site perimeter drainage swale	25	ac	$ 38,890.55
Roads and Drainage	Roads and Drainage				$ 273,422.18
Distributon (I.C.)	Partial Bypass Canal	Excavation	87120	cy	$ 376,460.54
Distributon (I.C.)	Partial Bypass Canal	Conveyance (6x72" CMP, materials and installation)	450	lf	$ 172,090.69
Distributon (I.C.)	Partial Bypass Canal				$ -
Partial Bypass Canal	Partial Bypass Canal				$ 548,551.23
Supporting Facilities (III.B.)	Security Fencing	woven wire fence - site perimeter	21980	lf	$ 47,489.68
Supporting Facilities (III.B.)	Security Fencing	16' swing gate	4	ea	$ 6,481.76
Security Fencing	Security Fencing				$ 53,971.44
Supporting Facilities (III.A.)	Building & Electrical	building pad, concrete slab, pre-engineered metal building, floor drains, building electrical installation - materials and installation	1	ls	$ 1,597,351.63
Building & Electrical	Building & Electrical				$ 1,597,351.63

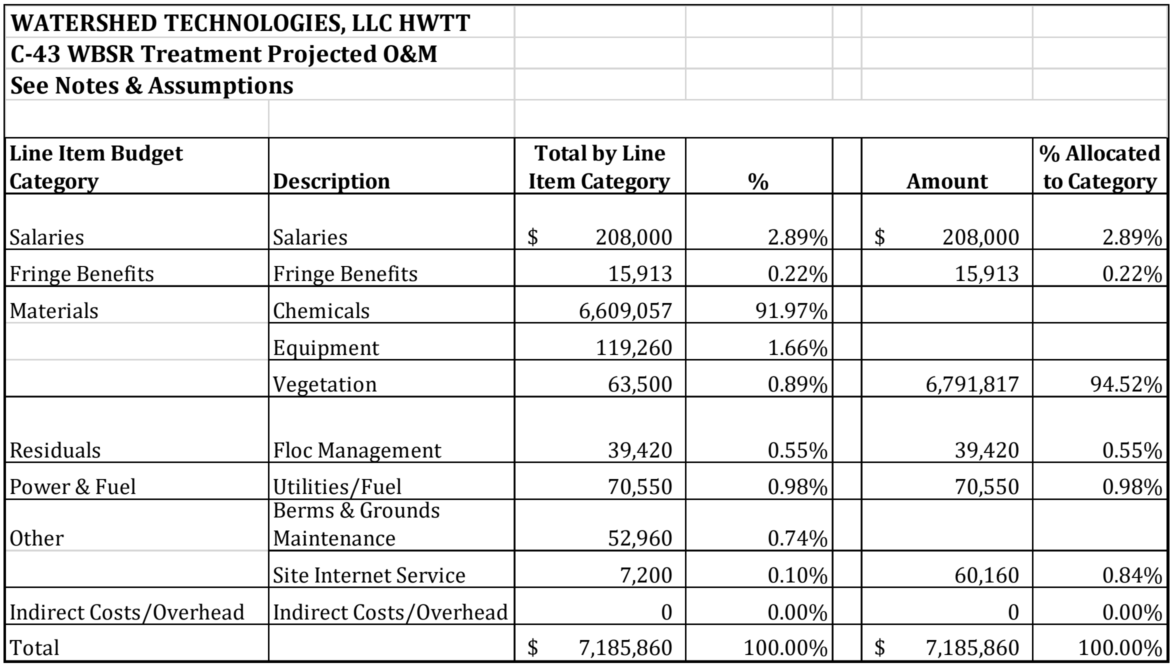
PROJECTED WBSR HWTT TREATMENT CAPITAL COSTS*

Process Facility	Category	Item	C43 Quantit	Unit	Cost (in 2020 Dollar
Residual Storage (II.A,B,C.)	Floc Recycling	floating booms	1	ls	$ 10,802.93
Residual Storage (II.A,B,C.)	Floc Recycling	floating boom installation (incl. anchor materials)	1	ls	$ 2,160.59
Residual Storage (II.A,B,C.)	Floc Recycling	clearing/grubbing - drying bed (strip and pile field topsoil; berm footprint only)	15.87	ac	$ 17,284.69
Residual Storage (II.A,B,C.)	Floc Recycling	excavation - drying bed	851840	cy	$ 2,760,710.62
Treatment Facility (III.A.)	Chemical Dosing	tanks	1	ls	$ 576,565.39
Treatment Facility (III.A.)	Chemical Dosing	dosing pumps	1	ls	$ 222,907.68
Treatment Facility (III.A.)	Chemical Dosing	plumbing/electrical	1	ls	$ 267,476.25
Treatment Facility (III.A.)	Chemical Dosing	lightning protection	1	ls	$ 21,605.86
Treatment Facility (III.A.)	Chemical Dosing	remote monitoring/control	1	ls	$ 56,715.39
Chemical Dosing	Chemical Dosing				$ 1,145,270.57
Treatment Facility (III.A.)	Instrumentation	pH, turbidity, remote monitoring	1	ls	$ 443,352.29
Instrumentation & Controls	Instrumentation				$ 443,352.29
Construction Subtotal	Subtotal				$ 20,181,836.95
Mobilization	Mobilization	Mobilization (3%)	3%		$ 605,455.11
Survey/Geotech	Survey/Geotech	Construction staking/testing/asbuilts (2%)	2%		$ 403,636.74
Grand Total (Excluding Contingency, CMS, Engineering Design, post construction surveys/certification)					$ 21,190,929.00
*See Assumptions and Text					

VIII. Operations & Maintenance (Annual)

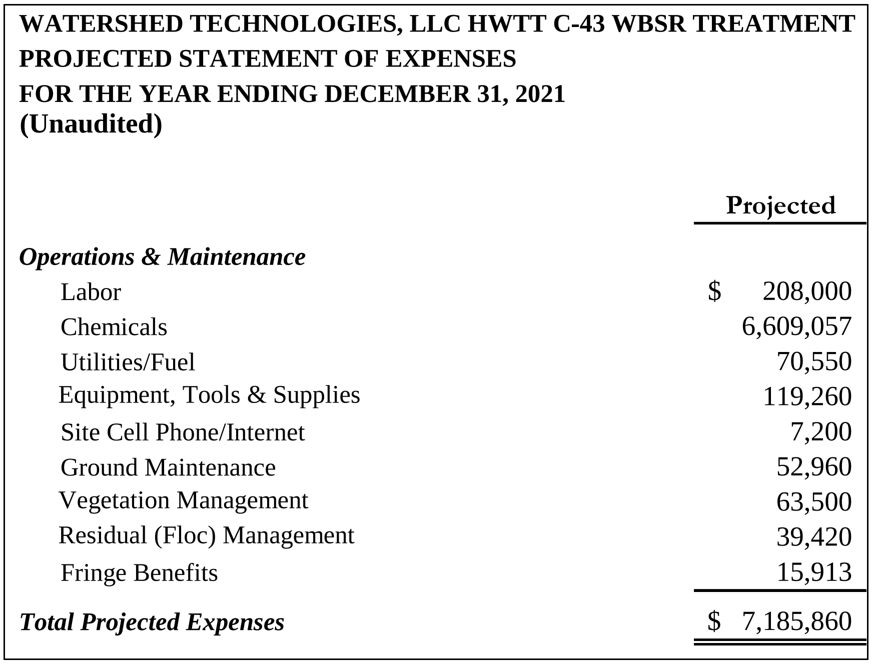
The projected Operations & Maintenance (O&M) costs are based upon a set of assumptions contained within X. A summary by expense type is presented in Table VIII-1, and detailed supporting schedules are provided in Table VIII-2 through Table VIII-11.

Table VIII-1. C-43 WBSR HWTT Treatment System projected O&M by Category & Line Item.



WATERSHED TECHNOLOGIES, LLC HWTT
C-43 WBSR Treatment Projected O&M
See Notes & Assumptions

Line Item Budget Category	Description	Total by Line Item Category	%		Amount	% Allocated to Category
Salaries	Salaries	$ 208,000	2.89%		$ 208,000	2.89%
Fringe Benefits	Fringe Benefits	15,913	0.22%		15,913	0.22%
Materials	Chemicals	6,609,057	91.97%			
	Equipment	119,260	1.66%			
	Vegetation	63,500	0.89%		6,791,817	94.52%
Residuals	Floc Management	39,420	0.55%		39,420	0.55%
Power & Fuel	Utilities/Fuel	70,550	0.98%		70,550	0.98%
Other	Berms & Grounds Maintenance	52,960	0.74%			
	Site Internet Service	7,200	0.10%		60,160	0.84%
Indirect Costs/Overhead	Indirect Costs/Overhead	0	0.00%		0	0.00%
Total		$ 7,185,860	100.00%		$ 7,185,860	100.00%



WATERSHED TECHNOLOGIES, LLC HWTT C-43 WBSR TREATMENT
PROJECTED STATEMENT OF EXPENSES
FOR THE YEAR ENDING DECEMBER 31, 2021
(Unaudited)

	Projected
Operations & Maintenance	
Labor	$ 208,000
Chemicals	6,609,057
Utilities/Fuel	70,550
Equipment, Tools & Supplies	119,260
Site Cell Phone/Internet	7,200
Ground Maintenance	52,960
Vegetation Management	63,500
Residual (Floc) Management	39,420
Fringe Benefits	15,913
Total Projected Expenses	$ 7,185,860

A. Labor

Labor includes Field Personnel to operate, maintain and monitor the HWTT system on a daily basis for an average cost of $208,000 annually.

Table VIII-2. Projected Labor Field Personnel

Watershed Technologies, LLC HWTT				
C-43 WBSR Treatment Project				
Labor Operations & Maintenance				
Field Personnel				
Site	**FTEs**	**Hourly Rate**	**# Hours per Year**	**Total Labor**
C-43	2	$ 50.00	2080	$ 208,000

B. Materials

Materials for the HWTT system include chemicals, tools, supplies, equipment, and vegetation. Chemicals will be acquired from a certified chemical company at a bulk rate price. Safety procedures are followed for all deliveries and management thereafter. Disposal of the chemical residual (floc) is discussed under the O&M Residuals Section. Tools, supplies and equipment are acquired, managed and disposed via a management tracking system. Vegetation for the FAV and SAV Ponds is managed through periodic vegetation surveys; disposal of the FAV, when necessary, is performed through tilling in the O&M Residuals Section.

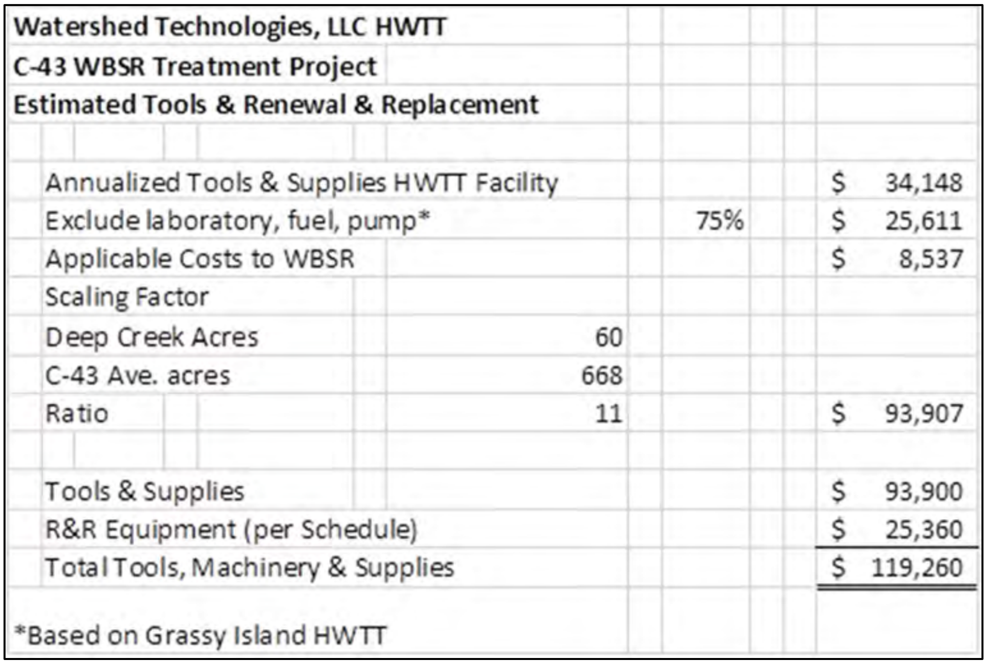
Detailed calculations of projected chemical costs are shown in Table VIII-3, based upon an average 457 cfs and an intermittent effective dosing rate of 6.61 mg/L. Table VIII-4 and Table VIII-5 contain data on equipment, and vegetation is presented in Table VIII-6.

Table VIII-3. Projected Chemicals*

C-43 WBSR HWTT TREATMENT		31	31	30	31	30	31	31	28	31	30	31	30
Projected Chemicals													
	Month	7	8	9	10	11	12	1	2	3	4	5	6
Chemicals	6,609,057	561,317	561,317	543,210	561,317	543,210	561,317	561,317	506,996	561,317	543,210	561,317	543,210
Total Monthly cfs	166,816	14,167.9	14,167.9	13,710.9	14,167.9	13,710.9	14,167.9	14,167.9	12,796.9	14,167.9	13,710.9	14,167.9	13,710.9
Ave. daily cfs	457.03	457.03	457.03	457.03	457.03	457.03	457.03	457.03	457.03	457.03	457.03	457.03	457.03
		Alum	Alum	Alum	Alum	Alum	Alum	Alum	Alum	Alum	Alum	Alum	Alum
Cost basis (unit)		Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton	Dry ton
Product cost per unit ($)	$ 202	202	202	202	202	202	202	202	202	202	202	202	202
Volume of product per unit (L)		1406	1406	1406	1406	1406	1406	1406	1406	1406	1406	1406	1406
Al content of product (% by wt.)		4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41
Al mass (kg) per unit of product		82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4
Al concentration in product (g Al/L)		58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6
Product cost per liter ($)		0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144
Product cost per mg of Al ($)		0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002
Specific gravity of product		1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Active ingredient in product (%)		48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5
Dosing rate (as ppm Al)	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61
Flow rate (cfs)		1	1	1	1	1	1	1	1	1	1	1	1
Flow duration (days)		1	1	1	1	1	1	1	1	1	1	1	1
Conversion Factor cfs to L		2446575.55	2446575.55	2446575.55	2446575.55	2446575.5	2446575.55	2446575.55	2446575.55	2446575.55	2446575.55	2446575.55	2446575.55
Treated volume (L)		2446576	2446576	2446576	2446576	2446576	2446576	2446576	2446576	2446576	2446576	2446576	2446576
Treated volume (MG)		0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Volume of product required (L)		276	276	276	276	276	276	276	276	276	276	276	276
Volume of product required (gal)		73	73	73	73	73	73	73	73	73	73	73	73
Cost of product used for treated volume (L)		$39.62	$39.62	$39.62	$39.62	$39.62	$39.62	$39.62	$39.62	$39.62	$39.62	$39.62	$39.62

*Note: Minor differences due to rounding.

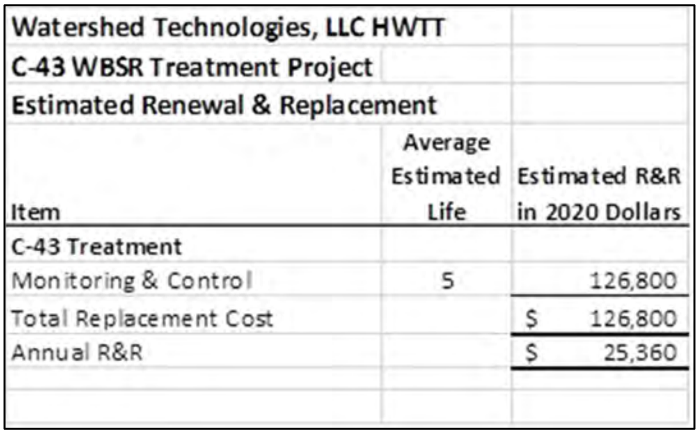
Table VIII-4. Projected Tools & Renewal & Replacement



Watershed Technologies, LLC HWTT			
C-43 WBSR Treatment Project			
Estimated Tools & Renewal & Replacement			
Annualized Tools & Supplies HWTT Facility			$ 34,148
Exclude laboratory, fuel, pump*		75%	$ 25,611
Applicable Costs to WBSR			$ 8,537
Scaling Factor			
Deep Creek Acres	60		
C-43 Ave. acres	668		
Ratio	11		$ 93,907
Tools & Supplies			$ 93,900
R&R Equipment (per Schedule)			$ 25,360
Total Tools, Machinery & Supplies			$ 119,260

*Based on Grassy Island HWTT

Table VIII-5. Projected Renewal & Replacement



Watershed Technologies, LLC HWTT
C-43 WBSR Treatment Project
Estimated Renewal & Replacement

Item	Average Estimated Life	Estimated R&R in 2020 Dollars
C-43 Treatment		
Monitoring & Control	5	126,800
Total Replacement Cost		$ 126,800
Annual R&R		$ 25,360

Table VIII-6. Projected Vegetative Management

Watershed Technologies, LLC HWTT		
C-43 WBSR Treatment Project		
Estimated Vegetative Management		
Herbiciding	**HWTT Site Settling Pond, FAV 1&2 and SAV**	**HWTT Site Settling Pond, FAV 1&2 and SAV 1&2**
Annual	$ 1,080	$ 1,440
area in acres	16	60
per acre	$ 67.50	$ 24.00
C-43 # acres	668	668
Total C-43 Herbiciding	$ 45,090	$ 16,032
Plant Acquisition		
Purchase	$ 629	$ 3,566
area in acres	16	60
per acre	$ 39.33	$ 59.43
C-43 # acres	668	668
Total C-43 Plant Renewal	$ 26,272	$ 39,699
Total Vegetative Management	$ 71,362	$ 55,731
Average Vegetative Management		$ 63,500

C. Residuals

Residual costs for the HWTT system are contained within the expense item Floc Management and are represented by Tilling. Disposal of the chemical residual (floc) is typically excavated from the drying beds and spread throughout an FAV cell during the routine maintenance of those Ponds. An alternative disposal method is available if, and when, the Reservoir sufficiently dries. During drying periods, solids could be opportunistically deposited within the Reservoir to the extent possible. Detailed calculations of projected tilling costs are shown in Table VIII-7.

Table VIII-7. Projected Floc Management

Watershed Technologies, LLC HWTT					
C-43 WBSR Treatment Project					
Estimated Residual (Floc) Management					
Tilling Post Drying Bed	**# FAV Ponds Tilled per Year (in %)**	**Total # Acres FAV Pond Shallow Zone**	**# Acres Tilled per Year**	**Unit Cost**	**Total**
Tilling	50%	154	77	512	$ 39,420

D. Power

Power (utilities) for the proposed HWTT WBSR Project relate to the building, the chemical dosing tanks, floc pumps, and monitoring equipment. (See assumptions excluding inflow and outflow pumps.) Detailed calculations of projected utility costs are shown in Table VIII-8.

Table VIII-8. Projected Power

Watershed Technologies, LLC HWTT	
C-43 WBSR Treatment Project	
Estimated Power Building, Dosing, Floc Pumps & Monitoring	
Annualized*	1,008
Scaling Factor:	
Trout Lake ave. cfs	7
Cost per ave. cfs	$ 144
C-43 ave. cfs	457.03
Projected Utilities C-43	$ 65,800
*Based on Trout Lake HWTT Facility	
Power	$ 65,800
Fuel	4,750
Total Power & Fuel	$ 70,550

E. Fuel

Fuel costs represent gasoline for site visits for the field personnel. Fuel associated with movement of dried floc are included under unit prices for tilling. Detailed calculations of projected utility costs are shown Table VIII-9.

Table VIII-9. Projected Fuel

Watershed Technologies, LLC HWTT	
C-43 WBSR Treatment Project	
Estimated Fuel	
Estimated Annual Truck Fuel Cost	
LaBelle to the Caloosahatchee FAVT	
LaBelle to Caloosahatchee FAVT # Miles	28.1
Trips per Day	2
Days per Week	5
Number of Weeks	52
Total Miles	14,612
Heavy Duty Truck*	
Average Mileage per Gallon*	6.4
Average Costs per Gallon**	
Regular Unleaded	$ 1.764
1 Year Est. Price Growth	36%
Est. Average Price over 12 Months	$ 2.082
Estimated Truck Gas Expense	$ 4,750
*https://www.eia.gov/totalenergy/data/annual/showtext.php?t=pTB0208	
** FL 5/4/20 Avg Regular Unleaded Price 1.764; -36.09& YTD (https://ycharts.com/indicators/us_gas_price)	

F. Other

Other costs include Berms and Ground Maintenance and Site Internet Service. Detailed calculations of these costs are shown in Table VIII-10 and Table VIII-11, respectively.

Table VIII-10. Projected Other Costs

Watershed Technologies, LLC HWTT			
C-43 WBSR Treatment Project			
Estimated Berms & Grounds Maintenance			
	Total # Acres	**Unit Cost***	**Total**
Berms & Grounds	66.2	$ 800	$ 52,960
*Based on HWTT Facility			

Table VIII-11. Projected Site Internet Service

Watershed Technologies, LLC HWTT
C-43 WBSR Treatment Project
Estimated Site Cell and/or Satellite Internet

Cell and/or Satellite Internet for Remote Monitoring, Communications & Control including Establishment/Maintenance of Separate Networks for Site Security Cameras, Security Alarm Service for Chemical Storage Buildings, & Data Transmission

Site	**Total**
C-43	$ 7,200

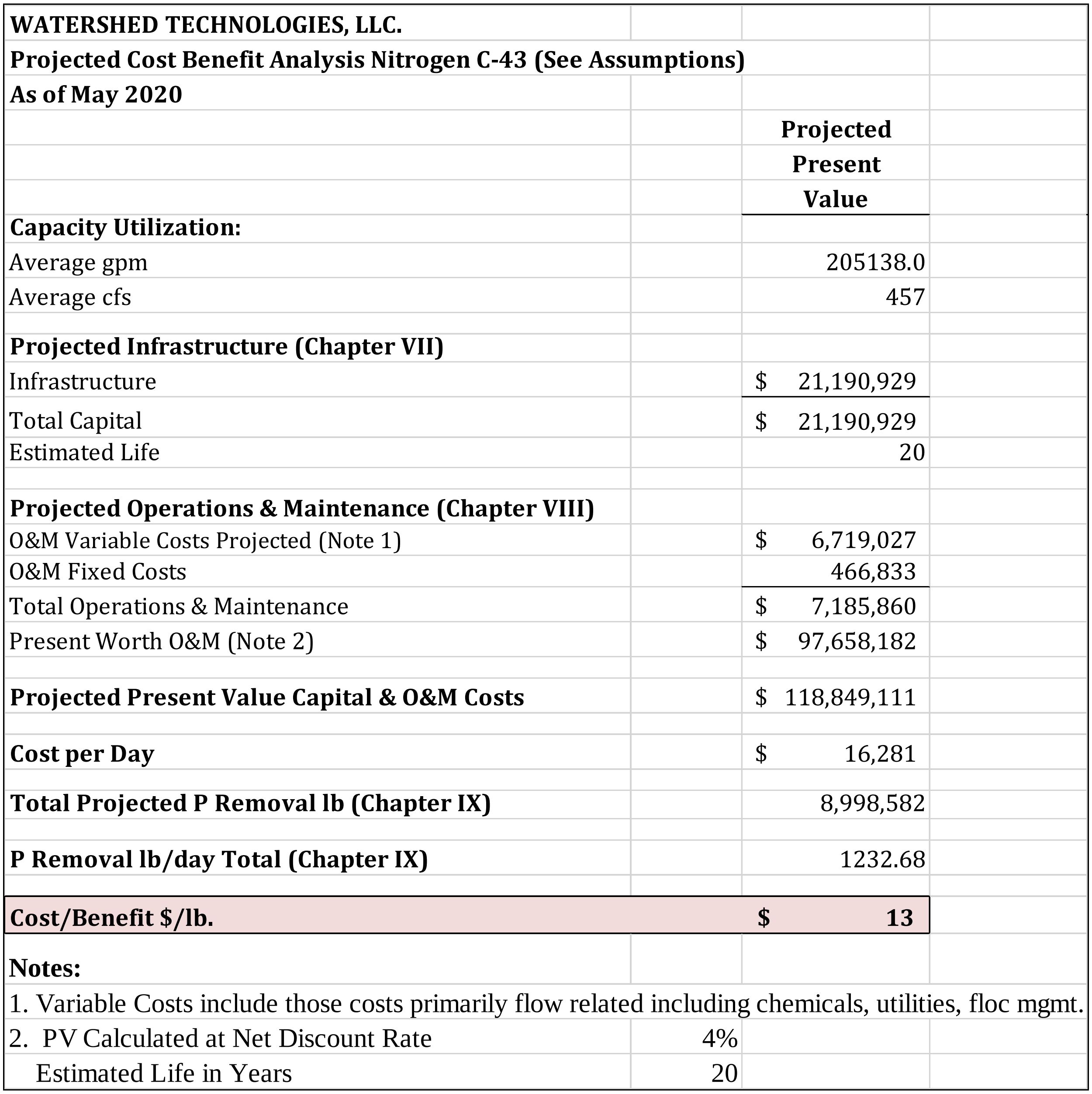
IX. Performance Statistics

Each of the treatment discharge objectives specified for the C-43 WBSR treatment project are identified below for the HWTT system, including flow, P, N, TSS, and Water Quality. All goals are attained in the proposal. Projected Cost Benefit values for phosphorus, nitrogen and phosphorus and nitrogen combined are shown in Table IX-1 through Table IX-3, respectively. Cost Benefit has been calculated based upon the set of Assumptions (Chapter X), Capital Costs (Chapter VII), Operations & Maintenance Costs (Chapter VIII), and Performance Statistics (Chapter IX).

Table IX-1. Projected Cost Benefit Phosphorus

WATERSHED TECHNOLOGIES, LLC.		
Projected Cost Benefit Analysis Phosphorus C-43 (See Assumptions)		
As of May 2020		
		Projected Present Value
Capacity Utilization:		
Average gpm		205138.0
Average cfs		457
Projected Infrastructure (Chapter VII)		
Infrastructure		$ 21,190,929
Total Capital		$ 21,190,929
Estimated Life		20
Projected Operations & Maintenance (Chapter VIII)		
O&M Variable Costs Projected (Note 1)		$ 6,719,027
O&M Fixed Costs		466,833
Total Operations & Maintenance		$ 7,185,860
Present Worth O&M (Note 2)		$ 97,658,182
Projected Present Value Capital & O&M Costs		$ 118,849,111
Cost per Day		$ 16,281
Total Projected P Removal lb (Chapter IX)		1,439,773
P Removal lb/day Total (Chapter IX)		197.23
Cost/Benefit $/lb.		**$ 83**
Notes:		
1. Variable Costs include costs primarily flow related including chemicals, utilities, floc management.		
2. PV Calculated at Net Discount Rate	4%	
Estimated Life in Years	20	

Table IX-2. Projected Cost Benefit Nitrogen



WATERSHED TECHNOLOGIES, LLC.			
Projected Cost Benefit Analysis Nitrogen C-43 (See Assumptions)			
As of May 2020			
		Projected Present Value	
Capacity Utilization:			
Average gpm		205138.0	
Average cfs		457	
Projected Infrastructure (Chapter VII)			
Infrastructure		$ 21,190,929	
Total Capital		$ 21,190,929	
Estimated Life		20	
Projected Operations & Maintenance (Chapter VIII)			
O&M Variable Costs Projected (Note 1)		$ 6,719,027	
O&M Fixed Costs		466,833	
Total Operations & Maintenance		$ 7,185,860	
Present Worth O&M (Note 2)		$ 97,658,182	
Projected Present Value Capital & O&M Costs		$ 118,849,111	
Cost per Day		$ 16,281	
Total Projected P Removal lb (Chapter IX)		8,998,582	
P Removal lb/day Total (Chapter IX)		1232.68	
Cost/Benefit $/lb.		**$ 13**	
Notes:			
1. Variable Costs include those costs primarily flow related including chemicals, utilities, floc mgmt.			
2. PV Calculated at Net Discount Rate	4%		
Estimated Life in Years	20		

Table IX-3. Projected Cost Benefit Phosphorus & Nitrogen Combined

WATERSHED TECHNOLOGIES, LLC.		
Projected Cost Benefit Analysis Phosphorus & Nitrogen C-43 (See Assumptions)		
As of May 2020		
		Projected Present Value
Capacity Utilization:		
Average gpm		205138.0
Average cfs		457
Projected Infrastructure (Chapter VII)		
Infrastructure in 2020 Dollars		$ 21,190,929
Total Capital		$ 21,190,929
Estimated Life		20
Projected Operations & Maintenance (Chapter VIII)		
O&M Variable Costs Projected (Note 1)		$ 6,719,027
O&M Fixed Costs		466,833
Total Operations & Maintenance		$ 7,185,860
Present Worth O&M (Note 2)		$ 97,658,182
Projected Present Value Capital & O&M Costs		$ 118,849,111
Cost per Day		$ 16,281
Total Projected P Removal lb (Chapter IX)		10,438,355
P Removal lb/day Total (Chapter IX)		1429.91
Cost/Benefit $/lb.		**$ 11**
Notes:		
1. Variable Costs include those costs primarily flow related including chemicals, utilities, floc mgmt.		
2. PV Calculated at Net Discount Rate	4%	
Estimated Life in Years	20	

WATERSHED TECHNOLOGIES, LLC HWTT
Projected C-43 WBSR Treatment Project
Total Treated Flow Performance

Attainment of the C-43 WBSR Treatment Project goal of treatment of an average of 457 cubic feet per second (cfs) with a range between 300 and 600 cfs was used as the flow basis for projections. Outflow was assumed to equal inflow; therefore, no benefits were assumed from seepage. Compared to STA performance calculations, the effects of measured outflow can be significant.

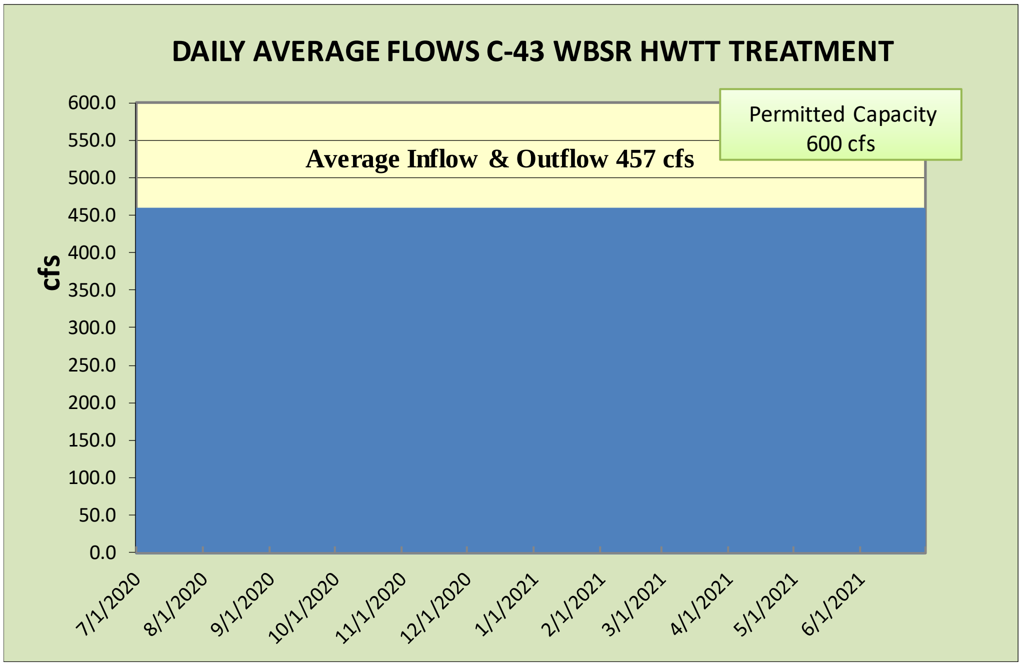


Figure IX-1. Projected daily flows C-43 WBSR HWTT Treatment System.

WATERSHED TECHNOLOGIES, LLC HWTT
Projected C-43 WBSR Treatment Project
Total Phosphorus (TP) Removal Performance

The ability to attain the C-43 WBSR Treatment Project TP goal of 50% reduction is demonstrated through performance statistics taken from the HWTT facilities shown graphically below (Figure IX-4 and Figure IX-5. Percent reductions range from 95% to 47%. The Trout Lake site (88% TP removal) was selected as most representative of treatment of reservoir waters. (Wolff Ditch is not representative of performance as the site was constructed without all efficiency components due to lack of land availability.) Detailed operating data for the C-43 WBSR Treatment Proposal, including average flow treated of 457 cfs, daily and total TP mass in, TP out, load, and concentrations, are shown below (Figure IX-2 and Figure IX-3 and Table IX-4).

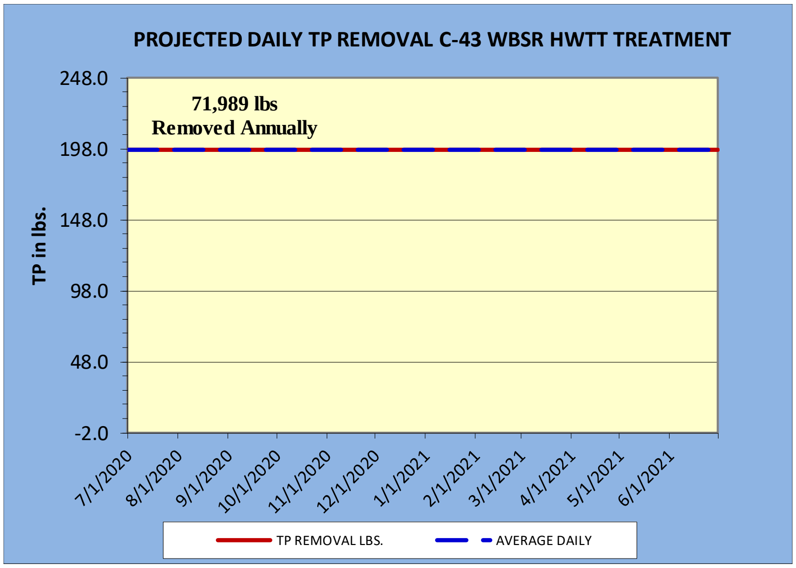


Figure IX-2. Projected daily TP removal C-43 WBSR HWTT Treatment System.

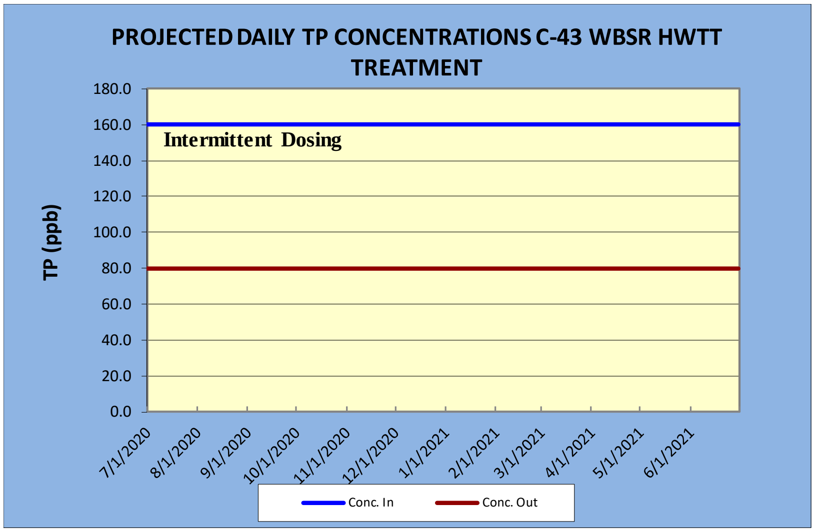
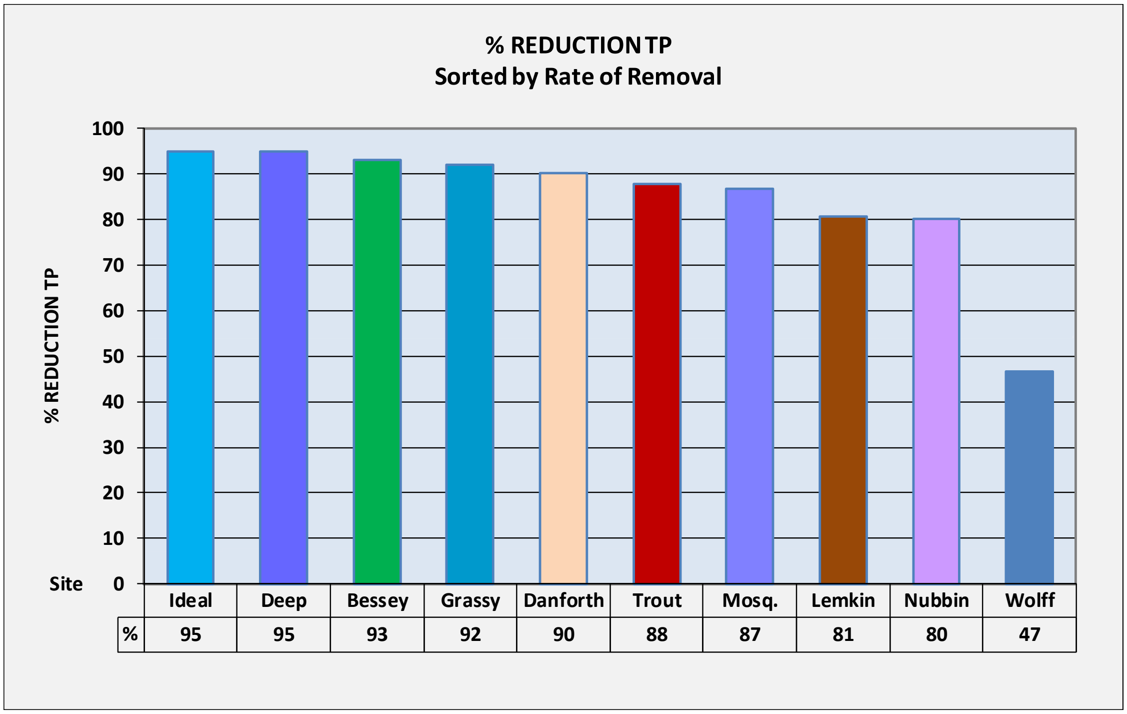
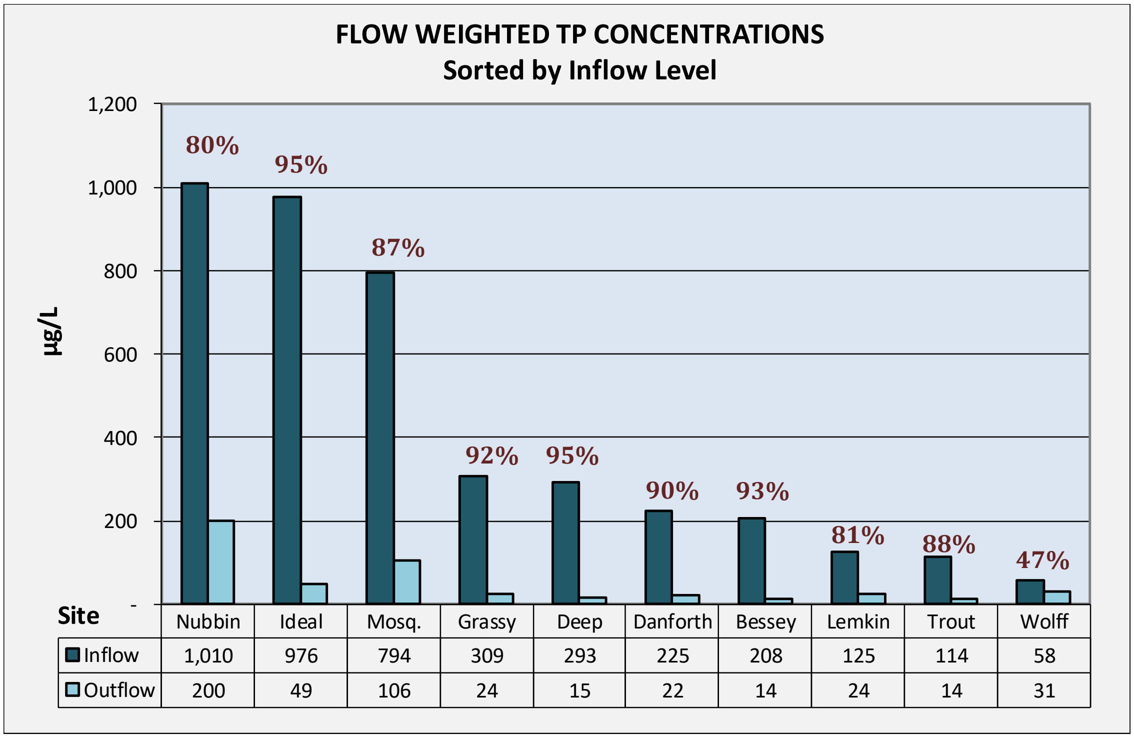


Figure IX-3. Projected daily TP concentrations C-43 WBSR HWTT Treatment System.



Site	Ideal	Deep	Bessey	Grassy	Danforth	Trout	Mosq.	Lemkin	Nubbin	Wolff
%	95	95	93	92	90	88	87	81	80	47

Figure IX-4. Percent TP reduction HWTT facilities 2018-2019.

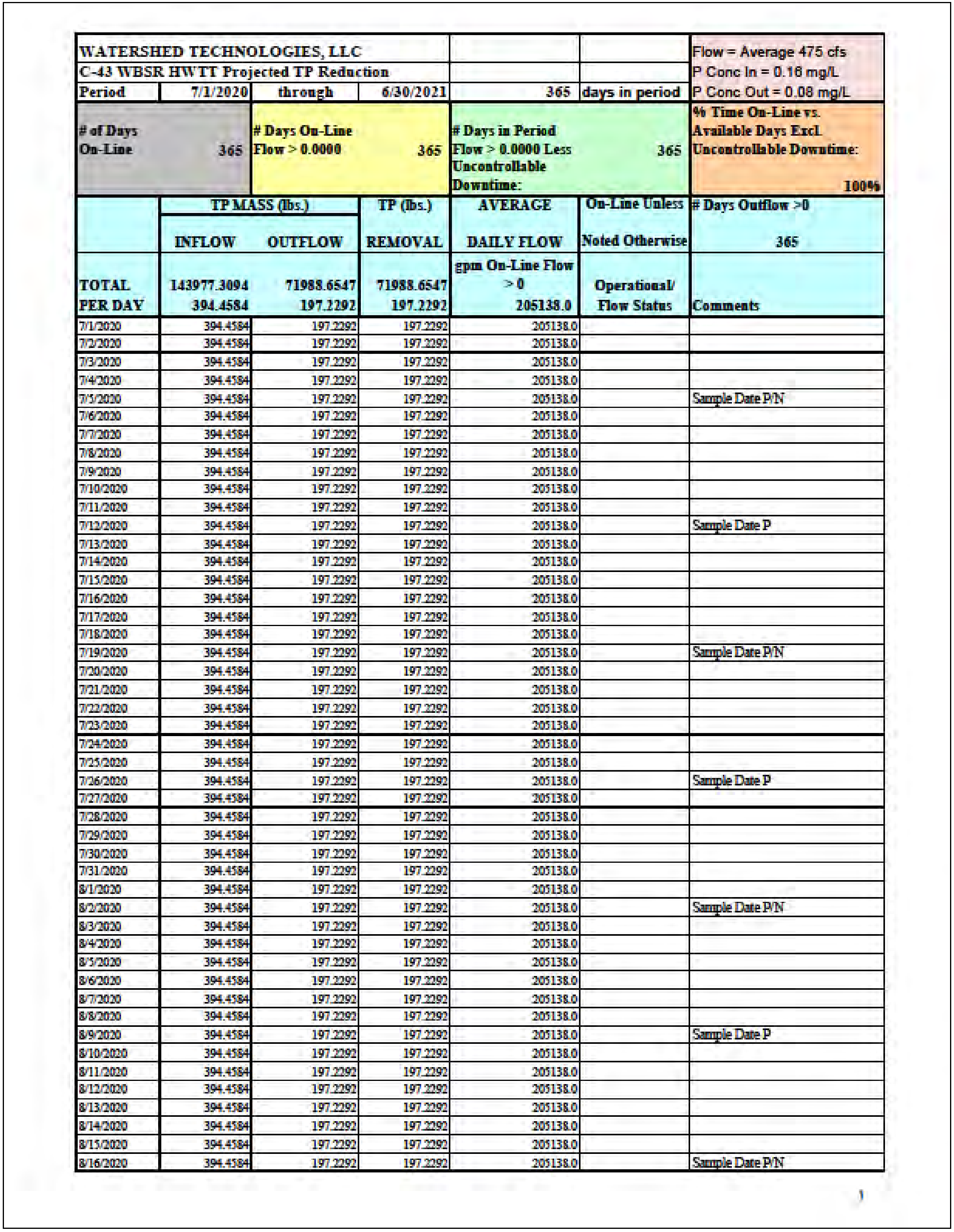


Site	Nubbin	Ideal	Mosq.	Grassy	Deep	Danforth	Bessey	Lemkin	Trout	Wolff
■ Inflow	1,010	976	794	309	293	225	208	125	114	58
□ Outflow	200	49	106	24	15	22	14	24	14	31

Figure IX-5. FWM TP concentrations HWTT facilities 2018-2019.

Table IX-4. TP Load Performance Calculations.

(Double Click to Open Linked File)



WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line 365		**# Days On-Line Flow > 0.0000** 365		**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:** 365		**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** 100%
	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
TOTAL **PER DAY**	**143977.3094** **394.4584**	**71988.6547** **197.2292**	**71988.6547** **197.2292**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
7/1/2020	394.4584	197.2292	197.2292	205138.0		
7/2/2020	394.4584	197.2292	197.2292	205138.0		
7/3/2020	394.4584	197.2292	197.2292	205138.0		
7/4/2020	394.4584	197.2292	197.2292	205138.0		
7/5/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
7/6/2020	394.4584	197.2292	197.2292	205138.0		
7/7/2020	394.4584	197.2292	197.2292	205138.0		
7/8/2020	394.4584	197.2292	197.2292	205138.0		
7/9/2020	394.4584	197.2292	197.2292	205138.0		
7/10/2020	394.4584	197.2292	197.2292	205138.0		
7/11/2020	394.4584	197.2292	197.2292	205138.0		
7/12/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
7/13/2020	394.4584	197.2292	197.2292	205138.0		
7/14/2020	394.4584	197.2292	197.2292	205138.0		
7/15/2020	394.4584	197.2292	197.2292	205138.0		
7/16/2020	394.4584	197.2292	197.2292	205138.0		
7/17/2020	394.4584	197.2292	197.2292	205138.0		
7/18/2020	394.4584	197.2292	197.2292	205138.0		
7/19/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
7/20/2020	394.4584	197.2292	197.2292	205138.0		
7/21/2020	394.4584	197.2292	197.2292	205138.0		
7/22/2020	394.4584	197.2292	197.2292	205138.0		
7/23/2020	394.4584	197.2292	197.2292	205138.0		
7/24/2020	394.4584	197.2292	197.2292	205138.0		
7/25/2020	394.4584	197.2292	197.2292	205138.0		
7/26/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
7/27/2020	394.4584	197.2292	197.2292	205138.0		
7/28/2020	394.4584	197.2292	197.2292	205138.0		
7/29/2020	394.4584	197.2292	197.2292	205138.0		
7/30/2020	394.4584	197.2292	197.2292	205138.0		
7/31/2020	394.4584	197.2292	197.2292	205138.0		
8/1/2020	394.4584	197.2292	197.2292	205138.0		
8/2/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
8/3/2020	394.4584	197.2292	197.2292	205138.0		
8/4/2020	394.4584	197.2292	197.2292	205138.0		
8/5/2020	394.4584	197.2292	197.2292	205138.0		
8/6/2020	394.4584	197.2292	197.2292	205138.0		
8/7/2020	394.4584	197.2292	197.2292	205138.0		
8/8/2020	394.4584	197.2292	197.2292	205138.0		
8/9/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
8/10/2020	394.4584	197.2292	197.2292	205138.0		
8/11/2020	394.4584	197.2292	197.2292	205138.0		
8/12/2020	394.4584	197.2292	197.2292	205138.0		
8/13/2020	394.4584	197.2292	197.2292	205138.0		
8/14/2020	394.4584	197.2292	197.2292	205138.0		
8/15/2020	394.4584	197.2292	197.2292	205138.0		
8/16/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N

WATERSHED TECHNOLOGIES, LLC HWTT
Projected C-43 WBSR Treatment Project
Total Nitrogen (TN) Removal Performance

The ability to attain the C-43 WBSR Treatment Project TN goal of 50% reduction is demonstrated through performance statistics taken from the HWTT facilities shown graphically below (Figure IX-8 and Figure IX-9). Percent reductions range from 68% to 21%. The Trout Lake site (68% TN removal) was selected as most representative of treatment of reservoir waters. (Wolff Ditch is not representative of performance as the site was constructed without all efficiency components due to lack of land availability.) Detailed operating data for the C-43 WBSR Treatment Proposal, including average flow treated of 457 cfs, daily and total TN mass in, TN out, load, and concentrations, are shown below (Figure IX-6 and Figure IX-7 and Table IX-5).

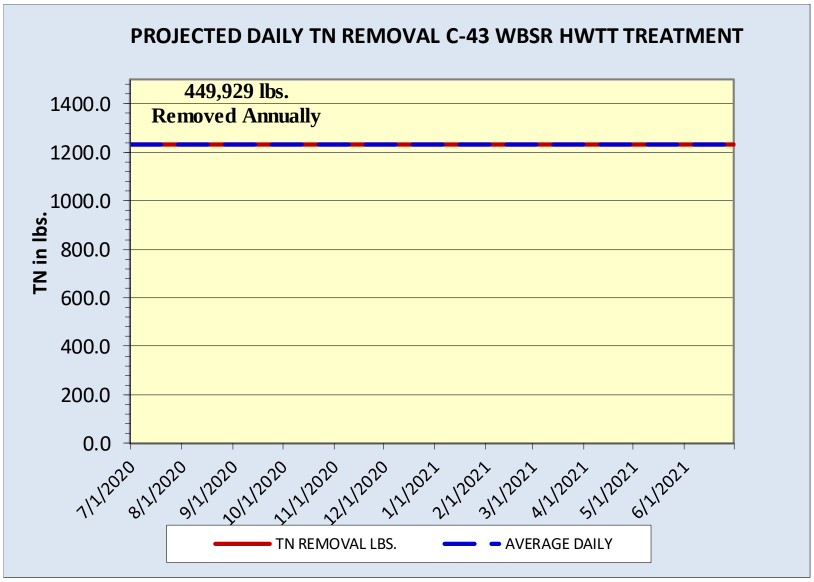


Figure IX-6. Projected daily TN removal C-43 WBSR HWTT Treatment System.

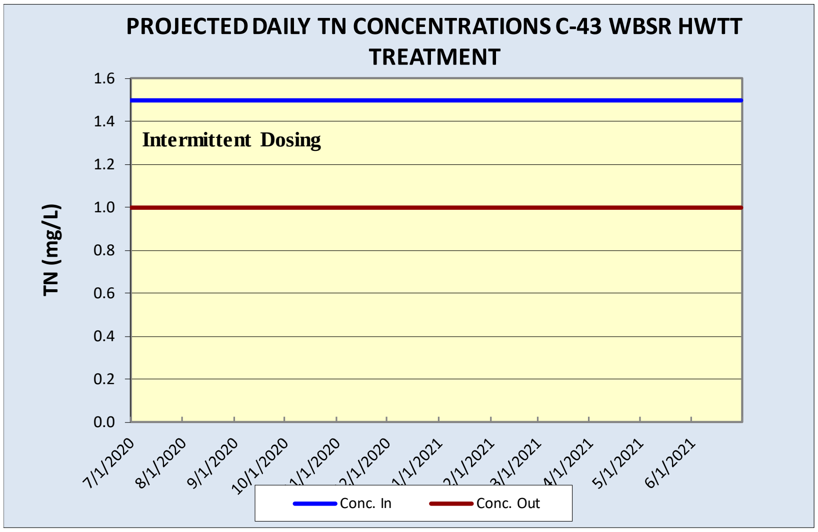
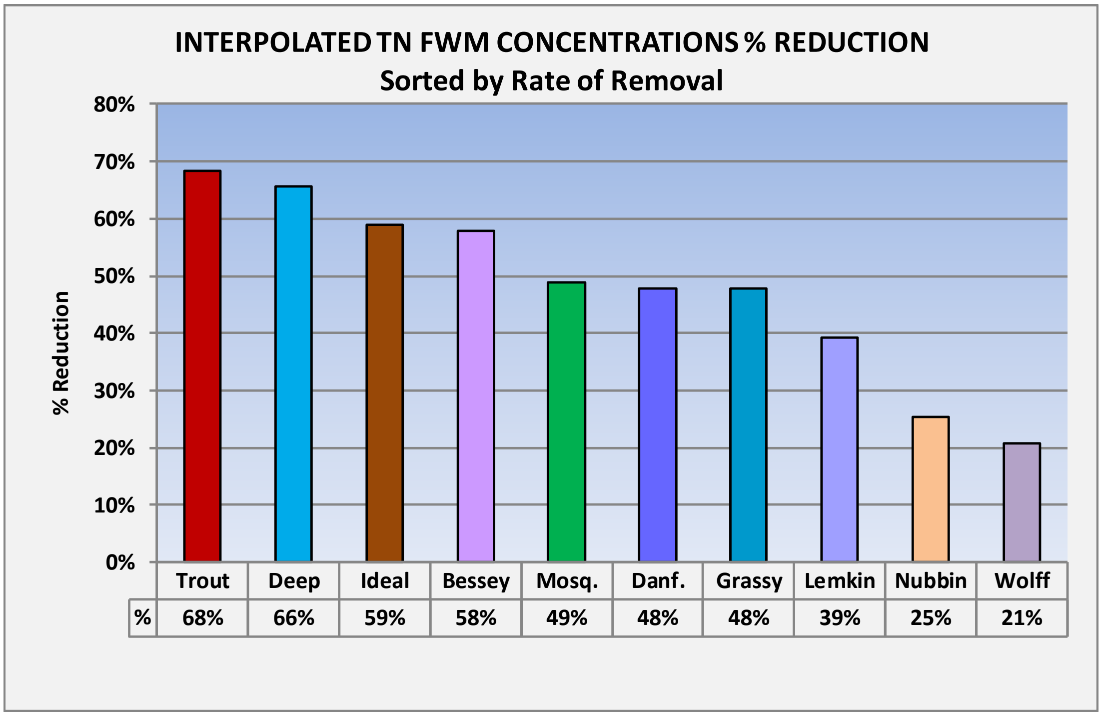
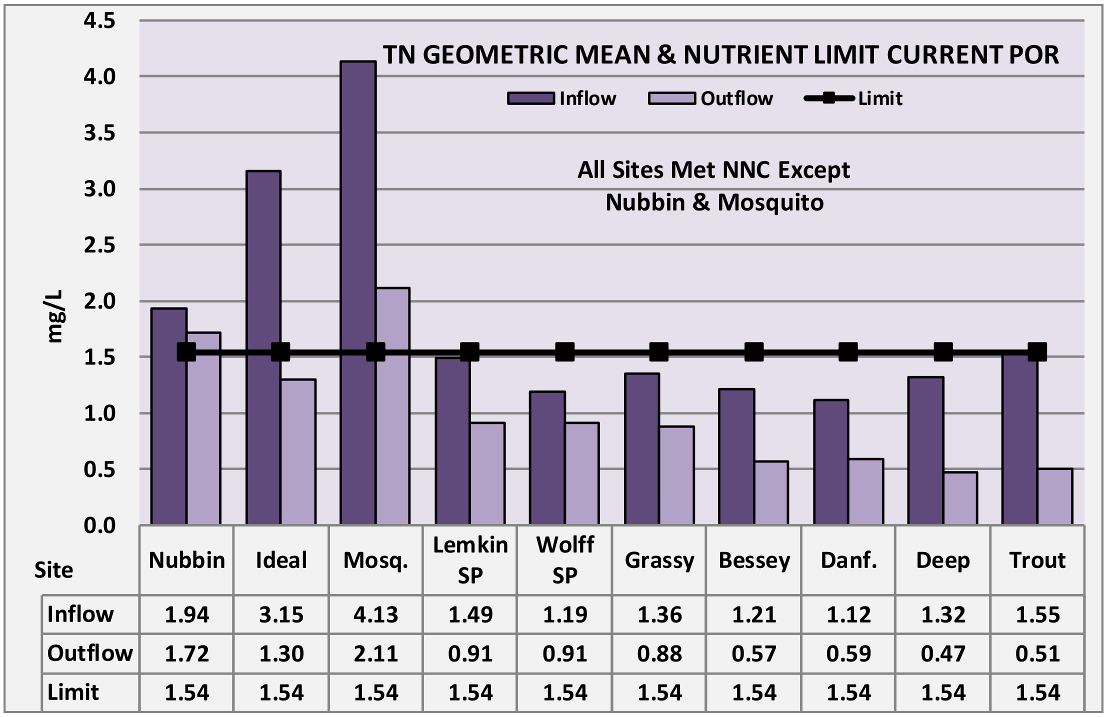


Figure IX-7. Projected daily TN concentrations C-43 WBSR HWTT Treatment System.



	Trout	Deep	Ideal	Bessey	Mosq.	Danf.	Grassy	Lemkin	Nubbin	Wolff
%	68%	66%	59%	58%	49%	48%	48%	39%	25%	21%

Figure IX-8. Percent TN reduction HWTT facilities 2018-2019.

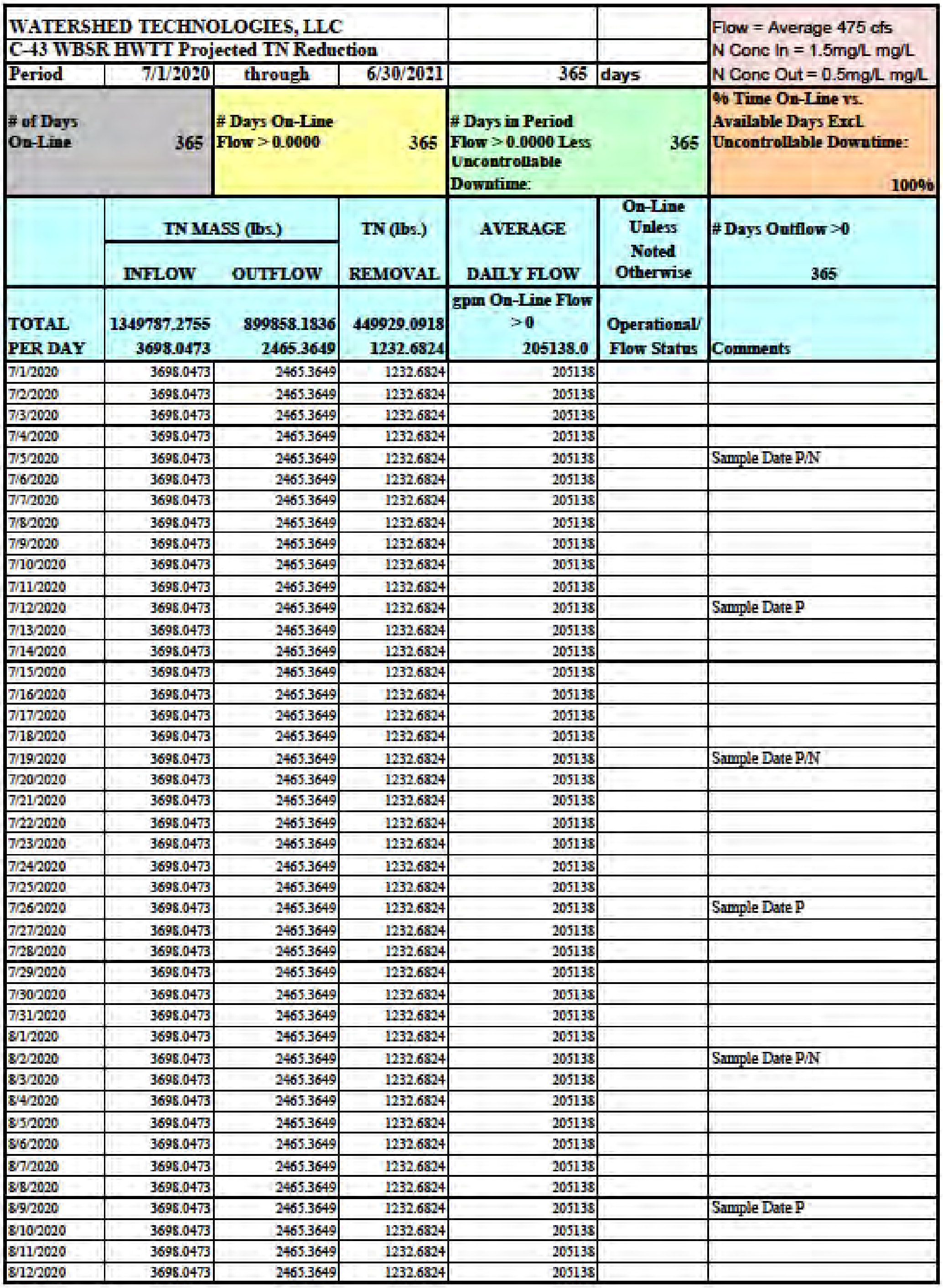


Site	Nubbin	Ideal	Mosq.	Lemkin SP	Wolff SP	Grassy	Bessey	Danf.	Deep	Trout
Inflow	1.94	3.15	4.13	1.49	1.19	1.36	1.21	1.12	1.32	1.55
Outflow	1.72	1.30	2.11	0.91	0.91	0.88	0.57	0.59	0.47	0.51
Limit	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54

Figure IX-9. Geometric Mean TN HWTT facilities 2018-2019.

Table IX-5. TP Load Performance Calculations.

(Double Click to Open Linked File)



WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	7/1/2020	through	6/30/2021	365	days	N Conc Out = 0.5mg/L mg/L
# of Days On-Line 365		# Days On-Line Flow > 0.0000 365		# Days in Period Flow > 0.0000 Less Uncontrollable Downtime: 365		% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%
	TN MASS (lbs.)		TN (lbs.)	AVERAGE	On-Line Unless Noted Otherwise	# Days Outflow >0
	INFLOW	OUTFLOW	REMOVAL	DAILY FLOW		365
TOTAL PER DAY	1349787.2755 3698.0473	899858.1836 2465.3649	449929.0918 1232.6824	gpm On-Line Flow > 0 205138.0	Operational/ Flow Status	Comments
7/1/2020	3698.0473	2465.3649	1232.6824	205138		
7/2/2020	3698.0473	2465.3649	1232.6824	205138		
7/3/2020	3698.0473	2465.3649	1232.6824	205138		
7/4/2020	3698.0473	2465.3649	1232.6824	205138		
7/5/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
7/6/2020	3698.0473	2465.3649	1232.6824	205138		
7/7/2020	3698.0473	2465.3649	1232.6824	205138		
7/8/2020	3698.0473	2465.3649	1232.6824	205138		
7/9/2020	3698.0473	2465.3649	1232.6824	205138		
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7/11/2020	3698.0473	2465.3649	1232.6824	205138		
7/12/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
7/13/2020	3698.0473	2465.3649	1232.6824	205138		
7/14/2020	3698.0473	2465.3649	1232.6824	205138		
7/15/2020	3698.0473	2465.3649	1232.6824	205138		
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7/18/2020	3698.0473	2465.3649	1232.6824	205138		
7/19/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
7/20/2020	3698.0473	2465.3649	1232.6824	205138		
7/21/2020	3698.0473	2465.3649	1232.6824	205138		
7/22/2020	3698.0473	2465.3649	1232.6824	205138		
7/23/2020	3698.0473	2465.3649	1232.6824	205138		
7/24/2020	3698.0473	2465.3649	1232.6824	205138		
7/25/2020	3698.0473	2465.3649	1232.6824	205138		
7/26/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
7/27/2020	3698.0473	2465.3649	1232.6824	205138		
7/28/2020	3698.0473	2465.3649	1232.6824	205138		
7/29/2020	3698.0473	2465.3649	1232.6824	205138		
7/30/2020	3698.0473	2465.3649	1232.6824	205138		
7/31/2020	3698.0473	2465.3649	1232.6824	205138		
8/1/2020	3698.0473	2465.3649	1232.6824	205138		
8/2/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
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8/4/2020	3698.0473	2465.3649	1232.6824	205138		
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8/10/2020	3698.0473	2465.3649	1232.6824	205138		
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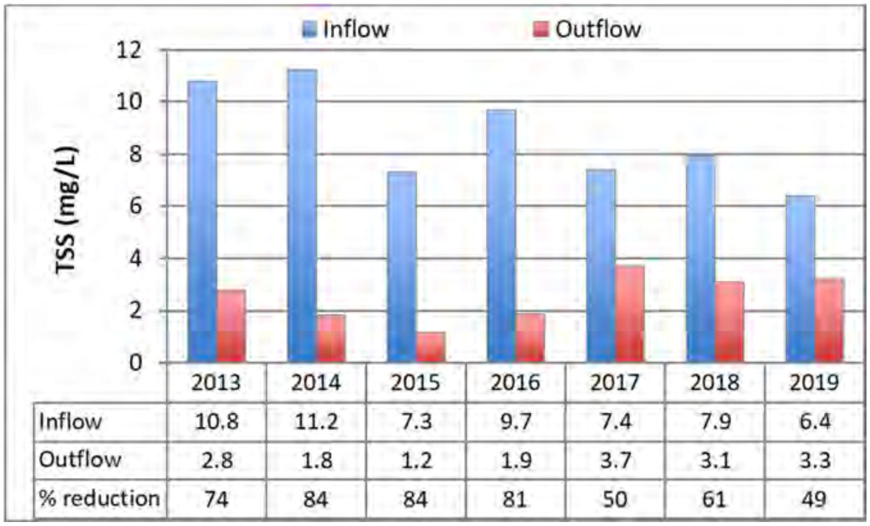
WATERSHED TECHNOLOGIES, LLC HWTT
Projected C-43 WBSR Treatment Project
Total Suspended Solids (TSS) Performance

The ability to attain the C-43 WBSR Treatment Project TSS goal of 50% reduction is demonstrated through performance statistics taken from the HWTT Grassy Island facility shown graphically below (Figure IX-10. Percent reductions range from 84% to 49% over the previous 7-year period.

Grassy Island HWTT TSS Summary

Inflow-outflow annual means and % reduction



	2013	2014	2015	2016	2017	2018	2019
Inflow	10.8	11.2	7.3	9.7	7.4	7.9	6.4
Outflow	2.8	1.8	1.2	1.9	3.7	3.1	3.3
% reduction	74	84	84	81	50	61	49

Figure IX-10. HWTT historical TSS performance.

WATERSHED TECHNOLOGIES, LLC HWTT
Projected C-43 WBSR Treatment Project
Water Quality Performance

HWTT can achieve low mean outflow TP and TN concentrations in waters of the State of Florida. There are various numeric TP criteria as a point of reference for projects, not formal applications of the standards. The first is a Peninsula Florida Numeric Nutrient Criteria (PF NNC) of 120 μg/L TP concentration, which includes waters of the Caloosahatchee River. There are no State of Florida numeric criteria for canals in the WBSR geographic area; the narrative nutrient criteria for the canals south of the River is no imbalance in natural populations of flora and fauna. The second criterion is the Upper Caloosahatchee River Estuary Numeric Nutrient Criteria (UCRE NNC) equal to 86 μg/L TP concentration. The NNC calculations are based upon annual geometric means not to be exceeded more than once in any three-year period. Both criteria are projected to be met by the HWTT proposed WBSR treatment system as demonstrated by continued performance at existing HWTT facilities.

There are various numeric TN criteria as a point of reference, not formal applications of the standards. The first is a PF NNC (62-302.531 Florida Administrative Code (FAC) (Numeric Interpretations of Narrative Nutrient Criteria) (FAC, 2013) of 1.54 milligrams per liter (mg/L) TN concentration, which includes waters of the Caloosahatchee River. There are no State of Florida numeric criteria for canals in the WBSR geographic area; the narrative nutrient criteria for the canals south of the River is no imbalance in natural populations of flora and fauna. The second criterion is the UCRE NNC equal to 0.82 mg/L TN concentration. The TN criteria are based on the annual geometric mean not to be exceeded more than once in any three-year period. The PF NNC criteria is projected to be met by the HWTT proposed WBSR treatment system. The water quality targets presented in the specification for this project are slightly greater than the UCRE NNC; however, the criteria is attained for all non-retrofitted HWTT sites (Figure IX-9).

X. Assumptions

The WBSR HWTT Treatment Proposal is based upon a set of assumptions and conditions. The following list specifies the major items, which form the basis of this proposal.

1. Inflow range to the HWTT facility is 300 to 600 cfs.
2. Average flow to the HWTT facility is 457 cfs as the daily flow.
3. Inflow is equal to outflow, that is, there is no seepage loss.
4. Inflow water quality will be consistent with C-43 test cell water quality summary report for both P and N.
5. Effluent water quality targets are to be achieved at all times and are not annual averages.
6. Inflow and outflow pump station and associated conveyance costs are specifically excluded from the cost estimates for both capital and O&M.
7. Engineering design, permitting, surveys, and construction management services are not included in cost estimate. Mobilization and as-builts *are included* in the capital projections.
8. No contingencies are contained within the estimate for both capital and O&M.
9. HWTT facility effectiveness is based on performance of similar existing facilities in the state of Florida.
10. HWTT O&M costs are based in part on similar existing facilities in the state of Florida.
11. Net Present Values were based upon on a net discount rate of 4% over a twenty-year period. The Net Present Values are used in calculating the Cost Benefit costs per pound. Changes in the discount rate and time will affect the calculations.
12. A bulk rate for chemical costs was obtained from a HWTT vendor and utilized for projected chemicals.
13. The O&M costs consist only of operational expenses. The following costs are specifically *excluded* from this proposal: administrative and overhead, management, scientific personnel, laboratory fees, and rate of return. The excluded costs noted are not necessarily all inconclusive.
14. Land fees or land acquisition costs are not included in the proposal.

4.29.14
Ag Water - [illegible]
Budell

MARTIN COUNTY
BOARD OF COUNTY COMMISSIONERS
2401 S.E. MONTEREY ROAD • STUART, FL 34996

Telephone: 772-221-2358
Fax: 772-288-5432
Email: sheard@martin.fl.us

DOUG SMITH
Commissioner, District 1

ED FIELDING
Commissioner, District 2

ANNE SCOTT
Commissioner, District 3

SARAH HEARD
Commissioner, District 4

JOHN HADDOX
Commissioner, District 5

TARYN KRYZDA, CPM
County Administrator

MICHAEL D. DURHAM
County Attorney

TELEPHONE
772-288-5400

WEB ADDRESS
http://www.martin.fl.us

April 22, 2014

The Honorable Adam H. Putnam
Commissioner of Agriculture
Department of Agriculture and Consumer Services
The Capitol
Tallahassee, FL 32399-0800

Dear Commissioner Putnam:

On behalf of the citizens and visitors of Martin County, I extend our most sincere gratitude for your significant support for water quality improvement projects in Martin County and the Treasure Coast region. Your efforts and leadership to invest in innovative approaches to water quality improvement in partnership with local governments is greatly appreciated and will result in direct improvements to local water quality.

Martin County has been proactive in addressing water quality improvement in our local water bodies. We have spent $50 million in local stormwater projects in partnership with the state of Florida and other entities that have improved water quality and assisted Martin County with meeting our obligations under the St. Lucie Watershed Total Maximum Daily Load (TMDL) program and its associated Basin Management Action Plan (BMAP). We are interested in exploring optimal efficiencies in water treatment through innovative treatment technologies, and are particularly excited about constructing Hybrid Wetland Treatment Technology (HWTT) projects in Martin County in partnership with the Florida Department of Agriculture and Consumer Services (FDACS). Thanks to your support, we have initiated work for an HWTT project at Bessey Creek in Palm City, and if successful with additional support, we will also complete a similar project at Danforth Creek. This technology has the potential to change the approach of stormwater quality treatment by reducing the footprint of land required to build projects, and increasing treatment efficiencies. We are eager to complete these projects and test their ability to evolve our options in improving local water quality.

Thank you again for your active and effective support on water quality improvement in Martin County and on the Treasure Coast.

Sincerely,

Sarah Heard

Sarah Heard, Chair
Martin County Board of County Commissioners

SH/dd

c: Honorable Members of the Martin County Board of County Commissioners
Taryn Kryzda, County Administrator

Human migration to avoid calamity has

they own would be the likeliest to migrate.

Hybrid wetland treatment projects help reduce Trout Lake nutrient levels

By PRAKASH GANDHI

Officials in the central Florida city of Eustis are heralding a major project that will help breathe new life into a polluted lake.

A $3 million hybrid wetland treatment facility will help clean up Trout Lake, helping to remove nutrients that have plagued the lake for years.

Last year, Watershed Technologies LLC leased 17 acres from the city to build the facility after the Florida Department of Environmental Protection declared Trout Lake an impaired waterbody due to high levels of phosphorus.

City officials said the project is good for the city and for the environment.

"This is a win-win situation for us," said Rick Gierok, city engineer and public works director for Eustis.

Trout Lake is on the state's list of impaired waterbodies, with current total phosphorus levels exceeding allowable levels by about 2,000 pounds per year.

A pump station has been in operation since the fall, moving water from Hicks Ditch into various ponds at the main facility.

The Eustis City Commission recently approved construction of a second pumping facility to be used during the dry season when there is no water flow in Hicks Ditch.

The Phase 2 project is located on five acres of city property in the Country Club Manor Mobile Home Park in what was once a wastewater treatment plant.

The second pump station will take water from Trout Lake, move it through about 4,550 feet of pipe running north to County Road 44, then east to the Phase 1 pump station. There, it will be filtered, sent back through the pipes and pumped back into the lake.

Gierok said it is important to bring the lake back to good health.

"Hicks Ditch pulls a tremendous amount of agricultural runoff that feeds into Trout Lake," he said. "Half of the lake is surrounded by wetlands and conservation areas."

City officials said the facility will also treat Trout Lake waters during the dry season. The goal is to remove more than 2,000 pounds a year of phosphorus, enabling Trout Lake to meet its TMDL target for the nutrient.

The state is covering all costs associated with construction of the second pump station, plus maintenance and operational costs, and has agreed to fund hybrid wetland treatment facilities across the state to help clean up polluted lakes.

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TP MASS (lbs.) INFLOW	**OUTFLOW**	**TP (lbs.) REMOVAL**	**AVERAGE DAILY FLOW**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0 365**
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**	**gpm On-Line Flow > 0**	**Operational/ Flow Status**	**Comments**
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**		
7/1/2020	394.4584	197.2292	197.2292	205138.0		
7/2/2020	394.4584	197.2292	197.2292	205138.0		
7/3/2020	394.4584	197.2292	197.2292	205138.0		
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7/13/2020	394.4584	197.2292	197.2292	205138.0		
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7/15/2020	394.4584	197.2292	197.2292	205138.0		
7/16/2020	394.4584	197.2292	197.2292	205138.0		
7/17/2020	394.4584	197.2292	197.2292	205138.0		
7/18/2020	394.4584	197.2292	197.2292	205138.0		
7/19/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
7/20/2020	394.4584	197.2292	197.2292	205138.0		
7/21/2020	394.4584	197.2292	197.2292	205138.0		
7/22/2020	394.4584	197.2292	197.2292	205138.0		
7/23/2020	394.4584	197.2292	197.2292	205138.0		
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7/26/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
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WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**	**gpm On-Line Flow > 0**	**Operational/ Flow Status**	**Comments**
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**		
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9/14/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
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9/20/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
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# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
				gpm On-Line Flow > 0		
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**		**Operational/**	
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**	**Flow Status**	**Comments**
10/3/2020	394.4584	197.2292	197.2292	205138.0		
10/4/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
10/5/2020	394.4584	197.2292	197.2292	205138.0		
10/6/2020	394.4584	197.2292	197.2292	205138.0		
10/7/2020	394.4584	197.2292	197.2292	205138.0		
10/8/2020	394.4584	197.2292	197.2292	205138.0		
10/9/2020	394.4584	197.2292	197.2292	205138.0		
10/10/2020	394.4584	197.2292	197.2292	205138.0		
10/11/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
10/12/2020	394.4584	197.2292	197.2292	205138.0		
10/13/2020	394.4584	197.2292	197.2292	205138.0		
10/14/2020	394.4584	197.2292	197.2292	205138.0		
10/15/2020	394.4584	197.2292	197.2292	205138.0		
10/16/2020	394.4584	197.2292	197.2292	205138.0		
10/17/2020	394.4584	197.2292	197.2292	205138.0		
10/18/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
10/19/2020	394.4584	197.2292	197.2292	205138.0		
10/20/2020	394.4584	197.2292	197.2292	205138.0		
10/21/2020	394.4584	197.2292	197.2292	205138.0		
10/22/2020	394.4584	197.2292	197.2292	205138.0		
10/23/2020	394.4584	197.2292	197.2292	205138.0		
10/24/2020	394.4584	197.2292	197.2292	205138.0		
10/25/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
10/26/2020	394.4584	197.2292	197.2292	205138.0		
10/27/2020	394.4584	197.2292	197.2292	205138.0		
10/28/2020	394.4584	197.2292	197.2292	205138.0		
10/29/2020	394.4584	197.2292	197.2292	205138.0		
10/30/2020	394.4584	197.2292	197.2292	205138.0		
10/31/2020	394.4584	197.2292	197.2292	205138.0		
11/1/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
11/2/2020	394.4584	197.2292	197.2292	205138.0		
11/3/2020	394.4584	197.2292	197.2292	205138.0		
11/4/2020	394.4584	197.2292	197.2292	205138.0		
11/5/2020	394.4584	197.2292	197.2292	205138.0		
11/6/2020	394.4584	197.2292	197.2292	205138.0		
11/7/2020	394.4584	197.2292	197.2292	205138.0		
11/8/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
11/9/2020	394.4584	197.2292	197.2292	205138.0		
11/10/2020	394.4584	197.2292	197.2292	205138.0		
11/11/2020	394.4584	197.2292	197.2292	205138.0		
11/12/2020	394.4584	197.2292	197.2292	205138.0		
11/13/2020	394.4584	197.2292	197.2292	205138.0		
11/14/2020	394.4584	197.2292	197.2292	205138.0		
11/15/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
11/16/2020	394.4584	197.2292	197.2292	205138.0		
11/17/2020	394.4584	197.2292	197.2292	205138.0		
11/18/2020	394.4584	197.2292	197.2292	205138.0		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L

# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:**	**100%**

	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
				gpm On-Line Flow > 0	**Operational/ Flow Status**	**Comments**
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**			
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**		
11/19/2020	394.4584	197.2292	197.2292	205138.0		
11/20/2020	394.4584	197.2292	197.2292	205138.0		
11/21/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
11/22/2020	394.4584	197.2292	197.2292	205138.0		
11/23/2020	394.4584	197.2292	197.2292	205138.0		
11/24/2020	394.4584	197.2292	197.2292	205138.0		
11/25/2020	394.4584	197.2292	197.2292	205138.0		
11/26/2020	394.4584	197.2292	197.2292	205138.0		
11/27/2020	394.4584	197.2292	197.2292	205138.0		
11/28/2020	394.4584	197.2292	197.2292	205138.0		
11/29/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
11/30/2020	394.4584	197.2292	197.2292	205138.0		
12/1/2020	394.4584	197.2292	197.2292	205138.0		
12/2/2020	394.4584	197.2292	197.2292	205138.0		
12/3/2020	394.4584	197.2292	197.2292	205138.0		
12/4/2020	394.4584	197.2292	197.2292	205138.0		
12/5/2020	394.4584	197.2292	197.2292	205138.0		
12/6/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
12/7/2020	394.4584	197.2292	197.2292	205138.0		
12/8/2020	394.4584	197.2292	197.2292	205138.0		
12/9/2020	394.4584	197.2292	197.2292	205138.0		
12/10/2020	394.4584	197.2292	197.2292	205138.0		
12/11/2020	394.4584	197.2292	197.2292	205138.0		
12/12/2020	394.4584	197.2292	197.2292	205138.0		
12/13/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
12/14/2020	394.4584	197.2292	197.2292	205138.0		
12/15/2020	394.4584	197.2292	197.2292	205138.0		
12/16/2020	394.4584	197.2292	197.2292	205138.0		
12/17/2020	394.4584	197.2292	197.2292	205138.0		
12/18/2020	394.4584	197.2292	197.2292	205138.0		
12/19/2020	394.4584	197.2292	197.2292	205138.0		
12/20/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
12/21/2020	394.4584	197.2292	197.2292	205138.0		
12/22/2020	394.4584	197.2292	197.2292	205138.0		
12/23/2020	394.4584	197.2292	197.2292	205138.0		
12/24/2020	394.4584	197.2292	197.2292	205138.0		
12/25/2020	394.4584	197.2292	197.2292	205138.0		
12/26/2020	394.4584	197.2292	197.2292	205138.0		
12/27/2020	394.4584	197.2292	197.2292	205138.0		Sample Date P
12/28/2020	394.4584	197.2292	197.2292	205138.0		
12/29/2020	394.4584	197.2292	197.2292	205138.0		
12/30/2020	394.4584	197.2292	197.2292	205138.0		
12/31/2020	394.4584	197.2292	197.2292	205138.0		
1/1/2021	394.4584	197.2292	197.2292	205138.0		
1/2/2021	394.4584	197.2292	197.2292	205138.0		
1/3/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
1/4/2021	394.4584	197.2292	197.2292	205138.0		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**	**gpm On-Line Flow > 0**	**Operational/**	
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**	**Flow Status**	**Comments**
1/5/2021	394.4584	197.2292	197.2292	205138.0		
1/6/2021	394.4584	197.2292	197.2292	205138.0		
1/7/2021	394.4584	197.2292	197.2292	205138.0		
1/8/2021	394.4584	197.2292	197.2292	205138.0		
1/9/2021	394.4584	197.2292	197.2292	205138.0		
1/10/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
1/11/2021	394.4584	197.2292	197.2292	205138.0		
1/12/2021	394.4584	197.2292	197.2292	205138.0		
1/13/2021	394.4584	197.2292	197.2292	205138.0		
1/14/2021	394.4584	197.2292	197.2292	205138.0		
1/15/2021	394.4584	197.2292	197.2292	205138.0		
1/16/2021	394.4584	197.2292	197.2292	205138.0		
1/17/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
1/18/2021	394.4584	197.2292	197.2292	205138.0		
1/19/2021	394.4584	197.2292	197.2292	205138.0		
1/20/2021	394.4584	197.2292	197.2292	205138.0		
1/21/2021	394.4584	197.2292	197.2292	205138.0		
1/22/2021	394.4584	197.2292	197.2292	205138.0		
1/23/2021	394.4584	197.2292	197.2292	205138.0		
1/24/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
1/25/2021	394.4584	197.2292	197.2292	205138.0		
1/26/2021	394.4584	197.2292	197.2292	205138.0		
1/27/2021	394.4584	197.2292	197.2292	205138.0		
1/28/2021	394.4584	197.2292	197.2292	205138.0		
1/29/2021	394.4584	197.2292	197.2292	205138.0		
1/30/2021	394.4584	197.2292	197.2292	205138.0		
1/31/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
2/1/2021	394.4584	197.2292	197.2292	205138.0		
2/2/2021	394.4584	197.2292	197.2292	205138.0		
2/3/2021	394.4584	197.2292	197.2292	205138.0		
2/4/2021	394.4584	197.2292	197.2292	205138.0		
2/5/2021	394.4584	197.2292	197.2292	205138.0		
2/6/2021	394.4584	197.2292	197.2292	205138.0		
2/7/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
2/8/2021	394.4584	197.2292	197.2292	205138.0		
2/9/2021	394.4584	197.2292	197.2292	205138.0		
2/10/2021	394.4584	197.2292	197.2292	205138.0		
2/11/2021	394.4584	197.2292	197.2292	205138.0		
2/12/2021	394.4584	197.2292	197.2292	205138.0		
2/13/2021	394.4584	197.2292	197.2292	205138.0		
2/14/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
2/15/2021	394.4584	197.2292	197.2292	205138.0		
2/16/2021	394.4584	197.2292	197.2292	205138.0		
2/17/2021	394.4584	197.2292	197.2292	205138.0		
2/18/2021	394.4584	197.2292	197.2292	205138.0		
2/19/2021	394.4584	197.2292	197.2292	205138.0		
2/20/2021	394.4584	197.2292	197.2292	205138.0		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** **100%**
	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
				gpm On-Line Flow > 0		
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**		**Operational/**	
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**	**Flow Status**	**Comments**
2/21/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
2/22/2021	394.4584	197.2292	197.2292	205138.0		
2/23/2021	394.4584	197.2292	197.2292	205138.0		
2/24/2021	394.4584	197.2292	197.2292	205138.0		
2/25/2021	394.4584	197.2292	197.2292	205138.0		
2/26/2021	394.4584	197.2292	197.2292	205138.0		
2/27/2021	394.4584	197.2292	197.2292	205138.0		
2/28/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
3/1/2021	394.4584	197.2292	197.2292	205138.0		
3/2/2021	394.4584	197.2292	197.2292	205138.0		
3/3/2021	394.4584	197.2292	197.2292	205138.0		
3/4/2021	394.4584	197.2292	197.2292	205138.0		
3/5/2021	394.4584	197.2292	197.2292	205138.0		
3/6/2021	394.4584	197.2292	197.2292	205138.0		
3/7/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
3/8/2021	394.4584	197.2292	197.2292	205138.0		
3/9/2021	394.4584	197.2292	197.2292	205138.0		
3/10/2021	394.4584	197.2292	197.2292	205138.0		
3/11/2021	394.4584	197.2292	197.2292	205138.0		
3/12/2021	394.4584	197.2292	197.2292	205138.0		
3/13/2021	394.4584	197.2292	197.2292	205138.0		
3/14/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
3/15/2021	394.4584	197.2292	197.2292	205138.0		
3/16/2021	394.4584	197.2292	197.2292	205138.0		
3/17/2021	394.4584	197.2292	197.2292	205138.0		
3/18/2021	394.4584	197.2292	197.2292	205138.0		
3/19/2021	394.4584	197.2292	197.2292	205138.0		
3/20/2021	394.4584	197.2292	197.2292	205138.0		
3/21/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
3/22/2021	394.4584	197.2292	197.2292	205138.0		
3/23/2021	394.4584	197.2292	197.2292	205138.0		
3/24/2021	394.4584	197.2292	197.2292	205138.0		
3/25/2021	394.4584	197.2292	197.2292	205138.0		
3/26/2021	394.4584	197.2292	197.2292	205138.0		
3/27/2021	394.4584	197.2292	197.2292	205138.0		
3/28/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
3/29/2021	394.4584	197.2292	197.2292	205138.0		
3/30/2021	394.4584	197.2292	197.2292	205138.0		
3/31/2021	394.4584	197.2292	197.2292	205138.0		
4/1/2021	394.4584	197.2292	197.2292	205138.0		
4/2/2021	394.4584	197.2292	197.2292	205138.0		
4/3/2021	394.4584	197.2292	197.2292	205138.0		
4/4/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
4/5/2021	394.4584	197.2292	197.2292	205138.0		
4/6/2021	394.4584	197.2292	197.2292	205138.0		
4/7/2021	394.4584	197.2292	197.2292	205138.0		
4/8/2021	394.4584	197.2292	197.2292	205138.0		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** **100%**
	TP MASS (lbs.) **INFLOW**	**OUTFLOW**	**TP (lbs.)** **REMOVAL**	**AVERAGE** **DAILY FLOW**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0** **365**
TOTAL **PER DAY**	**143977.3094** **394.4584**	**71988.6547** **197.2292**	**71988.6547** **197.2292**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
4/9/2021	394.4584	197.2292	197.2292	205138.0		
4/10/2021	394.4584	197.2292	197.2292	205138.0		
4/11/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
4/12/2021	394.4584	197.2292	197.2292	205138.0		
4/13/2021	394.4584	197.2292	197.2292	205138.0		
4/14/2021	394.4584	197.2292	197.2292	205138.0		
4/15/2021	394.4584	197.2292	197.2292	205138.0		
4/16/2021	394.4584	197.2292	197.2292	205138.0		
4/17/2021	394.4584	197.2292	197.2292	205138.0		
4/18/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
4/19/2021	394.4584	197.2292	197.2292	205138.0		
4/20/2021	394.4584	197.2292	197.2292	205138.0		
4/21/2021	394.4584	197.2292	197.2292	205138.0		
4/22/2021	394.4584	197.2292	197.2292	205138.0		
4/23/2021	394.4584	197.2292	197.2292	205138.0		
4/24/2021	394.4584	197.2292	197.2292	205138.0		
4/25/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
4/26/2021	394.4584	197.2292	197.2292	205138.0		
4/27/2021	394.4584	197.2292	197.2292	205138.0		
4/28/2021	394.4584	197.2292	197.2292	205138.0		
4/29/2021	394.4584	197.2292	197.2292	205138.0		
4/30/2021	394.4584	197.2292	197.2292	205138.0		
5/1/2021	394.4584	197.2292	197.2292	205138.0		
5/2/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
5/3/2021	394.4584	197.2292	197.2292	205138.0		
5/4/2021	394.4584	197.2292	197.2292	205138.0		
5/5/2021	394.4584	197.2292	197.2292	205138.0		
5/6/2021	394.4584	197.2292	197.2292	205138.0		
5/7/2021	394.4584	197.2292	197.2292	205138.0		
5/8/2021	394.4584	197.2292	197.2292	205138.0		
5/9/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
5/10/2021	394.4584	197.2292	197.2292	205138.0		
5/11/2021	394.4584	197.2292	197.2292	205138.0		
5/12/2021	394.4584	197.2292	197.2292	205138.0		
5/13/2021	394.4584	197.2292	197.2292	205138.0		
5/14/2021	394.4584	197.2292	197.2292	205138.0		
5/15/2021	394.4584	197.2292	197.2292	205138.0		
5/16/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
5/17/2021	394.4584	197.2292	197.2292	205138.0		
5/18/2021	394.4584	197.2292	197.2292	205138.0		
5/19/2021	394.4584	197.2292	197.2292	205138.0		
5/20/2021	394.4584	197.2292	197.2292	205138.0		
5/21/2021	394.4584	197.2292	197.2292	205138.0		
5/22/2021	394.4584	197.2292	197.2292	205138.0		
5/23/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
5/24/2021	394.4584	197.2292	197.2292	205138.0		
5/25/2021	394.4584	197.2292	197.2292	205138.0		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TP Reduction						P Conc In = 0.16 mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days in period**	P Conc Out = 0.08 mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TP MASS (lbs.)		**TP (lbs.)**	**AVERAGE**	**On-Line Unless**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**	**Noted Otherwise**	**365**
TOTAL	**143977.3094**	**71988.6547**	**71988.6547**	**gpm On-Line Flow > 0**	**Operational/ Flow Status**	**Comments**
PER DAY	**394.4584**	**197.2292**	**197.2292**	**205138.0**		
5/26/2021	394.4584	197.2292	197.2292	205138.0		
5/27/2021	394.4584	197.2292	197.2292	205138.0		
5/28/2021	394.4584	197.2292	197.2292	205138.0		
5/29/2021	394.4584	197.2292	197.2292	205138.0		
5/30/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
5/31/2021	394.4584	197.2292	197.2292	205138.0		
6/1/2021	394.4584	197.2292	197.2292	205138.0		
6/2/2021	394.4584	197.2292	197.2292	205138.0		
6/3/2021	394.4584	197.2292	197.2292	205138.0		
6/4/2021	394.4584	197.2292	197.2292	205138.0		
6/5/2021	394.4584	197.2292	197.2292	205138.0		
6/6/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
6/7/2021	394.4584	197.2292	197.2292	205138.0		
6/8/2021	394.4584	197.2292	197.2292	205138.0		
6/9/2021	394.4584	197.2292	197.2292	205138.0		
6/10/2021	394.4584	197.2292	197.2292	205138.0		
6/11/2021	394.4584	197.2292	197.2292	205138.0		
6/12/2021	394.4584	197.2292	197.2292	205138.0		
6/13/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
6/14/2021	394.4584	197.2292	197.2292	205138.0		
6/15/2021	394.4584	197.2292	197.2292	205138.0		
6/16/2021	394.4584	197.2292	197.2292	205138.0		
6/17/2021	394.4584	197.2292	197.2292	205138.0		
6/18/2021	394.4584	197.2292	197.2292	205138.0		
6/19/2021	394.4584	197.2292	197.2292	205138.0		
6/20/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P/N
6/21/2021	394.4584	197.2292	197.2292	205138.0		
6/22/2021	394.4584	197.2292	197.2292	205138.0		
6/23/2021	394.4584	197.2292	197.2292	205138.0		
6/24/2021	394.4584	197.2292	197.2292	205138.0		
6/25/2021	394.4584	197.2292	197.2292	205138.0		
6/26/2021	394.4584	197.2292	197.2292	205138.0		
6/27/2021	394.4584	197.2292	197.2292	205138.0		Sample Date P
6/28/2021	394.4584	197.2292	197.2292	205138.0		
6/29/2021	394.4584	197.2292	197.2292	205138.0		
6/30/2021	394.4584	197.2292	197.2292	205138.0		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L

# of Days On-Line 365	**# Days On-Line Flow > 0.0000 365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime: 365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**

	TN MASS (lbs.)		**TN (lbs.)**	**AVERAGE**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**		**365**
TOTAL **PER DAY**	**1349787.2755** **3698.0473**	**899858.1836** **2465.3649**	**449929.0918** **1232.6824**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
7/1/2020	3698.0473	2465.3649	1232.6824	205138		
7/2/2020	3698.0473	2465.3649	1232.6824	205138		
7/3/2020	3698.0473	2465.3649	1232.6824	205138		
7/4/2020	3698.0473	2465.3649	1232.6824	205138		
7/5/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
7/6/2020	3698.0473	2465.3649	1232.6824	205138		
7/7/2020	3698.0473	2465.3649	1232.6824	205138		
7/8/2020	3698.0473	2465.3649	1232.6824	205138		
7/9/2020	3698.0473	2465.3649	1232.6824	205138		
7/10/2020	3698.0473	2465.3649	1232.6824	205138		
7/11/2020	3698.0473	2465.3649	1232.6824	205138		
7/12/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
7/13/2020	3698.0473	2465.3649	1232.6824	205138		
7/14/2020	3698.0473	2465.3649	1232.6824	205138		
7/15/2020	3698.0473	2465.3649	1232.6824	205138		
7/16/2020	3698.0473	2465.3649	1232.6824	205138		
7/17/2020	3698.0473	2465.3649	1232.6824	205138		
7/18/2020	3698.0473	2465.3649	1232.6824	205138		
7/19/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
7/20/2020	3698.0473	2465.3649	1232.6824	205138		
7/21/2020	3698.0473	2465.3649	1232.6824	205138		
7/22/2020	3698.0473	2465.3649	1232.6824	205138		
7/23/2020	3698.0473	2465.3649	1232.6824	205138		
7/24/2020	3698.0473	2465.3649	1232.6824	205138		
7/25/2020	3698.0473	2465.3649	1232.6824	205138		
7/26/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
7/27/2020	3698.0473	2465.3649	1232.6824	205138		
7/28/2020	3698.0473	2465.3649	1232.6824	205138		
7/29/2020	3698.0473	2465.3649	1232.6824	205138		
7/30/2020	3698.0473	2465.3649	1232.6824	205138		
7/31/2020	3698.0473	2465.3649	1232.6824	205138		
8/1/2020	3698.0473	2465.3649	1232.6824	205138		
8/2/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
8/3/2020	3698.0473	2465.3649	1232.6824	205138		
8/4/2020	3698.0473	2465.3649	1232.6824	205138		
8/5/2020	3698.0473	2465.3649	1232.6824	205138		
8/6/2020	3698.0473	2465.3649	1232.6824	205138		
8/7/2020	3698.0473	2465.3649	1232.6824	205138		
8/8/2020	3698.0473	2465.3649	1232.6824	205138		
8/9/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
8/10/2020	3698.0473	2465.3649	1232.6824	205138		
8/11/2020	3698.0473	2465.3649	1232.6824	205138		
8/12/2020	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TN MASS (lbs.)		**TN (lbs.)**	**AVERAGE**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**		**365**
				gpm On-Line Flow > 0		
TOTAL	**1349787.2755**	**899858.1836**	**449929.0918**		**Operational/**	
PER DAY	**3698.0473**	**2465.3649**	**1232.6824**	**205138.0**	**Flow Status**	**Comments**
8/13/2020	3698.0473	2465.3649	1232.6824	205138		
8/14/2020	3698.0473	2465.3649	1232.6824	205138		
8/15/2020	3698.0473	2465.3649	1232.6824	205138		
8/16/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
8/17/2020	3698.0473	2465.3649	1232.6824	205138		
8/18/2020	3698.0473	2465.3649	1232.6824	205138		
8/19/2020	3698.0473	2465.3649	1232.6824	205138		
8/20/2020	3698.0473	2465.3649	1232.6824	205138		
8/21/2020	3698.0473	2465.3649	1232.6824	205138		
8/22/2020	3698.0473	2465.3649	1232.6824	205138		
8/23/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
8/24/2020	3698.0473	2465.3649	1232.6824	205138		
8/25/2020	3698.0473	2465.3649	1232.6824	205138		
8/26/2020	3698.0473	2465.3649	1232.6824	205138		
8/27/2020	3698.0473	2465.3649	1232.6824	205138		
8/28/2020	3698.0473	2465.3649	1232.6824	205138		
8/29/2020	3698.0473	2465.3649	1232.6824	205138		
8/30/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
8/31/2020	3698.0473	2465.3649	1232.6824	205138		
9/1/2020	3698.0473	2465.3649	1232.6824	205138		
9/2/2020	3698.0473	2465.3649	1232.6824	205138		
9/3/2020	3698.0473	2465.3649	1232.6824	205138		
9/4/2020	3698.0473	2465.3649	1232.6824	205138		
9/5/2020	3698.0473	2465.3649	1232.6824	205138		
9/6/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
9/7/2020	3698.0473	2465.3649	1232.6824	205138		
9/8/2020	3698.0473	2465.3649	1232.6824	205138		
9/9/2020	3698.0473	2465.3649	1232.6824	205138		
9/10/2020	3698.0473	2465.3649	1232.6824	205138		
9/11/2020	3698.0473	2465.3649	1232.6824	205138		
9/12/2020	3698.0473	2465.3649	1232.6824	205138		
9/13/2020	3698.0473	2465.3649	1232.6824	205138		
9/14/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
9/15/2020	3698.0473	2465.3649	1232.6824	205138		
9/16/2020	3698.0473	2465.3649	1232.6824	205138		
9/17/2020	3698.0473	2465.3649	1232.6824	205138		
9/18/2020	3698.0473	2465.3649	1232.6824	205138		
9/19/2020	3698.0473	2465.3649	1232.6824	205138		
9/20/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
9/21/2020	3698.0473	2465.3649	1232.6824	205138		
9/22/2020	3698.0473	2465.3649	1232.6824	205138		
9/23/2020	3698.0473	2465.3649	1232.6824	205138		
9/24/2020	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line **365**		**# Days On-Line Flow > 0.0000** **365**		**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:** **365**		**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** **100%**

	TN MASS (lbs.)		**TN (lbs.)**	**AVERAGE**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**		**365**
TOTAL **PER DAY**	**1349787.2755** **3698.0473**	**899858.1836** **2465.3649**	**449929.0918** **1232.6824**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
9/25/2020	3698.0473	2465.3649	1232.6824	205138		
9/26/2020	3698.0473	2465.3649	1232.6824	205138		
9/27/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
9/28/2020	3698.0473	2465.3649	1232.6824	205138		
9/29/2020	3698.0473	2465.3649	1232.6824	205138		
9/30/2020	3698.0473	2465.3649	1232.6824	205138		
10/1/2020	3698.0473	2465.3649	1232.6824	205138		
10/2/2020	3698.0473	2465.3649	1232.6824	205138		
10/3/2020	3698.0473	2465.3649	1232.6824	205138		
10/4/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
10/5/2020	3698.0473	2465.3649	1232.6824	205138		
10/6/2020	3698.0473	2465.3649	1232.6824	205138		
10/7/2020	3698.0473	2465.3649	1232.6824	205138		
10/8/2020	3698.0473	2465.3649	1232.6824	205138		
10/9/2020	3698.0473	2465.3649	1232.6824	205138		
10/10/2020	3698.0473	2465.3649	1232.6824	205138		
10/11/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
10/12/2020	3698.0473	2465.3649	1232.6824	205138		
10/13/2020	3698.0473	2465.3649	1232.6824	205138		
10/14/2020	3698.0473	2465.3649	1232.6824	205138		
10/15/2020	3698.0473	2465.3649	1232.6824	205138		
10/16/2020	3698.0473	2465.3649	1232.6824	205138		
10/17/2020	3698.0473	2465.3649	1232.6824	205138		
10/18/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
10/19/2020	3698.0473	2465.3649	1232.6824	205138		
10/20/2020	3698.0473	2465.3649	1232.6824	205138		
10/21/2020	3698.0473	2465.3649	1232.6824	205138		
10/22/2020	3698.0473	2465.3649	1232.6824	205138		
10/23/2020	3698.0473	2465.3649	1232.6824	205138		
10/24/2020	3698.0473	2465.3649	1232.6824	205138		
10/25/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
10/26/2020	3698.0473	2465.3649	1232.6824	205138		
10/27/2020	3698.0473	2465.3649	1232.6824	205138		
10/28/2020	3698.0473	2465.3649	1232.6824	205138		
10/29/2020	3698.0473	2465.3649	1232.6824	205138		
10/30/2020	3698.0473	2465.3649	1232.6824	205138		
10/31/2020	3698.0473	2465.3649	1232.6824	205138		
11/1/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
11/2/2020	3698.0473	2465.3649	1232.6824	205138		
11/3/2020	3698.0473	2465.3649	1232.6824	205138		
11/4/2020	3698.0473	2465.3649	1232.6824	205138		
11/5/2020	3698.0473	2465.3649	1232.6824	205138		
11/6/2020	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** **100%**
	TN MASS (lbs.) **INFLOW**	**OUTFLOW**	**TN (lbs.)** **REMOVAL**	**AVERAGE** **DAILY FLOW**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0** **365**
TOTAL **PER DAY**	**1349787.2755** **3698.0473**	**899858.1836** **2465.3649**	**449929.0918** **1232.6824**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
11/7/2020	3698.0473	2465.3649	1232.6824	205138		
11/8/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
11/9/2020	3698.0473	2465.3649	1232.6824	205138		
11/10/2020	3698.0473	2465.3649	1232.6824	205138		
11/11/2020	3698.0473	2465.3649	1232.6824	205138		
11/12/2020	3698.0473	2465.3649	1232.6824	205138		
11/13/2020	3698.0473	2465.3649	1232.6824	205138		
11/14/2020	3698.0473	2465.3649	1232.6824	205138		
11/15/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
11/16/2020	3698.0473	2465.3649	1232.6824	205138		
11/17/2020	3698.0473	2465.3649	1232.6824	205138		
11/18/2020	3698.0473	2465.3649	1232.6824	205138		
11/19/2020	3698.0473	2465.3649	1232.6824	205138		
11/20/2020	3698.0473	2465.3649	1232.6824	205138		
11/21/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
11/22/2020	3698.0473	2465.3649	1232.6824	205138		
11/23/2020	3698.0473	2465.3649	1232.6824	205138		
11/24/2020	3698.0473	2465.3649	1232.6824	205138		
11/25/2020	3698.0473	2465.3649	1232.6824	205138		
11/26/2020	3698.0473	2465.3649	1232.6824	205138		
11/27/2020	3698.0473	2465.3649	1232.6824	205138		
11/28/2020	3698.0473	2465.3649	1232.6824	205138		
11/29/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
11/30/2020	3698.0473	2465.3649	1232.6824	205138		
12/1/2020	3698.0473	2465.3649	1232.6824	205138		
12/2/2020	3698.0473	2465.3649	1232.6824	205138		
12/3/2020	3698.0473	2465.3649	1232.6824	205138		
12/4/2020	3698.0473	2465.3649	1232.6824	205138		
12/5/2020	3698.0473	2465.3649	1232.6824	205138		
12/6/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
12/7/2020	3698.0473	2465.3649	1232.6824	205138		
12/8/2020	3698.0473	2465.3649	1232.6824	205138		
12/9/2020	3698.0473	2465.3649	1232.6824	205138		
12/10/2020	3698.0473	2465.3649	1232.6824	205138		
12/11/2020	3698.0473	2465.3649	1232.6824	205138		
12/12/2020	3698.0473	2465.3649	1232.6824	205138		
12/13/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
12/14/2020	3698.0473	2465.3649	1232.6824	205138		
12/15/2020	3698.0473	2465.3649	1232.6824	205138		
12/16/2020	3698.0473	2465.3649	1232.6824	205138		
12/17/2020	3698.0473	2465.3649	1232.6824	205138		
12/18/2020	3698.0473	2465.3649	1232.6824	205138		
12/19/2020	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** **100%**
	TN MASS (lbs.) **INFLOW**	**OUTFLOW**	**TN (lbs.)** **REMOVAL**	**AVERAGE** **DAILY FLOW**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0** **365**
TOTAL **PER DAY**	**1349787.2755** **3698.0473**	**899858.1836** **2465.3649**	**449929.0918** **1232.6824**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
12/20/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
12/21/2020	3698.0473	2465.3649	1232.6824	205138		
12/22/2020	3698.0473	2465.3649	1232.6824	205138		
12/23/2020	3698.0473	2465.3649	1232.6824	205138		
12/24/2020	3698.0473	2465.3649	1232.6824	205138		
12/25/2020	3698.0473	2465.3649	1232.6824	205138		
12/26/2020	3698.0473	2465.3649	1232.6824	205138		
12/27/2020	3698.0473	2465.3649	1232.6824	205138		Sample Date P
12/28/2020	3698.0473	2465.3649	1232.6824	205138		
12/29/2020	3698.0473	2465.3649	1232.6824	205138		
12/30/2020	3698.0473	2465.3649	1232.6824	205138		
12/31/2020	3698.0473	2465.3649	1232.6824	205138		
1/1/2021	3698.0473	2465.3649	1232.6824	205138		
1/2/2021	3698.0473	2465.3649	1232.6824	205138		
1/3/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
1/4/2021	3698.0473	2465.3649	1232.6824	205138		
1/5/2021	3698.0473	2465.3649	1232.6824	205138		
1/6/2021	3698.0473	2465.3649	1232.6824	205138		
1/7/2021	3698.0473	2465.3649	1232.6824	205138		
1/8/2021	3698.0473	2465.3649	1232.6824	205138		
1/9/2021	3698.0473	2465.3649	1232.6824	205138		
1/10/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
1/11/2021	3698.0473	2465.3649	1232.6824	205138		
1/12/2021	3698.0473	2465.3649	1232.6824	205138		
1/13/2021	3698.0473	2465.3649	1232.6824	205138		
1/14/2021	3698.0473	2465.3649	1232.6824	205138		
1/15/2021	3698.0473	2465.3649	1232.6824	205138		
1/16/2021	3698.0473	2465.3649	1232.6824	205138		
1/17/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
1/18/2021	3698.0473	2465.3649	1232.6824	205138		
1/19/2021	3698.0473	2465.3649	1232.6824	205138		
1/20/2021	3698.0473	2465.3649	1232.6824	205138		
1/21/2021	3698.0473	2465.3649	1232.6824	205138		
1/22/2021	3698.0473	2465.3649	1232.6824	205138		
1/23/2021	3698.0473	2465.3649	1232.6824	205138		
1/24/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
1/25/2021	3698.0473	2465.3649	1232.6824	205138		
1/26/2021	3698.0473	2465.3649	1232.6824	205138		
1/27/2021	3698.0473	2465.3649	1232.6824	205138		
1/28/2021	3698.0473	2465.3649	1232.6824	205138		
1/29/2021	3698.0473	2465.3649	1232.6824	205138		
1/30/2021	3698.0473	2465.3649	1232.6824	205138		
1/31/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N

WATERSHED TECHNOLOGIES, LLC					Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction					N Conc In = 1.5mg/L mg/L
Period	7/1/2020	through	6/30/2021	365 days	N Conc Out = 0.5mg/L mg/L

# of Days On-Line	# Days On-Line Flow > 0.0000	# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:	% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:
365	365	365	100%

	TN MASS (lbs.)		TN (lbs.)	AVERAGE	On-Line Unless Noted Otherwise	# Days Outflow >0
	INFLOW	OUTFLOW	REMOVAL	DAILY FLOW		365
TOTAL	1349787.2755	899858.1836	449929.0918	gpm On-Line Flow > 0	Operational/	
PER DAY	3698.0473	2465.3649	1232.6824	205138.0	Flow Status	Comments
2/1/2021	3698.0473	2465.3649	1232.6824	205138		
2/2/2021	3698.0473	2465.3649	1232.6824	205138		
2/3/2021	3698.0473	2465.3649	1232.6824	205138		
2/4/2021	3698.0473	2465.3649	1232.6824	205138		
2/5/2021	3698.0473	2465.3649	1232.6824	205138		
2/6/2021	3698.0473	2465.3649	1232.6824	205138		
2/7/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
2/8/2021	3698.0473	2465.3649	1232.6824	205138		
2/9/2021	3698.0473	2465.3649	1232.6824	205138		
2/10/2021	3698.0473	2465.3649	1232.6824	205138		
2/11/2021	3698.0473	2465.3649	1232.6824	205138		
2/12/2021	3698.0473	2465.3649	1232.6824	205138		
2/13/2021	3698.0473	2465.3649	1232.6824	205138		
2/14/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
2/15/2021	3698.0473	2465.3649	1232.6824	205138		
2/16/2021	3698.0473	2465.3649	1232.6824	205138		
2/17/2021	3698.0473	2465.3649	1232.6824	205138		
2/18/2021	3698.0473	2465.3649	1232.6824	205138		
2/19/2021	3698.0473	2465.3649	1232.6824	205138		
2/20/2021	3698.0473	2465.3649	1232.6824	205138		
2/21/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
2/22/2021	3698.0473	2465.3649	1232.6824	205138		
2/23/2021	3698.0473	2465.3649	1232.6824	205138		
2/24/2021	3698.0473	2465.3649	1232.6824	205138		
2/25/2021	3698.0473	2465.3649	1232.6824	205138		
2/26/2021	3698.0473	2465.3649	1232.6824	205138		
2/27/2021	3698.0473	2465.3649	1232.6824	205138		
2/28/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
3/1/2021	3698.0473	2465.3649	1232.6824	205138		
3/2/2021	3698.0473	2465.3649	1232.6824	205138		
3/3/2021	3698.0473	2465.3649	1232.6824	205138		
3/4/2021	3698.0473	2465.3649	1232.6824	205138		
3/5/2021	3698.0473	2465.3649	1232.6824	205138		
3/6/2021	3698.0473	2465.3649	1232.6824	205138		
3/7/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
3/8/2021	3698.0473	2465.3649	1232.6824	205138		
3/9/2021	3698.0473	2465.3649	1232.6824	205138		
3/10/2021	3698.0473	2465.3649	1232.6824	205138		
3/11/2021	3698.0473	2465.3649	1232.6824	205138		
3/12/2021	3698.0473	2465.3649	1232.6824	205138		
3/13/2021	3698.0473	2465.3649	1232.6824	205138		
3/14/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
3/15/2021	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime:** **100%**
	TN MASS (lbs.)		**TN (lbs.)**	**AVERAGE**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**		**365**
				gpm On-Line Flow > 0		
TOTAL	**1349787.2755**	**899858.1836**	**449929.0918**			
PER DAY	**3698.0473**	**2465.3649**	**1232.6824**	**205138.0**	**Operational/ Flow Status**	**Comments**
3/16/2021	3698.0473	2465.3649	1232.6824	205138		
3/17/2021	3698.0473	2465.3649	1232.6824	205138		
3/18/2021	3698.0473	2465.3649	1232.6824	205138		
3/19/2021	3698.0473	2465.3649	1232.6824	205138		
3/20/2021	3698.0473	2465.3649	1232.6824	205138		
3/21/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
3/22/2021	3698.0473	2465.3649	1232.6824	205138		
3/23/2021	3698.0473	2465.3649	1232.6824	205138		
3/24/2021	3698.0473	2465.3649	1232.6824	205138		
3/25/2021	3698.0473	2465.3649	1232.6824	205138		
3/26/2021	3698.0473	2465.3649	1232.6824	205138		
3/27/2021	3698.0473	2465.3649	1232.6824	205138		
3/28/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
3/29/2021	3698.0473	2465.3649	1232.6824	205138		
3/30/2021	3698.0473	2465.3649	1232.6824	205138		
3/31/2021	3698.0473	2465.3649	1232.6824	205138		
4/1/2021	3698.0473	2465.3649	1232.6824	205138		
4/2/2021	3698.0473	2465.3649	1232.6824	205138		
4/3/2021	3698.0473	2465.3649	1232.6824	205138		
4/4/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
4/5/2021	3698.0473	2465.3649	1232.6824	205138		
4/6/2021	3698.0473	2465.3649	1232.6824	205138		
4/7/2021	3698.0473	2465.3649	1232.6824	205138		
4/8/2021	3698.0473	2465.3649	1232.6824	205138		
4/9/2021	3698.0473	2465.3649	1232.6824	205138		
4/10/2021	3698.0473	2465.3649	1232.6824	205138		
4/11/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
4/12/2021	3698.0473	2465.3649	1232.6824	205138		
4/13/2021	3698.0473	2465.3649	1232.6824	205138		
4/14/2021	3698.0473	2465.3649	1232.6824	205138		
4/15/2021	3698.0473	2465.3649	1232.6824	205138		
4/16/2021	3698.0473	2465.3649	1232.6824	205138		
4/17/2021	3698.0473	2465.3649	1232.6824	205138		
4/18/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
4/19/2021	3698.0473	2465.3649	1232.6824	205138		
4/20/2021	3698.0473	2465.3649	1232.6824	205138		
4/21/2021	3698.0473	2465.3649	1232.6824	205138		
4/22/2021	3698.0473	2465.3649	1232.6824	205138		
4/23/2021	3698.0473	2465.3649	1232.6824	205138		
4/24/2021	3698.0473	2465.3649	1232.6824	205138		
4/25/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
4/26/2021	3698.0473	2465.3649	1232.6824	205138		
4/27/2021	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line	**365**	**# Days On-Line Flow > 0.0000**	**365**	**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime:**	**365**	**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TN MASS (lbs.)		**TN (lbs.)**	**AVERAGE**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**		**365**
TOTAL	**1349787.2755**	**899858.1836**	**449929.0918**	**gpm On-Line Flow > 0**	**Operational/**	
PER DAY	**3698.0473**	**2465.3649**	**1232.6824**	**205138.0**	**Flow Status**	**Comments**
4/28/2021	3698.0473	2465.3649	1232.6824	205138		
4/29/2021	3698.0473	2465.3649	1232.6824	205138		
4/30/2021	3698.0473	2465.3649	1232.6824	205138		
5/1/2021	3698.0473	2465.3649	1232.6824	205138		
5/2/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
5/3/2021	3698.0473	2465.3649	1232.6824	205138		
5/4/2021	3698.0473	2465.3649	1232.6824	205138		
5/5/2021	3698.0473	2465.3649	1232.6824	205138		
5/6/2021	3698.0473	2465.3649	1232.6824	205138		
5/7/2021	3698.0473	2465.3649	1232.6824	205138		
5/8/2021	3698.0473	2465.3649	1232.6824	205138		
5/9/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
5/10/2021	3698.0473	2465.3649	1232.6824	205138		
5/11/2021	3698.0473	2465.3649	1232.6824	205138		
5/12/2021	3698.0473	2465.3649	1232.6824	205138		
5/13/2021	3698.0473	2465.3649	1232.6824	205138		
5/14/2021	3698.0473	2465.3649	1232.6824	205138		
5/15/2021	3698.0473	2465.3649	1232.6824	205138		
5/16/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
5/17/2021	3698.0473	2465.3649	1232.6824	205138		
5/18/2021	3698.0473	2465.3649	1232.6824	205138		
5/19/2021	3698.0473	2465.3649	1232.6824	205138		
5/20/2021	3698.0473	2465.3649	1232.6824	205138		
5/21/2021	3698.0473	2465.3649	1232.6824	205138		
5/22/2021	3698.0473	2465.3649	1232.6824	205138		
5/23/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
5/24/2021	3698.0473	2465.3649	1232.6824	205138		
5/25/2021	3698.0473	2465.3649	1232.6824	205138		
5/26/2021	3698.0473	2465.3649	1232.6824	205138		
5/27/2021	3698.0473	2465.3649	1232.6824	205138		
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5/29/2021	3698.0473	2465.3649	1232.6824	205138		
5/30/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
5/31/2021	3698.0473	2465.3649	1232.6824	205138		
6/1/2021	3698.0473	2465.3649	1232.6824	205138		
6/2/2021	3698.0473	2465.3649	1232.6824	205138		
6/3/2021	3698.0473	2465.3649	1232.6824	205138		
6/4/2021	3698.0473	2465.3649	1232.6824	205138		
6/5/2021	3698.0473	2465.3649	1232.6824	205138		
6/6/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
6/7/2021	3698.0473	2465.3649	1232.6824	205138		
6/8/2021	3698.0473	2465.3649	1232.6824	205138		
6/9/2021	3698.0473	2465.3649	1232.6824	205138		

WATERSHED TECHNOLOGIES, LLC						Flow = Average 475 cfs
C-43 WBSR HWTT Projected TN Reduction						N Conc In = 1.5mg/L mg/L
Period	**7/1/2020**	**through**	**6/30/2021**	**365**	**days**	N Conc Out = 0.5mg/L mg/L
# of Days On-Line 365		**# Days On-Line Flow > 0.0000 365**		**# Days in Period Flow > 0.0000 Less Uncontrollable Downtime: 365**		**% Time On-Line vs. Available Days Excl. Uncontrollable Downtime: 100%**
	TN MASS (lbs.)		**TN (lbs.)**	**AVERAGE**	**On-Line Unless Noted Otherwise**	**# Days Outflow >0**
	INFLOW	**OUTFLOW**	**REMOVAL**	**DAILY FLOW**		**365**
TOTAL **PER DAY**	**1349787.2755** **3698.0473**	**899858.1836** **2465.3649**	**449929.0918** **1232.6824**	**gpm On-Line Flow > 0** **205138.0**	**Operational/ Flow Status**	**Comments**
6/10/2021	3698.0473	2465.3649	1232.6824	205138		
6/11/2021	3698.0473	2465.3649	1232.6824	205138		
6/12/2021	3698.0473	2465.3649	1232.6824	205138		
6/13/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
6/14/2021	3698.0473	2465.3649	1232.6824	205138		
6/15/2021	3698.0473	2465.3649	1232.6824	205138		
6/16/2021	3698.0473	2465.3649	1232.6824	205138		
6/17/2021	3698.0473	2465.3649	1232.6824	205138		
6/18/2021	3698.0473	2465.3649	1232.6824	205138		
6/19/2021	3698.0473	2465.3649	1232.6824	205138		
6/20/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P/N
6/21/2021	3698.0473	2465.3649	1232.6824	205138		
6/22/2021	3698.0473	2465.3649	1232.6824	205138		
6/23/2021	3698.0473	2465.3649	1232.6824	205138		
6/24/2021	3698.0473	2465.3649	1232.6824	205138		
6/25/2021	3698.0473	2465.3649	1232.6824	205138		
6/26/2021	3698.0473	2465.3649	1232.6824	205138		
6/27/2021	3698.0473	2465.3649	1232.6824	205138		Sample Date P
6/28/2021	3698.0473	2465.3649	1232.6824	205138		
6/29/2021	3698.0473	2465.3649	1232.6824	205138		
6/30/2021	3698.0473	2465.3649	1232.6824	205138		

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Bessey Creek project in Martin would cleanse water bound for Indian River Lagoon

By Mark Burneko

Friday, February 28, 2014

PALM CITY — A new type of surface water filtration system planned for Bessey Creek may provide a model for reducing the amount of nitrogen and phosphorus carried from watershed streams into the Indian River Lagoon.

The South Florida Water Management District has identified the Bessey Creek area as one of the top 10 contributors of phosphorous into the St. Lucie Estuary.

The Hybrid Wetland/Chemical Treatment Technology system combines a chemical treatment process with conventional wetlands filtration using pond water and specially selected aquatic plants.

Only six other systems of this kind, in use since 2007, have been constructed in the state, all of them along streams in Okeechobee County north of Lake Okeechobee, said Deborah Drum, Martin County’s environmental quality manager.

Those systems have been effective in removing from 65 percent to 95 percent of phosphorous runoff, most of which comes from fertilizers, Drum told Martin County commissioners at a Jan. 7 meeting.

Commissioners unanimously agreed to a 30-year, $1 annual lease for 46 acres to the Florida Department of Agriculture and Consumer Services for the project, with the facility being county-owned when the lease expires.

“The design is still being worked out but the technology is new and has never been used in Martin County before,” Drum said. “This is going to give us a great chance to look at the cost-effectiveness of the system and consider whether we may be able to use similar systems in the future.”

State officials estimate it will cost the agency $3 million to build and operate the system, which will be adjacent to the Citrus Boulevard storm treatment area developed in 2008.

The system involves diverting and pumping a portion of the flow from Bessey Creek over a lime rock bed and mixing in a chemical such as aluminum sulfate, which settles out a large portion of the nitrogen and phosphorus. The water is further filtered in holding ponds using floating and submerged vegetation that consume more of the nutrients before the water flows back into the creek.

“This falls right into the type of effective system we’re looking for,” Drum said. “Because less land is needed, it seems like a good solution, particularly for coastal communities.”

The system could be operational in a year, Drum said.

Upon approving the land lease, Commission Chairwoman Sarah Heard and Commissioner Ed Fielding said they favored more state focus on finding the sources of nutrient pollution.

“In a year, this will be useful in moderating pollution,” Fielding said, “but we still need to determine the source.”

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Environmental Conservation
Solutions

C-43 WBSR Water Quality Feasibility Study Group

June 16, 2020

Reference: Response to Questions Emailed to ECS on June 9, 2020

Mr. Bays:

The following letter contains our responses to the questions sent in an email on June 9, 2020.

Question: Descriptions of the system(s) most similar to the proposed 5-acre cell concept. You mentioned a 4.5-acre cell in Marion County. That information would be useful for us to assess scalability.

Bold & Gold® has been installed in several basins larger than one-acre in size. Table 1 provides a list of the projects with associated permit numbers.

Table 1

Project	Permitting Agency	Permit Number	Project Size
Rainbow Springs 5th Replat CP#67 DRA #2216 (DRA #3)[1]	SWFWMD	11926	0.5 Acres
Rainbow Springs 5th Replat Stormwater Retrofit CP-72[1]	SWFWMD	43139	0.44 Acres
Rainbow Springs 5th Replat CP #71	SWFWMD	43614	0.82 Acres
Silver Springs Shores Unit 19 DRA's 7219, 7237, & 7366- CP 76[2]	SJRWMD	151505-1	1.75 Acres
Silver Springs Shores Unit 7 Stormwater Retrofit- DRA 7396[2]	SJRWMD	149003-1	1 Acre
Silver Springs Shores Unit 7 Stormwater Retrofit- DRA 7244[2]	SJRWMD	51780-2	3.5 Acres

[1] Projects were completed at the same time and should be considered one project

[2] Projects were completed at the same time and should be considered one project

ECS manufactures Bold & Gold® in a pugmill plant. A 5-acre Bold & Gold® cell requires twenty-four thousand and two hundred (24,200) cubic yards of media, or thirty-two thousand, six hundred and seventy (32,670) tons of Bold & Gold® CTS media. The pugmill plant produces four hundred tons of Bold & Gold® per hour which translates to approximately eighty-two hours to produce the material required for a 5-acre basin. A picture of the equipment is presented in Figure 1.

Figure 1

The pugmill plant is portable and we intend to manufacture the Bold & Gold® CTS media at the C-43 project site. It will be up to the contractor to choose the means and methods to install the Bold & Gold® material. It is common for an installing contractor to use a dump truck to move the media throughout the basin. The media is then spread and leveled using some variety of tracked equipment. Based on our experience with previous projects, ECS can produce the Bold & Gold® CTS media faster than a contractor can install the material. A picture of the City of DeLand Public Works division installing Bold & Gold® CTS media at the Bent Oaks RIB is presented in Figure 2. The installation crew installed a one-acre basin in three days using a small Bobcat and bulldozer.

Figure 2

Question: Revised annual maintenance cost. As we discussed, there will be hydraulic maintenance of the cells to ensure adequate distribution, but vegetation maintenance seems like a likely need. One feature of

the Bold & Gold® that I don't want to lose sight of is that it can dry out and still function. The operation of the reservoir will likely yield a 3-month period during the summer when the reservoir is being loaded and then water is stored, which means the treatment system may not see water for 3-6 months. Weeds and other vegetation seem likely to grow, particularly given the nutrient loading.

Given this information, we suggest including an annual maintenance cost. We suggest mowing the bottom and sides of the 5-acre Bold & Gold® cell once every twenty-one days during periods when the filter is not in operation. The estimated annual cost to perform the service for a 5-acre cell is $2,125 per year. The cost includes maintaining the cell 8.5 times per year. It is common to use a tractor and batwing to perform this type of maintenance. An example of this equipment is included in Figure 3.

Figure 3

Question: Revised design cost. As we discussed, the estimate should reflect the design effort needed to yield a biddable document set, either as a % of the construction cost, or scaled from prior experience or based upon multi-disciplinary labor effort.

Our original estimate of $80,000 did not account for the work necessary to design the system, permit the system, create a biddable document set, and be involved in the construction process. We spoke to several professional engineers who have experience designing Bold & Gold® filters to devise a reasonable budget to include those task items. Please modify our design budget to $1,075,000 for the project.

Question: I apologize for the late addition to the list of questions, but we've taken a closer look at the performance projections for B&G, and a question came up. Could you please comment on the following calculation of the nominal media life for the C-43 project?

B&G per 5-ac	**24200**	**cy**
	653400	**ft3**
bulk density	**63**	**lb/ft3**
# 5-ac units	**15**	
total media mass	**617463000**	**lb**
	2.80075E+11	**g**
adsorption	**0.2**	**mg/g**
sorbed	**56015008434**	**mg**
	123493	**lb**
flow	**457**	**cfs**
	295	**mgd**
P in	**0.16**	**mg/L**
P out	**0.08**	**mg/L**
removed	**71941**	**lb/yr**
life expectancy	**1.72**	**yr**

Service life (years) of the filters is the nutrient removal capacity of the filters divided by capacity used in one year. Service life is based on the removal capacity of dissolved phosphorus in the B&G CTS media (sorption capacity), the augmented river flow needed to achieve a minimum flow level (MFL), the maximum allowable concentration of total phosphorus in the river, the concentration in the water entering the filter, and the filter flow. It is understood that these data are stochastic (time variable) numbers and thus providing a flexible treatment system will help in meeting these changing conditions. To calculate service life, estimates are made for average conditions, but with the understanding that the treatment system is flexible to meet other flow and water quality conditions. To meet a water quality of 0.08 mg/L TP, filter effluent is blending with source water at a ratio of 64% filtered water to 36% source.

Shown in Figure 4 is the historical flow measurements in the river at S-79 used to determine minimum fresh-water flow. There is a period of time during which the river flow should be at a Minimum fresh-water Flow Level (MFL) to the estuary. During this period of time, river flow augmentation is needed. The difference between the river flow and the MFL is calculated at 48,264 ac-ft (difference between flow and MFL). For comparison, this is an equivalent flow of 160 CFS for 152 days (160 CFS x 449 gpm/CFS x 1440 min/day x 152 days / 325,800 gallons per acre foot)). The filters treat 64% of the augmented flow or **30,889 ac-ft** (0.64 x 48,264) because of the blending of source and filtered water. The detailed calculations based on needed river flow from the filters, media treatment capacity based on OP removal, and water quality conditions are shown below resulting in a service life of 50.93 years. It is understood that the augmented flow and nutrient concentrations will be monitored and thus will permit modification of operating schedules that will affect service life. Building the filtration cells in 5-acre units allows the flexibility to use some of the 15 cells to meet variable flow and concentration conditions.

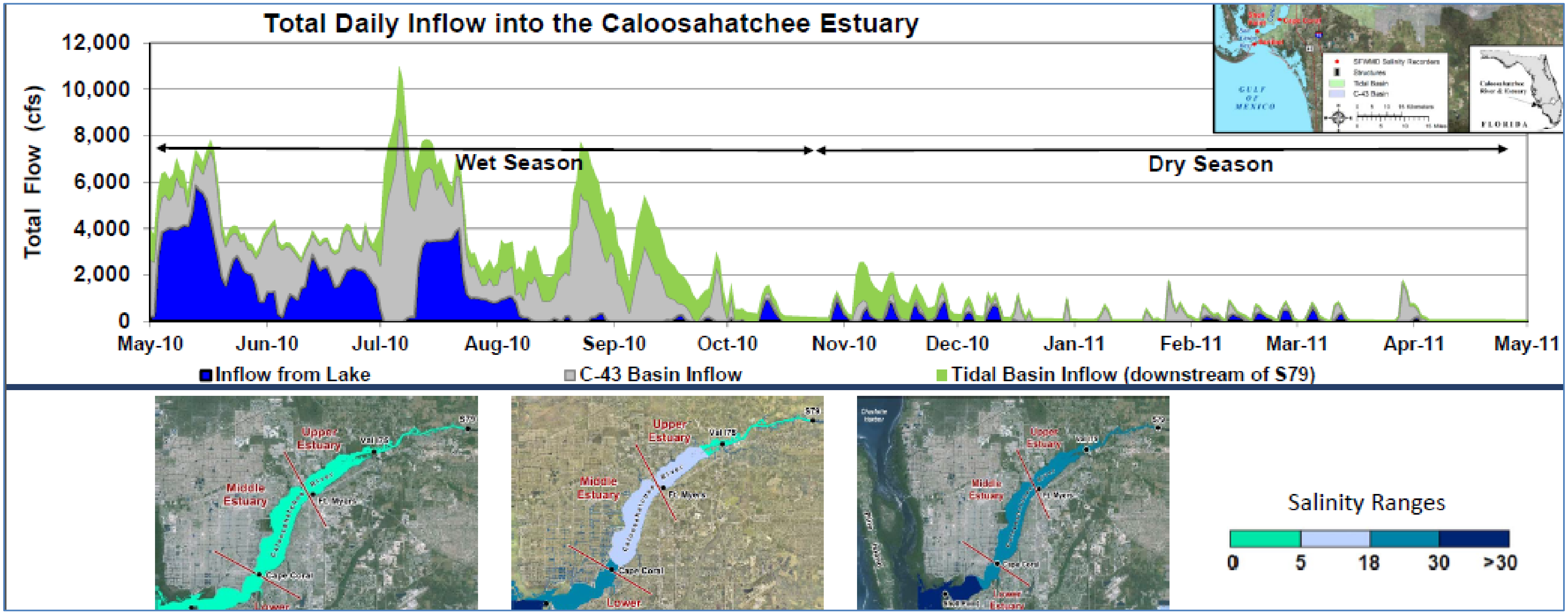

Figure 4 From: Don Medellin, SFWMD Governing Board Meeting, October 10.2019

Table 2 Detail Response the calculation for service life

s/no.	Description as presented	Committee Question	ECS Response	Responses/Comments
1a.	B&G per 5-acre	24,200 cy	24,200 cy	Agreement
1b.		653,400 ft^3	653,400 ft^3	Agreement
2.	Bulk Density	63 lb/ft^3	95 lb/ft^3	63 pcf is loose minimum density requirement at production. Field density (dry) used to estimate the OP removal rate from actual test sites is 95 pcf. (primarily sand)
3.	# 5-ac units	15	15	Agreement
4a.	Total media mass	617,463,000 lb	1,303,533,000 lb	= 15 × 1.4(95 pcf) × 653,400 cf. [At full saturation of a media with 40% void, saturated weight is $95 \times [1 + (40/100)] = 133\ pcf$]
4b.		2.80075E+11 g	591,272,622,843.21 g	Conversion rate of 1 pounds ≈ 453.592 grams
5.	Adsorption rate	0.2 mg/g	0.2 mg/g	Agreement, note removal is based saturated conditions and for OP
6a.	Removed (Sorption Capacity)	56,015,008,434 mg	118,254,524,568.642 mg	= 0.2 mg × 591,272,622,843.21 g and note as OP
6b.		123,493 lb	260,706.6 lb	Conversion rate of 1 mg ≈ 2.2045×10^{-6} lb
7a.	Flow	457 CFS	292 CFS from filter blended with 165 CFS of source water for a total output of 457 CFS	Refer to ECS proposal page 4: subheading "**Filter Size to Achieve Water Quality Target Concentrations"** The target TP removal percent is 50%. Based on an input of 0.16 mg/L, this leaves 0.08 mg/L TP discharge. The B&G CTS filter removes about 78% (rounded off) of TP, or 0.1254 mg/L removed: leaving a discharge of 0.0346 mg/L, or less than the target of 0.08 mg/L. Thus, a unique situation exists that provides flexibility for operation of the filter. Based on influent conditions, a blending of treated filter effluent with source water is possible to meet the target of 0.08 mg/L. For the treatment level specified and an average discharge of 457 CFS, 292 CFS must be treated by the filter. It is blended with 165 CFS from the source (canal, upstream river or reservoir). **The treated fraction is 64% (292/457)** of the total flow. This is based on the following TP mass balance: Mass in the Discharge = Mass from source (reservoir) + mass from Filter 457 x (0.08) = Flow from source x (0.16) + Flow from filter x (0.0346) And: 36.56 = S (0.16) + F (0.0346) with S+F=457, S is source and F=Filter flow 36.56 – 15.81 = (0.16-0.0346)S results in S = 165 CFS, F = **292 CFS.**
7b.		295 MGD	188.72 MGD	Filter Flow**:** 292 CFS x 0.646317 MGD/CFS
7c.	Flow capture		38,099,280,887 L/yr	Filter Flow for augmentation**: 30,889** ac-ft x 325,872 gal/ac-ft x 3.785 L/gal

s/no.	Description as presented	Committee Question	ECS Response	Responses/Comments
8.	P in	0.16 mg/L	0.093 mg/L	Removal for **OP** not TP. Influent OP=0.093 mg/L based on a 0.58 fraction OP in TP,
9.	P out	0.08 mg/L	0.032 mg/L	For 66% **OP** removal (appendix B, proposal), 0.061 mg/L of OP is removed (0.66 x 0.093). Thus, **OP** out of filter = 0.093 – 0.061 mg/L= 0.032 mg/L
10.	Removed (annual removal of OP)		2,324,056,134 mg of OP/yr	**OP** conc removed × Annual flow capture: i.e. 0.061 mg/L × 38,099,280,887 L/yr
10a		71,941 lb/yr	5,119 lb of OP/yr	Pounds = 2,324,056,134 mg / 454,000 mg/pound
11.	Service Life (Life Expectancy)	1.72 yr	50.93 years	Removal Capacity divided by annual removal or 260,706.6 lb / 5,119 lb per year.

Service life is 50.93 years for the conditions shown above. Service life will change with a different set of conditions. Nevertheless, the 15 5-acre cells provide for flexibility in meeting changing water quality and desired flow requirements at S-79. Each cell can treat 25.2 CFS. After blending with source water and for the water quality conditions, the flow is about 40 CFS. For 15 cells, the release of water is 600 CFS (15 cells x 40 CFS/cell). For the MFL (457 CFS), use 11.4 filters (11 filters per day and one filter over 10 hours per day) and with blended water after filtration.

Watershed Technologies Comments on C-43 WBSR Presentation

Watershed Technologies, LLC (WTLLC) was pleased to submit a proposal for use of the patented Hybrid Wetland Treatment Technology (HWTT) for the C-43 West Basin Storage Reservoir (WBSR) project. After a review of the July 16, 2020 presentation, the following is a summary of several significant comments, questions, and issues that have been identified. Various items included in our original proposal, which need to be emphasized, are also included. Since the detailed data set has been requested but is not yet available, it is necessary to make assumptions based on the information provided.

1. O&M Costs: HWTT can achieve a higher P and N removal rate per quantity of alum used at the same unit price; therefore, HWTT would be the less expensive technology (see technical analysis attached for supporting documentation). HWTT has been proven to treat waters at **50% to 70%** of the chemical cost of traditional alum systems. *The core technology, which does not require wetlands, can achieve these results for any coagulant based system, regardless of the configuration (e.g., within reservoir) for any application.*

   The annual HWTT O&M costs submitted were \$7.19 M; however, the costs used in the presentation were \$8.53 M. Since we cannot identify the nature of the extra expenses, it is possible that they relate in part to pumping. WTLLC was not advised of the option of locating the technology within the reservoir, but the HWTT dosing strategy can be employed *in situ,* thereby, eliminating any additional pumping costs. The wetland component of HWTT can be removed from the project with the patented technology operating as a stand-alone system. If the monies added to HWTT represent a factor for administration or contingencies, the amount added would result in a larger difference in costs, if the underlying base costs were overstated. Additionally, to compare HWTT and alum only systems, the same per unit price for chemicals must be utilized.

2. Capital Costs: \$26.58 M was added to the capital costs for HWTT, which equates to \$38,746 per acre, assuming the monies relate to land costs. By comparison, the Treatment Wetland capital costs are \$29,596 per acre (presuming there are NO other expenditures, e.g., berms, roads, excavation, clearing, etc., which is not feasible). As explained under O&M Costs, any pumping costs, capital or O&M, should be excluded from the analysis as HWTT can clearly be located directly within the reservoir and without the treatment ponds for a technology comparison.

3. Performance: According to the March 2020 Lake County Water Authority Staff Report, the rate of P removal for the alum Nutrient Reduction Facility (NuRF) is **58%** compared to the HWTT cumulative range of **94%** (Deep Creek) to **77%** (Wolff Ditch). The higher performance for HWTT **directly translates** to a reduction in chemical requirements and costs. The difference in reduction rates and the corresponding decrease in costs are significant and should be factored into the analysis.

4. Environmental Impacts: The incorporation of wetland treatment technology on the back end of an HWTT facility improves Aluminum and final/colloidal "micro-floc" removal prior to discharge. HWTT facilities typically export Aluminum at a concentration lower than the source water concentrations. Our understanding is that this differs significantly from large conventional alum treatment systems in Florida, such as Lake County's NURF, which have a history of routinely exporting high concentrations of micro-flocs and Aluminum. Moreover, as documented by standard bioassay chronic and acute toxicity tests and measurement of metals, which are

reviewed by FDEP (36 tests since 2011 at one of our sites), HWTT system outflows are not harmful to fish or invertebrates.

5. Scalability: HWTT was rated “0” for scalability; whereas, Alum was rated “1”; the HWTT core technology can be scaled in the same manner as the alum treatment option. Based on the Lake County Water Authority March 2020 Staff Report, the total pounds P removed for the NuRF was 32,862 lbs. of P over an 11-year period (2009-2020), equating to **2,987 lbs**. per year. Conversely, Deep Creek HWTT removed **4,337 lbs.** of P in FY 2018-19. The HWTT Grassy Island facility has removed 39,837 lbs. of P over an approximate 9-year period for an average reduction rate of **4,426 lbs**. per year. The long record of performance for Grassy Island coupled with the significantly greater quantity of treatment should result in a higher scalability rating for HWTT over alum systems. It is also noteworthy that for the flow treated at NuRF, 55% was attributed to one year, which negates use of volume of treated flow for scalability as the treatment was not over any reasonable period of time.

6. Residual Disposal Costs: The reduced floc volume associated with HWTT technology (See Technical Section) results in lower costs associated with floc disposal and reduced impacts to facility operations. Passive dewatering of floc in onsite drying beds allows for continuous floc removal and prevents the need for the site to be pulled offline for extended periods of time. It also reduces the land area required to dewater and store the accumulated material. Increases in floc formation may result in costly dredging, for example, the low bid for dredging of the NuRF ponds was $1.5 M. The bids ranged from $1.5 M to $3.7 M.

7. Cost Benefit: The Cost Benefit calculated for HWTT was $83 per lb. for P removed; whereas, the Presentation value was $163.68. Understanding a difference due to interest rates, the doubling of this item does not appear reasonable. Conversely, a rough calculation for NuRF yields a Cost Benefit of $254 without inflation adjustments to current year dollars and other costs. *Most importantly, the expected life of HWTT is 50 years, which is an important point not included in the comparisons.* An annual R&R was included in the HWTT O&M costs, and there are **no** other capital expenditures required for the technology. This is an extremely important aspect not considered in comparisons with most of the other systems, including Alum and Bold and Gold. In addition, the pounds of P removed should be the same across technologies, since the quantity was given as an assumption.

Technical and Science Background on HWTT Comparisons

After reviewing the PDF of the presentation your project team provided on July 16, 2020, we wanted to follow up with some clarification on several aspects of the Hybrid Wetland Treatment Technology (HWTT). We think this is particularly relevant, since we noticed that the alum treatment technology received the highest ranking among the technologies your team evaluated.

Much of what we mention below was included in the documents Watershed Technologies, LLC submitted for your review in May 2020, but we feel it useful to clarify some key aspects that should assist your team with their technology selection/optimization effort, and hopefully lead to the most cost effective water quality improvement solution for Caloosahatchee River stakeholders.

At its core, the HWTT technology was developed around a group of US patents focused on the reuse of coagulant flocs (e.g., resulting from alum application), such that additional nutrient removal from un-dosed water can be achieved by interacting with waters containing these previously-formed flocs. This approach provides a clear, direct benefit in that it increases the mass of nutrients that can be removed per unit volume of coagulant. An additional benefit is that for a given mass of nutrient removal, there is a lower volume of residuals formed.

These benefits can be achieved for any coagulant-based treatment system where the coagulant is dispersed into a water stream either on a batch or flow-through basis. As you know, laboratory jar tests commonly are used to determine the appropriate type and doses of coagulants, coagulant aids and buffers to be employed in a chemical treatment facility. Using the C-43 project as an example, jar tests might ultimately demonstrate that a 7 mgAl/L dose of alum is required for effective floc formation and nutrient removal from the reservoir waters. In a full-scale, operational treatment system, this dose likely would be fine-tuned over time using appropriate tests/instrumentation, while recognizing that there will be temporal variations in water chemistry that undoubtedly could influence the optimum coagulant dose. The important point to consider is that the starting point for coagulant dosing, based on jar test results, would be 7 mgAl/L whether a conventional alum or an HWTT system is deployed to treat C-43 Reservoir waters.

In the case of a conventional alum treatment system, the alum delivery pumps would thus be calibrated for a 7mgAl/L dose with the volume of alum delivery being driven by a signal from a flow metering device (i.e., the dosing pump “speed” would be flow proportional). While the coagulant dosing pumps for the HWTT system would also be calibrated to deliver 7 mgAl/L on a flow-proportional basis, additional controls and operational strategies would be deployed to facilitate techniques such as intermittent dosing and distribution of un-dosed waters into regions with previously formed, suspended flocs. In turn, these operational strategies would minimize the overall volume of coagulant used over time. In the case of a HWTT system, the coagulant dosing duty cycle (alum dosing “on” time vs dosing “off” time) would be influenced by the chemical characteristics (N speciation, P speciation, color, alkalinity, TSS) and target outflow nutrient concentrations of the reservoir waters. On-site testing and measurements therefore would be performed to determine the optimum dosing cycle, much as testing is typically done initially and over time (in both conventional and HWTT systems) to define optimum alum doses.

What gives us confidence that intermingling parcels of un-dosed water with recently formed coagulant flocs can be a cost-effective strategy for a chemical treatment system? The following simple bench-scale example demonstrates this concept.

One of our HWTT facilities in Okeechobee County treats waters from Mosquito Creek, which drains land from several dairies before eventually entering Lake Okeechobee. For this test, raw water was collected from Mosquito Creek, and initial jar tests were performed to define the most-cost effective alum dose for providing robust floc formation and effective TP removal. On this particular date, this proved to be 15 mgAl/L. Alum subsequently was added to a 2-liter aliquot of creek water in polycarbonate cylinder, at a dose equivalent to 15 mg Al/L, and stirred. The resulting floc was allowed to settle, then the supernatant water was sampled for TP analysis. Next, the supernatant was decanted, leaving only the settled floc in the container. A new 2 -liter aliquot of raw creek water was added to the existing floc in the original container, then stirred and allowed to settle. The supernatant was again sampled then discarded, leaving the original floc intact. The procedure was repeated again, whereby a new 2-liter aliquot of raw creek water was added to the container with original floc, representing the 3rd use of the same floc.

Experimental results (Figure 1) indicated that the original floc material achieved a substantial reduction in TP, not only for the initial application, but also for the two subsequent reuses of the floc. The raw inflow TP concentration of 327 µg/L was reduced by the first floc formation to 12 µg/L and reduced by the second and third floc uses to 71 and 233 µg/L, respectively. This was equivalent to a relative (per cent) TP reduction of 96% for the initial floc, 78% for the second floc and 29% for the third floc (second reuse) (Figure 1). This study provided a clear demonstration of the extended viability of recently formed alum floc for TP removal, and the potential effectiveness of wet floc reuse in full-scale treatment systems.

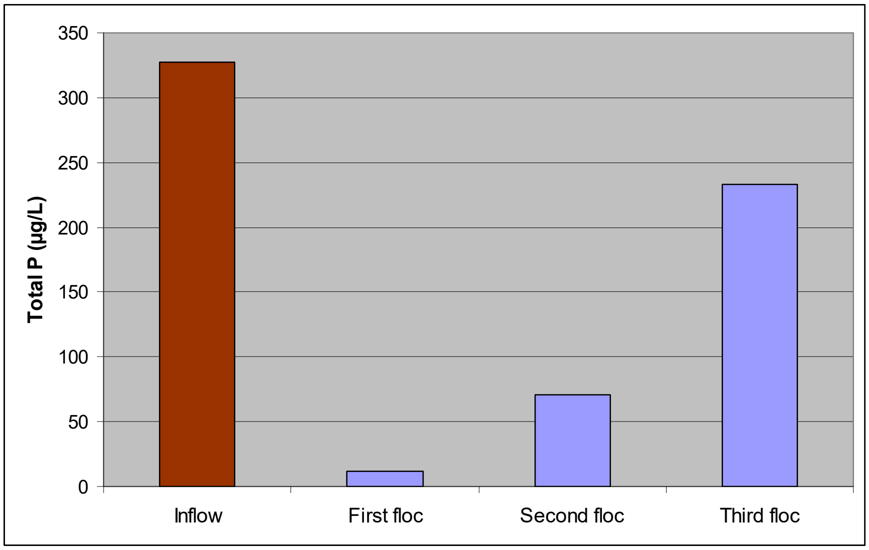

Figure 1. TP concentration in Mosquito Creek (Okeechobee County) waters and in supernatant solutions following formation of initial alum floc (first floc) and subsequent reuses of original floc (second and third flocs).

In 2006, following our development of an optimized chemical coagulant-based "front-end", we then added selected wetland components as a "back-end", thereby creating the HWTT. The back-end wetland provides the following benefits: 1) it provides enhanced nitrogen removal beyond that achieved with alum (for example, nitrate-N, which is not removed by alum additions, is readily removed in the downstream treatment wetland unit processes); and 2) the wetland facilitates settling of solids, in particular fine/colloidal "micro-flocs" that result from the front-end coagulant addition process. The micro-flocs (primarily composed of aluminum hydroxide) can be problematic in that they result in elevated levels of total Al in the treatment system outflow. For example, it is our understanding that the large conventional alum treatment systems in Florida, such as Lake County's NURF, routinely export high concentrations of micro-flocs and total aluminum (Figure 2). By contrast, total Al in the discharge from one of our largest HWTT facility in St. Johns County, typically are lower than inflow concentrations (Figure 3). Moreover, as documented by standard bioassay chronic and acute toxicity tests and measurement of metals, which are reviewed by FDEP (36 tests since 2011 at one of our sites), HWTT system outflows are not harmful to fish or invertebrates.

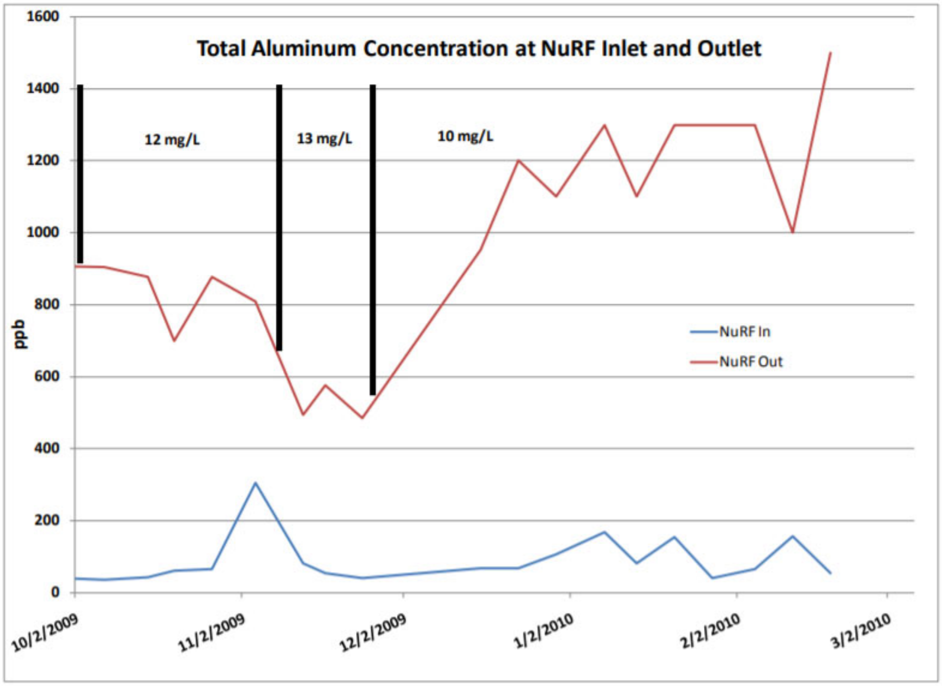

Figure 2. Inflow and outflow Total Aluminum concentrations at the NuRF from Lake County Water Authority Review of First Year of NuRF Operation.

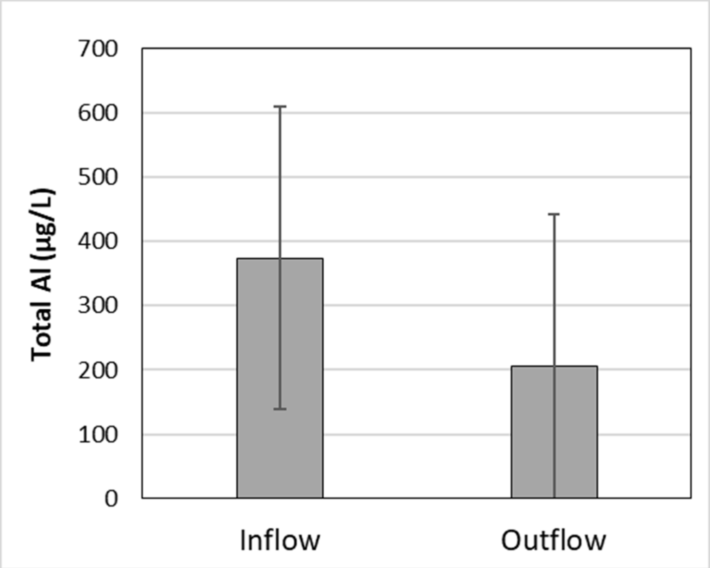

Figure 3. Mean (and std. dev.) of inflow and outflow total aluminum concentrations at the Deep Creek HWTT facility.

During the past 14 years, we have performed numerous side-by-side comparisons that document the benefits of the optimized HWTT components. One such evaluation was performed at the Ideal Grove HWTT system in St. Lucie County. At its inception, the Ideal HWTT facility consisted of a 0.7-acre pond, equipped with both shallow and deep zones, that were divided into equal size parallel flow paths with a flexible boom and barrier.

The Ideal Grove site has high alkalinity waters, and typically requires a high alum dose (25 mgAl/L as determined by laboratory jar tests) to form a robust floc and provide effective (96%) TP removal. A dose of about 17. 5 mgAl/L is barely adequate to support floc formation/settling, resulting in pinpoint flocs remaining in suspension, and a TP reduction of ~ 82%. Total P removal is almost totally ineffective at an alum dose of 12.5 mgAl/L with very poor flocculation and a TP removal of only 18%.

During 2008-2009, we performed a study at the Ideal site to assess the coagulant savings provided by an intermittent dosing strategy, in which the coagulant dosing duty cycle (at 25 mgAl/L) was 50% on:50% off, with the un-dosed water fed into a region of the pond containing previously-formed, suspended alum flocs. This was compared to performance of an adjacent flow path with continuous dosing at 25 mgAl/L.

Inflow – outflow TP monitoring of the two flow paths was performed quasi-weekly from November 2008 – November 2009 on 43 dates. TP removal during the period averaged 90 percent in flow path B (intermittent dosing), only slightly lower than the 92 percent removal rate observed for flow path A (continuous dosing). Mean inflow TP concentration during this period was 272 µg/L, compared to mean outflow concentrations of 22 and 27 µg/L in flow paths A and B (Figure 4). SRP, the predominant form of P in the system inflow was reduced from a mean inflow concentration 162 µg/L to 2 and 3 µg/L in flow paths A and B, representing reductions of 99 and 98 percent, respectively. Inflow DOP concentration was reduced from 47 µg/L to 6 and 8 µg/L in (88 and 83 percent reductions) in flow paths A and B. PP concentration was reduced from 73 µg/L in the inflow stream to 15 µg/L in flow path A (79 percent reduction) and 19 µg/L in flow path B (74 percent reduction).

Inflow and outflow N species were measured on an approximately monthly basis from January – October 2009 on a total of 7 occasions. Total N removal was comparable in Ideal flow paths A and B. TN removal averaged 58 percent in flow path A, with only a slightly lower TN removal of 52 percent in the intermittently-dosed flow path B (Figure 5). TON, the primary form of N in the Ideal system, was reduced from a mean concentration of 1.44 mg/L to a mean of 0.63 and 0.71 mg/L in flow paths A and B, respectively. The mean inflow ammonia concentration of 0.122 mg N/L was reduced to 0.028 and 0.034 mg/L in flow paths A and B, while NOx was reduced from a mean of 0.023 mgN/L at the inflow to 0.006 and 0.016 mgN/L in flow paths A and B.

Despite a 50% lower volume of coagulant use, flow path B provided very effective TP and TN removal performance, comparable to removal in flow path A. Of course, another approach to achieving a 50% reduction in alum would have been to reduce the actual continuously applied dose by 50% (from 25 mgAl/L to 12.5 mg/L), but as noted above from the jar test results, effective coagulation/flocculation cannot be supported at such a low dose, and the outflow water quality would have been extremely poor.

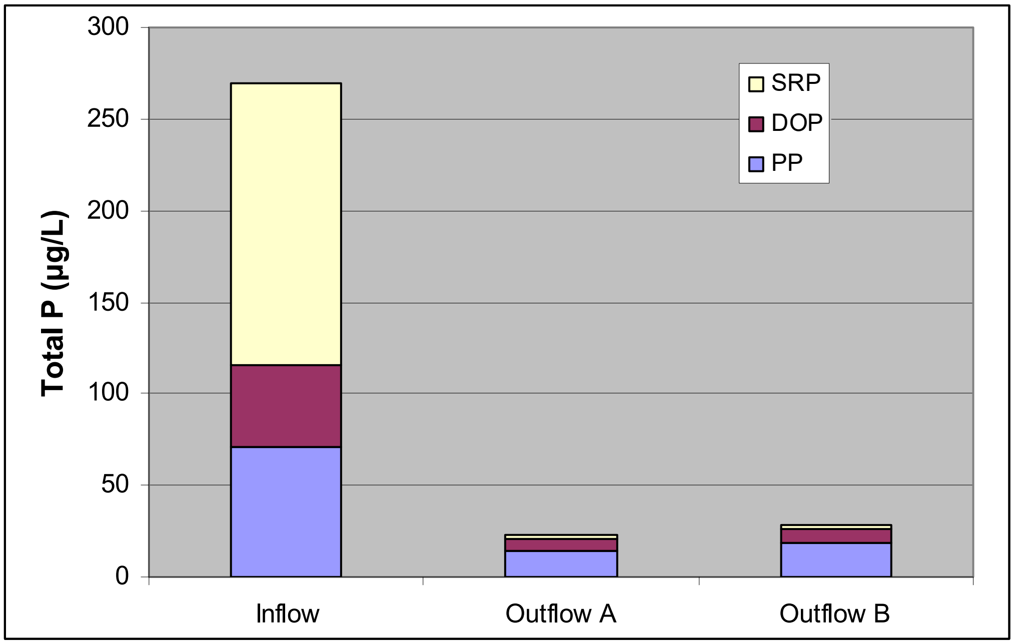

Figure 4. Mean concentration of P species in the Ideal Grove HWTT inflow and outflows in continuously-dosed (A) and intermittently-dosed (50% "on-time" dosing cycle) (B) flow paths. Total bar height represents total P concentration.

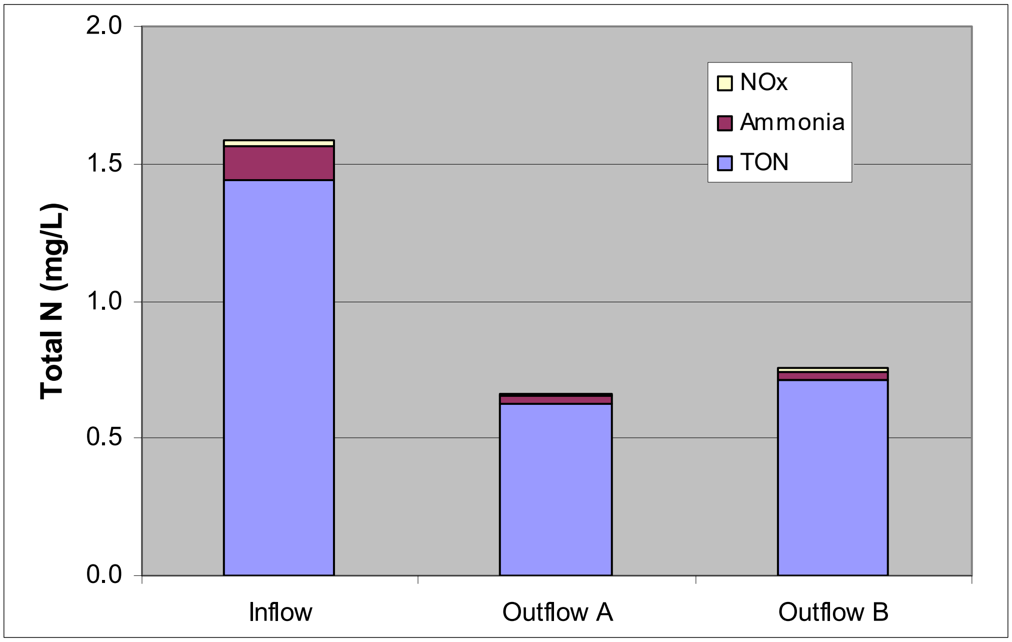

Figure 5. Mean concentration of N species in the Ideal Grove HWTT inflow and outflows in continuously-dosed (A) and intermittently-dosed (50% "on-time" dosing cycle) (B) flow paths. Total bar height represents total N concentration.

In summary, we strongly believe that if any configuration of an alum-treatment system is under serious consideration for treating C43 reservoir waters, the time-tested coagulant savings techniques incorporated in the HWTT system can help reduce operating costs, minimize residuals production per unit mass of nutrient removed, and likely improve effluent quality. We have not had the opportunity to review the alum treatment system designs that your team has promulgated for the C43 Reservoir, but one possible approach would be to simply add coagulant directly to the waters being delivered to the reservoir by the facility’s inflow pumps, and allow the wet floc to collect in the reservoir. Even for such a simple configuration as this, the intermittent dosing and wet floc recycling approach (i.e., the “front end” of the HWTT technology) could readily be incorporated into the treatment system, which would result in marked coagulant and cost savings.

We look forward to the opportunity to interact with your project team in the near future to discuss how HWTT systems, either as a stand-alone technology, or as a tandem technology (e.g., alum + HWTT “front-end”), could provide a cost-effective solution for treating C-43 reservoir waters.

MPC Buoy

Nutrigone

Proprietary and Confidential

EcoSense International
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Rockledge, FL 32955
321-636-6708

This document is provided by ESI, at the request of Jacobs Engineering Group and SFWMD, to facilitate a Feasibility Study and evaluation for the C-43 Water Quality Project. It is a description of an ESI proprietary filter system and process and is intended to be accessed by individuals involved in the approval process only. This document is not to be disseminated for any other purpose.

Response to: "Technology Information Request Outline, C-43 Water Quality Feasibility Study, April 14, 2020"

Randall Burden & Kenneth Andrews
May 2020

I. Treatment Process

We propose construction of a 93,000 cubic yard media filter comprised of fourteen, one-acre cells on property with proximity to the C-43 water source. Cells will measure 109' x 400' with an operational berm surrounding each. Filter cells will be arranged in an up-flow configuration. Water from the C-43 impoundment shall be delivered (by SFWMD) to a settling lagoon adjacent to the filter cells. Filter cells shall receive water from the lagoon through skirted weir boxes. Water flows down and under the berm; to be evenly distributed under each cell by 5-18" exfiltration pipes. Water shall then flow upward through the media to discharge over a weir to a TBD conduit. Exfiltration pipes will be fitted for bypass and flushing. Transport of treated water to final discharge point will be the responsibility of SFWMD or other.

Filter cells may be put into operation gradually. For example, one cell per month.

Note: We have internally discussed other functional designs for the filter cells [with our consultants] which may be implemented in the final design.

Media will require removal and replacement to harvest phosphorus and solids content. [Nitrogen loading will be attenuated biologically and will not influence frequency.] There are many factors which affect the frequency for removal/replacement of the media. An accurate schedule may be determined through monitoring in a pilot study. However, based on water quality data provided, we estimate removal and replacement frequency between 14 and 21 months.

A media production/processing plant will be constructed on private land either adjacent the treatment cells or near the source of media feedstock, whichever is most efficient. Our primary plan is for the production plant to be adjacent to the treatment cells. The plant will be capable of manufacturing media in excess of the required amount. Additional media will be manufactured at this site for other purposes that benefit water quality and agriculture in the state.

A. Process Flow Diagram: see appendix A

B. Flow Equalization: Flow to treatment cell shall be controlled by “weir box” orifice elevation. Maximum design flow of approximately 43 cfs per cell is accomplished with 20” head pressure.

C. Distribution: Water is distributed at the bottom of each filter cell by a multiple of perforated pipes. Limestone gravel encompasses the exfiltration piping.

D. Pre-treatment Process: Settling/header lagoon. Lagoon channel is adjacent to filter cells. Size is approximately 30’ x 1600’.

E. Treatment: Some prior Nutrient removal projects with monitoring for other EcoSense designs/products are listed below.
Note: A small scale filter project for NutriGone “D” variations is being conducted at a dredging site in Brevard County.

1. Prior Projects: see appendix B
    - i. see Stenstrom (for CaO Biochar)
    - ii. see Xiaoli Yuan, Kinetic and Thermodynamic Studies on the Phosphate Adsorption Removal by Dolomite Mineral
    - iii. see Gara Ramos Rodríguez, “Nitrate and Phosphate removal from Aqueous Solutions by biochar…”
    - iv. see Jing Li, “Removal of phosphate from aqueous solution by dolomite-modified biochar…”
    - v. see Lamont Baffle Box QAPP (for NutriGone A with high flow)
    - vi. see Compilation of Micco Lab Analysis and Micco Final Monitoring Report (for NutriGone A with high flow)
    - vii. see Johnson Jr. High project, 8-files; (for Nutrigone B)
    - viii. see “Evaluation of Performance Efficiencies of Casselberry Gross Pollutant Separators” Summary
2. Treatment chemicals and/or media required for the process will be described:
    NutriGone™ “D” will make up the majority of the 93,000 cubic yard filter volume. Additional material, limestone gravel, will cover exfiltration pipes and cap the media beds.

    NutriGone™ “D” is a proprietary mixture in the family of patented Nutrigone™ media formulations. It is composed of biochar and dolomitic limestone.

F. Post Treatment Process
Filter media will be in service for 14-21 months before it is phosphorus and solids loaded. After the service period, the top layers of the cell, approximately 4.5’, will be removed and brought to the production facility. Media be allowed to drain before loading on dump trailers or live floor trailers and transported to the secondary use site.

The secondary use site will be located within 150-200 miles of the C-43 area. Preferred location is near livestock farming facility such as dairies, pig and poultry farms. Used media materials will be crushed, combined with livestock waste in a patented process to create organic fertilizer. See "Earth Renew" power point, appendix-C.

G. Collection: Untreated water to be supplied (delivered) to the treatment area by State of Florida. Water will be received into a settling channel or lagoon then pass through weir boxes to the filter cells as described above (I. A.)
H. Chemical Supply: No chemical supply is required.

II. Residuals Process

A. Collection or removal: Filter cell to be drained prior to media removal. Used media will be scraped or otherwise removed from the filter cell every 14-21 months (depending on loading as determined by monitoring), transported via dump truck or conveyor to the production facility, allowed to dewater before loading on end dump trailers and transported to the secondary use facility.
B. Volume Reduction/ Dewatering: Piled used media will be allowed to drain. This is to limit water spillage while being transported to the secondary use facility.
C. Storage: Newly made biochar will be stockpiled during the month prior to replacement. Dolomite will be trucked in JIT to be mixed with biochar/feedstocks prior to delivery to the filter cell.
D. Transfer: Media mixture is loaded and delivered to the filter cell by dump trucks or a conveyor system, depending on proximity. Delivered media mixture is raked out into cells with excavator and/or "bobcat".
E. Disposal Process and Location: No disposal required. All materials are reconstituted into organic fertilizer, see appendix C for secondary use information.
F. Centrate Management: None required. Small amounts of water draining from the used media may be managed as stormwater.

III. Land Area (Total): Approximately 32-36 Acres

A. Treatment Facility (including process tanks or basins, chemical storage, electrical system, buildings): Approximately 20-22 acres will be required for the filter cells, surrounding berms and lagoon.

B. Supporting Facilities (Vehicle Access Roads, Fencing, Security, Equipment Garage, Storage, Parking, and Administration): Approximately 12-13 Acres including biochar kilns.
C. Residuals handling and solids storage: included in B.
D. Stormwater Management: Approximately 1.25 Acre.

IV. Power (Annual)

A. Process: Process is passive. Flow is gravity driven. We assume SFWMD pumps will be required to transfer water from reservoir.
B. Site Requirements: 600 amp service required for production facility and treatment operations. Treatment operation power requirement is nominal.
C. Monitoring: WQ monitoring is crucial to assure proper function and performance but its' power requirements are nominal.

V. Fuel Consumption

A. Chemical Supply Storage and Transport: Media made on site; transport is covered in B, below. Transport of dolomite to the production site will be the responsibility of dolomite (Ag Lime) producer.
B. Site Vehicle Operation: Loader, Bobcat and excavator total: 81K gallons/yr
C. Residuals Transport and Disposal: Residuals are transported to the secondary use facility; no disposal is required. Transport cost covered by secondary use partner. Based on a 17-month frequency for media removal and replacement, 353 truckloads per month will be required to transport spent materials to the secondary use site.

VI. Other Beneficial Attributes

A. Additional Vendor Provided Information. See Appendix B for UF IFAS info.

Biochar has many beneficial uses for agriculture, ground water remediation, storm and surface water. To my knowledge, there are no significant producers of quality biochar in Florida. The demand for Biochar is growing rapidly, especially in the AG sector. The production of high-quality Biochar in Florida has obvious benefits.

In addition to approximately 50 direct permanent employees needed to produce media and operate the treatment facility, as many as 150 indirect jobs would be created in areas such as logging, welding, transport and other service suppliers and vendors.

The secondary use facility also will create hundreds more in fertilizer production and agriculture.

1. In addition to N, P & TSS, NutriGone "D" biochar will remove a wide range of contaminants from water passing through it, including pesticides, petroleum distillates/VOC's, heavy metals, common pesticides, herbicides and others.
2. Production of Biochar at this facility will use feedstocks such as yard waste, used pallets, AG waste and other woody material wastes, reducing the need to disposes of them at landfills.
3. Biochar is a Carbon Sink. The process of producing Biochar, pyrolysis, locks up the carbon mass in the organic matter, potentially for thousands of years.
4. Biochar is used as a soil amendment which buffers pH, reduces irrigation requirements, reduces nutrient leaching and improves crop yields.
5. Biochar is beneficial for composting. It can be added to biosolids before field spreading to reduce ground and surface water contamination.
6. Reduces green-house gas emissions from soils.
7. Helps control pathogens in agricultural soils.
8. Reduces emission from landfills.
9. Use as livestock feed additive.
10. Use as cat litter additive.

VII. Capital Cost (2020 Dollars)

A. Process Facility (including components described under Items I and II):

1. The capital cost for the media production plant is approximately $6.54M including land acquisition. This is a direct investment by ESI and partners as this facility will produce products in addition to those for the C-43 project.
2. The cost for construction of the treatment cells is approximately $19.6M including land acquisition and filter media. This is the initial investment required for water treatment.
3. Direct investment for secondary use facilities, $16.0M, by ESI partner

B. Land (including components under Item III):

Treatment cells: 20 acres, $670K

Media production facility: 12-16 acres; direct investment by ESI and Partners covered in #1 above.

Secondary use facility: Investment by ESI partner, see #3 above.

VIII. Operations and Maintenance (Annual)

Cost of media per year, $11.8M; based on 17-month replacement cycle

Cost of Labor per year, $300K; operation of filter requires 2-3 equipment operators.

Cost of Management is $150K

Cost of fuel, $219K

Cost of machinery maintenance, $10K

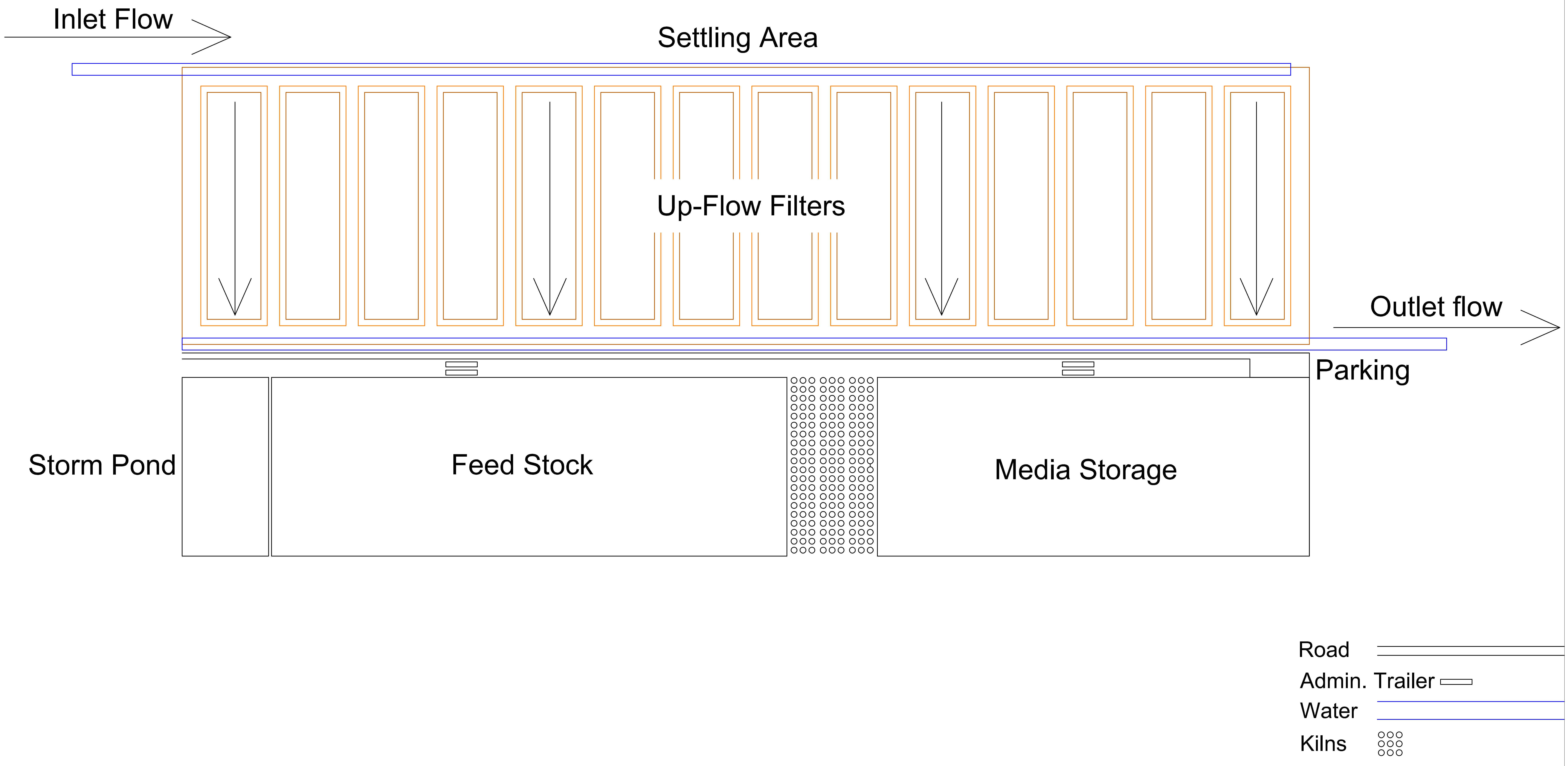
Cost of Monitoring, 45K

Cost of power, nominal, and provided by ESI partner, production facility

Appendix A

Dimensions in Feet

EcoSense C43 Water Treatment Flow Diagram



Appendix B

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Biochars effects potentially toxic elements and antioxidant enzymes in *Lactuca sativa* L. grown in multi-metals contaminated soil

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HIGHLIGHTS

- Rice husk, corn cobs and peanut shells biochars were amended at 5%.
- Bioaccumulation of metals reduced highly with amendment of peanut shells biochar.
- Stimulation and suppression of antioxidant enzymes were biochars dependent.

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ABSTRACT

Geogenic and anthropogenic activities can leads to agriculture soil pollution and land degradation. Many cost-effective and environment friendly strategies are applied to improve soil fertility, reduce soil pollution and human health risks caused by consumption of metals contaminated vegetables. In this study we evaluate the effects of rice husk biochar (RHB), biochar from corn cob (CCB) and biochar from peanut shells (PNB) on the bioavailability of potentially toxic elements (PTEs) in soil, its bioaccumulation and antioxidant enzymes activities in *Lactuca sativa* L. plants.

RHB, CCB and PNB amendments significantly ($P \leq 0.05$) increased *Lactuca sativa* L. biomass production (39%, 65% and 100%) as well as soil fertility. Amendments of PNB, RHB and CCB significantly ($P \leq 0.05$) increased soil available phosphorous (P), cation exchange capacity (CEC), pH, total nitrogen (TN), total carbon (TC) and dissolved organic carbon (DOC) concentration, but markedly reduced bioavailable concentrations of cadmium (Cd) (31%, 20% and 22%) arsenic (As) (33%, 22% and 27%), and lead (Pb) (46%, 24% and 32%). In addition, CCB and PNB amendments significantly ($P \leq 0.01$) decreased the shoot accumulation of Pb, Cd and As, while RHB amendment increased the shoot accumulations of nickel (Ni) and chromium (Cr). The reduction in PTEs accumulation may be linked with increased sorption of PTEs by biochars. Furthermore, amendments of CCB and PNB significantly ($P \leq 0.05$) suppressed the activities of SOD (53% and 69%),

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POD (22%, 31%) but stimulated (38% and 31%) with amendment of RHB. However, RHB, CCB and PNB amendments significantly ($P \leq 0.05$) suppressed the activity of CAT (21%, 41% and 48%) in *Lactuca sativa* L. plants.

PNB was the most effective soil amendment as compared with RHB and CCB. However, to fully elucidate the effects of the tested biochars, long-term field trails are needed.

1. Introduction

The pollution of agricultural soils by potentially toxic elements (PTEs) represents major risks to the environment and to human health. Because they are not biodegradable (Habiba et al., 2015; Bandara et al., 2017), and restrict the opportunities for future land use. Geogenic and anthropogenic activities are the major sources of PTEs particularly As, Cd, Pb, Cr and Ni globally (Pratas et al., 2013; Galuszka et al., 2016). In China, rapid economic development and industrialization in most coastal areas has led to elevated concentrations of PTEs (particularly Ni, Cr, As, Cd and Pb) in arable fields (Khan et al., 2014; Ibrahim et al., 2017). It is therefore important that methods of remediating PTEs affected soils are developed and applied quickly for China to meet its pressing needs to provide sufficient safe food. Elements such as Cd, Pb, Cr and As are essential in small amounts for normal plants growth and development (Noctor et al., 2007). However, in excess they become potentially toxic, inducing oxidative stress, toxicity and surplus accumulation of reactive oxygen species (ROS) in plants (Monteiro et al., 2009; Kim et al., 2015; Quartacci et al., 2015). This overproduction of ROS can result in DNA and RNA damage, enzyme inhibition and protein oxidation in plant cells (Chao and Seo, 2005; Lin et al., 2007). Plants have developed limited protective mechanisms, including the production of stress response proteins and synthesis of antioxidant enzymes (includes SOD, POD and CAT).

PTEs alter the normal ecosystem functioning and induce toxicity in vegetation (Singh et al., 2013; Gill et al., 2015). Green vegetables grown in PTEs contaminated soils are the main exposure route of PTEs to humans (Khan et al., 2008; Niu et al., 2013) and food contamination with PTEs is more prevalent in urban areas of China than some other countries such as United Kingdom and United States of America (Yuan et al., 2017). The dietary intake of excessive Pb and Cd can cause lung cancer, abdominal pain, kidney failure and stomach trouble (Patrick, 2003; Meharg et al., 2013). Elevated As intake can cause cardiovascular diseases, neurological disorders and infertility (Smoke and Smoking, 2004). Many biological, physical and chemical-based remediation technologies were developed to minimize PTEs availability in metals polluted soil (Kumpiene et al., 2008; Bolan et al., 2014). In-organic minerals, compost, agricultural residues and sewage sludge were used to reduce PTEs mobility and bioavailability in metals contaminated soil by ion exchange, co-precipitation, adsorption and surface complexion (Tsang and Hartley, 2014; Zhang et al., 2015). In-addition biodegradable cationic salts, organic acids and chelating agents have shown good effects on soil quality (Makino et al., 2008; Kim and Baek, 2015). Increased crop production and Pb precipitation was achieved with soil amendment with phosphogypsum (Anikwe et al., 2016; Yan et al., 2016) and phosphate minerals (Cao et al., 2009).

In the last few decades, biochar had been recognized as a significant element for soil fertility, crop growth and long term carbon sequestration (Lehmann, 2007; Laird et al., 2010; Luo et al., 2014; Zhao et al., 2014; Lima et al., 2018). It is emerging that soil amendment with biochar has the potential to restore metals polluted soils due to its porous structure, feedstock type, temperature, heat transfer rate, surface area, pH and cation exchange capacity (Jiang et al., 2012; Beesley et al., 2013; Ibrahim et al., 2016; Prapagdee and Tawinteung, 2017). Biochar is usually produced in oxygen-limited conditions at different pyrolysis temperatures and is commonly used for soil fertility and sorption of in-organic and organic contaminants (Melo et al., 2015; Xu et al., 2016; Hagemann et al., 2018). Biochar amendment affects the physio-chemical properties of the soil, notably bulk density, pH, carbon concentration, water holding capacity (WHC) and CEC (Rajapaksha et al., 2016; Beiyuan et al., 2017). There is research gap about the effects of plants based alkaline biochars on the remediation of multi-metals contaminated soil and its effects on antioxidant enzymes in vegetable plants.

Here we explore the effects of different plant based biochars amendments on multi-metals contaminated soil and the responses of the most widely consumed vegetable in China, lettuce (*Lactuca sativa* L.). In 2013, lettuce production reached 24.9 million tons globally, 13.5 million tons from China (FAOSTAT, 2013). Our approach was to a glasshouse study in which antioxidant enzymes were used as biomarkers for oxidative damage in plants (Sun et al., 2010; Wei et al., 2013), following previous studies (Li et al., 2013; Wu et al., 2013) that showed that PTEs accumulation can activate oxidative stress, thus promoting changes in the normal activities of antioxidant enzymes. Glasshouse pot trails were conducted from early November to late December 2016 to determine the effects of RHB, CCB and PNB on *Lactuca sativa* L. (1) biomass production, (2) PTEs bioaccumulation and (3) antioxidant enzymes, including SOD, POD and CAT.

2. Materials and methods

2.1. Site description and soil collection

Surface soil samples (0–15 cm) from agriculture field were collected with a small soil corer in triplicate from ten sites at Longyan County, Fujian Province (25° 54 ′N 118° 18 ′E), China. The climate of this experimental area is sub-tropical. The winters are mild, and the average temperature ranges from 7 °C to 10 °C, while the summers are hot with average temperatures between 21 °C and 25 °C. The average annual rainfall of 1400–2000 millimeters. This area is polluted with PTEs.

2.2. Soil characterization

The soil samples were transported to the glasshouse and spread in thin layers to be air dried. Physio-chemical characteristics such as pH, EC, TN, TC, S, DOC, O, H and particle size of the soil samples were measured using standard methods (Rayment and Higginson, 1992). Procedural details are provided in the Supportive Information (SI) section.

2.3. Biochar production and characterization

Corn cobs and rice husk waste residues were collected from agriculture fields in Xinglin Bay, while peanut shell residues were obtained from a peanut oil factory located in Siming District, Xiamen, China. After collection and transportation, these samples were sun-dried in a glasshouse. Biochars called CCB, RHB and PNB were produced from corn cobs, rice husk and peanut shell residues through pyrolysis at 500 °C for 6 h in a high performance automatic furnace (GWL-1200, Henan, China) in oxygen limited conditions under a constant flow of nitrogen (N_2). CCB, RHB and PNB were characterized using a previously published method (Wei et al., 2017). Surface area and porosity of the respective biochars were measured using surface and porosity analyzer (Micromeritics, ASAP 2020, USA). For proximate analysis, biochars samples were heated in a muffle furnace at a thermal temperature of 650 °C for 6 h adopting standard method (Ahmad et al., 2013). A macroanalyzer (Vario Max CNS, Germany) was used for the measurement of TN, TC, S, H and O concentration in biochar and soil samples. Micrograph and elemental composition of RHB, CCB and PNB were measured through a scanning electron microscopy and energy dispersive X-rays spectroscopy (SEM-EDAX, Carl Zeiss, Germany).

2.4. Experimental design and plant growth conditions

A complete randomized block design (CRBD) with at least four replicates for each four treatment was adopted. 4 kg of soil was amended at 5% of each biochar (w/w) called RHB, CCB and PNB in polyvinyl chloride (PVC) pots (14 cm of width and 25 cm of height) individually. 5% amendment ratio was chosen following our previous study (Ibrahim et al., 2016). Soil without biochar amendment called control treatment (CT) was also included. One week prior to the sowing of *Lactuca sativa* L. seeds, PVC pots were irrigated manually with double distilled water and incubated. Moisture content was kept at 60% water holding capacity through proper weighing and additional supplement of water as required. After one week, 10 g of soil samples were taken with a small soil corer from each treatment and were analyzed for quantification of physio-chemical changes in biochar-amended and non-amended control soil. *Lactuca sativa* L. seeds were surface sterilized for 10 min with 30% hydrogen peroxide (H_2O_2). After washing with double distilled water 5 seeds per pot were sown. The seedlings were thinned to two per pot after two weeks of growing period. The pot trial was conducted under 12/12 h day/night light conditions in a glasshouse. Daily temperature was recorded at 10 ± 1 °C, night temperature 6 ± 2 °C and humidity 50 ± 3%. In order to gain suitable light and temperature, PVC pots containing *Lactuca sativa* L. plants were randomly set at normal intervals throughout the growing period.

2.5. Chemical analysis of soil and biochar samples

The procedural method from Feng et al. (2012) was adopted for dissolved organic carbon (DOC) extraction from soil and biochar samples. To 4.0 g samples, 40 mL of 0.5M potassium sulfate (K_2SO_4) solution was added and shaken at 200 rpm (TS-2102, Shaker, China) for 1 h. Each sample was immediately centrifuged and filtered through membrane filters of 0.22 μm. The DOC concentration in each sample was analyzed using a total carbon analyzer (TOC-VCPH Shimadzu, Japan). Colwell P (plants available P) concentration in soil and biochar samples was determined adopting a standard method (Colwell, 1963). Briefly, each sample extraction container was contained 1: 100 (w/v) soil/sodium bicarbonate ($NaHCO_3$) solution (0.5 M, pH 8.5) and shaken at 180 rpm for 16 h. The samples were centrifuged immediately. The supernatant in each sample was filtered through 0.22 μm filters membrane and available P concentration was analyzed using ICP-OES (Perkin-Elmer, Downers Grove, IL, USA). For the analysis of available concentrations of PTEs in soil samples, the EDTA-extraction fraction method was adopted. Briefly, in 50 mL centrifuge tubes, air dried soil samples (10 g) and a mixture (20 mL) containing 0.5 M of ethylene-diamine-tetra-acetic disodium (EDTA-Na_2), 0.1 M tri ethanol amine (TEA) and 0.01 M $CaCl_2$ were added. The tubes were shaken at 180 rpm for 3 h and then centrifuged immediately. The supernatant was filtered through a 0.22 μm filter membrane and stored at 4 °C for further analysis. For the extraction of total PTEs the strong nitric and perchloric acids (HNO_3 and $HClO_4$) digestion method (Wong and Li, 2004) was adopted. Total and available PTEs concentrations in biochar and soil samples were analyzed through ICP-MS. (Agilent Technologies, 7500 CX, Santa, Clara, CA, USA).

2.6. Chemical analysis of plant samples

After seven weeks of growth, *Lactuca sativa* L. plants were harvested and root and shoot samples were manually separated after washing with double distilled water. Thereafter, root and shoot samples were oven-dried for 72 h at 70 °C and biomass was recorded. Shoot samples were powdered using a pestle and mortar, and 0.2 g of each sample was acid digested at a ratio of 1:1 (*v*/*v*) with 30% H_2O_2, (GR, Sinopharm, Shanghai, China) and 65% HNO_3, (GR, Merk, Germany) using a microwave accelerated reaction system (Mars 5, CEM Crop, Matthews NC, USA). The debris was then filtered through 0.22 μm filters. Each filtrate was set to 50 mL volume in polypropylene tubes with the addition of double distilled water (Ultra-pure Water Purification System, Shanghai, China). The bioaccumulated concentration of Ni, Cr, As, Cd and Pb in shoot samples were analyzed through ICP-MS (Agilent Technologies, 7500 CX Santa, Clara CA, USA).

Antioxidant enzymes such as superoxide dismutase (SOD), guaiacol peroxidase (POD) and catalase (CAT) were extracted adopting standard method (Kazemi et al., 2010). Briefly, 1.0 g fresh shoot samples were ground in 1 mL of 50 mmol L^{-1} phosphate buffer (pH 7.5) and then centrifuged at 12,000 rpm for 10 min at 4 °C. Thereafter, the supernatant was filtered through 0.22 μm filters and stored at 4 °C for further analysis. SOD enzyme activity was measured by inhibition of nitro blue tetrazolium (NBT) photochemical reduction (Bai et al., 2009). Briefly, the 3 mL reaction mixture contained 100 μl enzyme aliquot in 50 mM of phosphate buffer, 0.1 mM of ethylene diamine tetra acetic acid (EDTA), 0.002 mM of riboflavin, 13 mM of methionine and 0.075 mM of NBT. The tubes contained the respective mixtures were placed for 15 min in a light chamber. Using a UV-6300 double beam spectrophotometer the absorbance of SOD enzyme activity was measured at 560 nm. One unit of SOD enzyme activity was considered as the quantity of the enzyme assay mixture required to cause 50% inhibition of NBT during a chemical reaction at 560 nm. The POD enzyme activity was measured by adopting the standard method of Gorin and Heidema (1976). The 3 mL assay mixture composed of 0.1% p-phenylenediamine, 0.05% of H_2O_2, 100 μl of enzyme aliquot and 1.35 mL (100 mM) of MES buffer (pH 5.5). The variation in the absorbance was measured at 485 nm. The POD enzyme activity was calculated by applying the extinction coefficient (26 mm^{-1} cm^{-1}) for tetra-guaiacol and was presented in μmol tetra-guaiacol min^{-1} mg $protein^{-1}$. Shoot CAT enzyme activity was determined by adopting the standard method of Singh et al. (2010). The 3 mL enzyme assay mixture was composed of 0.04 mL enzyme extract, 0.4 mL (15 mM) of H_2O_2 and 2.6 mL of phosphate buffer 50 mM (pH 7.0). Breakdown of H_2O_2 molecules was determined by absorbance at 240 nm and the enzyme activity was represented by U mg^{-1} protein (U=1 mM of H_2O_2 reduction min^{-1} mg^{-1} of protein).

Plant and soil reference samples (GBW07602-GSV-1 and GBW07401-GSS-1) were purchased from the National Research Centre of Standards, China. The reference samples were incorporated in each set of plant and soil digestion for precision and accuracy.

2.7. Statistical analysis

One-way ANOVA in SPSS 11.5 and Sigma plot 12.0 were applied for the statistical and graphical analysis respectively. LSD test ($P<0.05$) was applied for significant differences among treatments.

3. Results and discussion

3.1. Physio-chemical characteristics of tested biochar and soil samples

The physio-chemical characteristics of the tested soil and biochars are shown in Table 1. In the tested soil, the total concentrations of Pb and Cr were 7.73 and 0.19 mg kg^{-1} while that of Ni, As and Cd, were 18.41, 28.94 and 64.52 μg kg^{-1}. The soil is polluted with PTEs and the concentrations of As, Pb and Cd surpassed the maximum permissible limits (State Environmental Protection Administration, China, SEPA, 1995). The soil used in pot experiment was slightly acidic (5.21). The concentrations of PTEs such as Ni, Cd, As, Cr and Pb, in PNB samples were 0.13, 7.43, 0.87 (μg kg^{-1}), 0.01 and 0.55 mg kg^{-1} respectively while in RHB samples were 0.252, 4.84, 0.14 (μg kg^{-1}), 0.03 and 0.90 (mg kg^{-1}). In CCB samples the total concentrations of Ni, As, Cd, Cr and Pb, were 0.19, 0.05, 0.02 (μg kg^{-1}), 0.02 and 0.13 mg kg^{-1} respectively (Table 1).

Soil particle size measurement gives us insight into the textural classification of the soil. In the current experiment, the tested soil had sand (44.92%), silt (49.50%) and clay (5.58%) and was classified as a silty loam. Biochars CCB, RHB and PNB showed contrasting physio-chemical characteristics such as pore volume, pore size, surface area, pH and EC. The physio-chemical properties of the biochars underpin the mechanisms of how soil fertility is improved. For any crop yield increment of soil fertility might be associated with improved water holding capacity of biochar amended soil (Jeffery et al., 2011). The mechanism involved is such that pores present on biochar surfaces can retain water molecules thus increasing WHC and assisting in improved soil fertility. Asai et al. (2009) reported that biochar porosity retains water molecules in tiny pores and thus assisting in improvement of soil fertility through increased water holding capacity. Increased CEC is the indirect measurement of soil fertility. These variable characteristics of soil depend on the waste residues used for production of biochars. In addition, increased pH values of biochars may be also associated with the changed properties of biochars amended soil. CCB showed the highest pH (10.12) as compared with RHB (8.94) and PNB (9.33). These biochars were alkaline in nature having the potential to an increase amended soil pH. SEM-EDAX micrographs investigated the elemental composition of RHB, CCB and PNB. Biochar elemental ratio (O/C and H/C) can be used as a marker of biochar

Table 1
Physico-chemical properties of soil and biochars (n = 4) and their comparison with permissible limits set for soil by the State Environmental Protection Administration (SEPA, 1995).

Parameters	Soil	PNB	RHB	CCB	Parameters	Soil	PNB	RHB	CCB	SEPA	Back ground soil
pH ($CaCl_2$)	5.21	9.33	8.94	10.12	Concentration	Total	Total	Total	Total		
EC ($\mu S\ cm^{-1}$)	509	713	933	842	Cr (mg/kg)	0.19	0.01	0.03	0.02		
BET surface area ($m^2\ g^{-1}$)	ND	12.49	1.85	5.48	Ni (μg/kg)	18.41	0.13	0.25	0.19		
Pore volume ($cm^3\ g^{-1}$)	ND	0.036	0.016	0.024	As (μg/kg)	**28.94**	0.87	0.14	0.05	0.03	5.88
Pore size (nm)	ND	10.07	3.48	4.57	Cd (μg/kg)	**64.52**	7.43	4.84	0.02	0.003	0.05
H (%)	0.74	3.22	2.79	3.68	Pb (mg/kg)	**7.73**	0.55	0.90	0.13	0.3	35.62
O (%)	13.63	10.82	15.04	13.36	TN (%)	0.14	1.45	0.63	0.55		
DOC (mg kg^{-1})	19.09	9.51	12.11	10.17	TC (%)	1.93	70.61	49.92	64.13		
Colwell P (mg kg^{-1})	30.69	4.03	4.63	2.96	S (%)	0.054	1.38	0.43	0.93		
Volatile matter (%)	ND	24.13	15.21	8.86	H/C	ND	0.04	0.06	0.05		
Fixed carbon (%)	ND	64.54	38.32	68.76	O/C	ND	0.15	0.30	0.21		
Ash content (%)	ND	6.57	18.97	12.61	(N+O)/C	ND	0.17	0.31	0.22		

An abbreviations PNB, RHB and CCB represents peanuts shell biochar, rice husk biochar and corn cobs biochar. ND No Data. Soil background value taken from Chen et al. (1992) for Fujian Province, China.

polarity. O/C for CCB and RHB were higher (0.21 and 0.30) than PNB (0.15) indicating that CCB and RHB might contain high polar surfaces (Table 1). Previous study (Uchimiya et al., 2011) revealed that O/C and H/C was used to assess biochar polarity and aromaticity. Present results revealed that carbon concentration in PNB was higher (70%) as compared with RHB (49.9%) and CCB (64.1%). SEM imaging gives us deeper insight about surface morphology of the tested biochar. PNB showed large sized pores as compared with RHB and CCB (Fig S2). Energy dispersive X-ray (EDX) spectroscopy confirmed the presence of various elements on the tested biochars surfaces on dry weight basis. Biochar RHB EDX data showed different elemental composition and confirmed the occurrence of Oxygen (O) (20.73%), Carbon (C) (77.03%), Sodium (Na) (0.04%), Aluminum (Al) (0.11%), Potassium (K) (0.68%), Silicon (Si) (1.21%) and Calcium (Ca) (0.22%) (Fig S1 A-B). Similarly, Fig S1 C-D of biochar CCB confirmed the concentration of O (17.31%), C (80.34%), Al (0.02%), Na (0.04%), K (2.23%), Si (0.04%) and Ca (0.02%). In addition, biochar PNB spectrum showed the presence of C (85.16%), O (12.79%), Al (0.08%), Na (0.05%), K (1.52%), Si (0.12%) and Ca (0.29%) (Fig S1 E-F).

3.2. Comparison of biochar amended and non-amended soil

The results showed that biochars amendments altered the soil pH, EC, TC, TN, S, O, H and DOC level as compared with non-amended control. Soil pH increased from 5.21 to 6.41 units amended with PNB, 5.21 to 6.78 units amended with RHB and 5.21 to 6.82 units with CCB amendment. This rise in amended soil pH may be associated with the higher precipitation of insoluble species and sorption of PTEs to biochar surfaces (Kołodyńska et al., 2012). A previous study (Wang et al., 2016a,b) showed that tea garden soil pH increased from 3.33 to 3.63 units with amendment of biochar. Hardwood biochars prepared from *Carya* spp and *Quercus* spp increased agricultural soil pH by 1 unit (Laird et al., 2010). The increase in soil pH with biochar amendments might have changed the soil nutrients status and assisted in adsorption of nutrients on *Lactuca sativa* L. root surfaces. The EC of the biochars amended soil significantly ($P \leq 0.01$) elevated by up to 34%, 24% and 29% (Table 2). This rise in EC may be related to the fact that biochar contain rich mineral compounds. Present results are in line with previous findings (Hossain et al., 2011) that with amendment of wastewater sludge biochar, soils EC significantly increased.

With amendments of the tested biochars i.e. PNB, RHB and CCB the concentration of Colwell P significantly ($P \leq 0.05$) increased by up to 50%, 26% and 33%. The highest increment of Colwell P was recorded in PNB amended soil. The TN concentration significantly ($P \leq 0.01$) elevated by up to 42%, 21% and 28% with amendment of PNB, RHB and CCB. Similarly, TC statistically ($P \leq 0.05$) increased by up to 44%, 23% and 39% with amendments of PNB, RHB and CCB. This increased concentration of TN and TC might improve the biochar amended soil fertility. The concentration of CEC remarkably increased with amendments of PNB, RHB and CCB by up to 96%, 59% and 65%. This increase in CEC values suggests improved soil fertility of biochars amended soil. Previous study (Laird et al., 2010) reported that soil CEC remarkably enhanced with amendment of biochar. Jien and Wang (2013) investigated that biochar (prepared from *Leucaena leucocephala*) amendment to high weathered soil significantly ($P \leq 0.01$) elevated CEC ranged from 7.14 to 10.8 cmol kg^{-1}. Present findings showed that effects of biochars on soil physiochemical properties varied with amendment of biochar type. Overall, with biochar amendment the improved soil physiochemical characteristics may be the direct or indirect measures of decreased nutrients leaching as well as increased nutrients status which are the popular mechanisms of soil fertility.

PNB amendment reduced the available concentrations of As, Cr, Ni, Pb and Cd by up to 33%, 33%, 40%, 46% and 31% respectively ($P \leq 0.05$). RHB amendment significantly ($P \leq 0.01$) reduced bioavailable concentrations of As, Pb, and Cd by up to 22%, 24% and 20% but increased that of Cr and Ni by up to 44% and 28%, compared to non-amended control. Similarly, CCB amendment statistically ($P \leq 0.05$) decreased the concentrations of As, Cr, Ni, Pb and Cd by up to 27%, 25%,

Table 2
Variations in the properties of biochars amended and non-amended soil after one week incubation before sowing. Mean values are shown ± standard deviation (n = 4). Different lowercase letters denote significant difference ($P \leq 0.05$) while similar letters indicate non-significant difference between treatments.

Parameters	CT	PNB	RHB	CCB
pH (CaCl$_2$)	5.21 ± 0.14 b	6.41 ± 0.15 b	6.78 ± 0.16 b	6.82 ± 0.18 a
EC (μS cm^{-1})	509.31 ± 0.71 b	685.26 ± 0.30 a	635.16 ± 0.80 b	660.16 ± 0.90 b
DOC (mg kg^{-1})	19.21 ± 1.48 b	45.15 ± 0.76 a	27.23 ± 1.30 b	32.33 ± 1.36 b
Colwell P (mg kg^{-1})	30.69 ± 1.10 b	45.57 ± 2.97 a	38.53 ± 1.20 b	40.95 ± 1.41 b
CEC (cmol kg^{-1})	1.96 ± 0.16 b	3.85 ± 0.12 a	3.13 ± 0.18 b	3.24 ± 0.17 b
TN (%)	0.14 ± 0.02 b	0.20 ± 0.04 a	0.17 ± 0.03 b	0.18 ± 0.02 b
TC (%)	1.93 ± 0.13 b	2.79 ± 0.18 a	2.39 ± 0.14 b	2.69 ± 0.15 b
S (%)	0.054 ± 0.01b	0.15 ± 0.22 b	0.29 ± 0.28 a	0.28 ± 0.23 b
H (%)	0.74 ± 0.16 a	0.61 ± 0.02 b	0.63 ± 0.03 b	0.59 ± 0.02 b
O (%)	13.63 ± 1.54 a	4.82 ± 0.23 b	5.83 ± 0.22 b	7.27 ± 0.23 b
	Available Concentrations			
As (μg/kg)	18.94 ± 0.56 a	12.24 ± 0.32 b	14.14 ± 0.31 b	13.90 ± 0.40 b
Cr (μg/kg)	9.24 ± 1.21 b	6.10 ± 0.92 b	13.96 ± 1.43 a	6.87 ± 0.80 b
Ni (μg/kg)	12.49 ± 0.91 b	7.37 ± 0.74 b	14.78 ± 1.54 a	8.76 ± 0.72 b
Pb (mg/kg)	4.71 ± 0.56 a	2.54 ± 0.32 b	3.55 ± 0.29 b	3.18 ± 0.31 b
Cd (μg/kg)	44.54 ± 0.90 a	30.44 ± 1.41 b	35.73 ± 1.35 b	34.87 ± 1.51 b

Colwell P. Bioavailable PTEs extracted with ethylene diamine tetra acetic acid (EDTA-Na$_2$) (0.05 M), tri ethanol.

29%, 32% and 22%. Highest decrease in PTEs availability was recorded in the PNB amended soils as compared with RHB and CCB. The decreased available concentration of PTEs in PNB amended soils may be related to the increased sorption of PTEs by PNB, as PNB has larger pore size (10.07 nm) as compared to RHB (3.48 nm) and CCB (4.57 nm). Another, reason may be the larger surface area of PNB (12.49 m^2 g^{-1}) as compared to RHB (1.85 m^2 g^{-1}) and CCB (5.48 m^2 g^{-1}) (Table 1). These findings are in line with Houben et al. (2013) that amendment of miscanthus straw biochar significantly ($P \leq 0.05$) decreased Cd, Pb and As bioavailability in metals polluted soil. Significant reduction in PTEs availability had also been explored with amendment of biochars produced from other waste residues (Ahmad et al., 2012). Indeed, pH is a vital parameter in PTEs sorption process therefore; the decreased PTEs availability in biochar amended soils in the current experiment may be related to the increased pH level (Smith, 1994; Zheng et al., 2015; Jelly and Najafi, 2018). In-addition, PTEs speciation and ionization processes as well as surfaces charges and chemistry of adsorbents could also be affected with increased pH levels of biochar amended soils (Kołodyńska et al., 2012; Martinsen et al., 2015). In another study, Uchimiya et al. (2010) reported that amendment of broiler litter-derived biochar could decrease the adsorption of PTEs through increasing the amended soil pH level. Soil organic matter contains a minor portion of DOC in soil but it plays an essential role in maintaining soil ecosystems due to its reactivity and mobility towards metals contaminants (Chantigny, 2003). When biochar is amended to soil it directly increases the soil organic matter concentration that subsequently alters sorption–adsorption processes of PTEs (Smernick, 2009). In the present study, the concentration of DOC increased by up to 138%, 42% and 68% in PNB, RHB and CCB amended soil. Due to the natural behavior of DOC direct sorption and formation of stable complexes with PTEs, increased DOC concentration in biochars amended soil might reduce the PTEs availability (Zheng et al., 2013). Furthermore, the occurrence of aromatic and non-aromatic functional groups on biochars surfaces could also alter PTEs bioavailability in biochars amended soils (Xu et al., 2013).

3.3. *Potentially toxic elements bioaccumulation and biomass production*

In the current study, PNB, RHB and CCB soil amendments improved *Lactuca sativa* L. plant growth and biomass production. Commonly, plants exposed to high metal stress revealed toxic visible symptoms such as necrosis, chlorosis, stunted growth and lower biomass production. However, at lower metals concentration these symptoms totally disappear due to lower toxicity and oxidative damage, as a result more plant biomass is produced (Vangronsveld and Clijsters, 1992). *Lactuca sativa* L. roots biomass significantly ($P \leq 0.01$) increased by up to 51%, 53% and 122% with amendments of RHB, CCB and PNB as compared with non-amended control. Similarly, with amendments of RHB, CCB and PNB shoots biomass elevated by up to 39%, 65% and 100% as compared with non-amended control (Fig. 2). This increase in biomass production may be associated with the lower PTEs phytoxicity to *Lactuca sativa* L. plants as well as oxidative damage. In comparison with RHB and CCB, biochar PNB amendment revealed the highest biomass production. The biochar source and type used as a feedstock may also be responsible for decreased bioaccumulation of PTEs and increased biomass production. Furthermore, the increased biomass production may be linked with improved soil fertility due to increased TC and TN concentration (44%, and 42%) in PNB amended soil as compared with RHB (23% and 21%) and CCB (39% and 28%). Therefore, the enhanced levels of TC and TN in PNB amended soil may have improved soil fertility and subsequently enhanced *Lactuca sativa* L. biomass production. Furthermore, phosphorus is an essential nutrient for plants growth and biomass production as well as many physiological processes such as nucleic acid and protein synthesis, cell division and formation of meristematic tissues (Parvage et al., 2013; Chintala et al., 2014). The increased concentration of available P

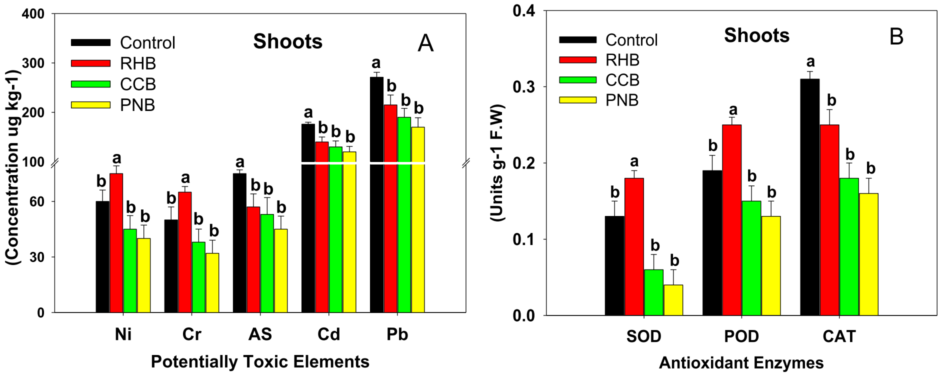

Fig. 1. (A–B) Potentially toxic elements bioaccumulation and antioxidant enzymes (SOD, POD and CAT activities, μmol tetra-guaiacol min^{-1} mg protein^{-1}, μmol consumed hydrogen peroxide H_2O_2 min^{-1} mg protein^{-1}) in *Lactuca sativa* L. grown in biochars amended and non-amended soil. The error bars represent standard deviations (n=4). Different letters on the bars indicate significant difference ($P \leq 0.05$), while similar letters indicate non-significant difference between treatments.

in biochars amended soil may be another factor that improved growth and biomass production of *Lactuca sativa* L. plants. Current findings are in line with previous studies that with amendments of Eucalyptus sapwood and pigeon pea biochar, spinach and spring onion biomass production significantly ($P \leq 0.01$) increased (Yu et al., 2009; Coumar et al., 2016). Other researchers (Hossain et al., 2010; Sun et al., 2017) reported that amendments of rice straw and waste water sludge biochars significantly ($P \leq 0.05$) increased maize and cherry tomato plant growth and biomass production remarkably

A prominent component of an ecosystem is plant which mobilizes elements from the abiotic to the biotic environment. In the present study, bioaccumulation of PTEs was affected contrastingly with amendments of PNB, RHB and CCB in *Lactuca sativa* L. plant tissues. Shoot bioaccumulation of PTEs significantly ($P \leq 0.05$) decreased such as Ni (25% and 33%), Cr (24% and 36%), As (29% and 40%), Cd (26% and 31) and Pb (29% and 37%) with amendments of CCB and PNB. Similarly, shoot accumulation of As, Cd and Pb statistically decreased by up to 24%, 20% and 21% with amendment of RHB. However, accumulation of Cr and Ni significantly ($P \leq 0.05$) elevated with amendment of RHB (Fig. 1A). Highest decrease in PTEs bioaccumulation was noticed with amendment of PNB as compared with RHB and CCB. The increased bioaccumulation of Ni and Cr in *Lactuca sativa* L. plants may be related with enhanced uptake of Ni and Cr or decreased sorption due to the smaller pore size of RHB as compared with PNB and CCB (Table 1). Another reason may be associated with higher concentration of Ni and Cr in the RHB samples. These findings are consistent with previous studies revealed that with amendment of rice bran, husk and straw biochars Cd, Pb and As bioaccumulation significantly ($P \leq 0.05$) decreased by up to 71%, 60% and 37% (Zheng et al., 2013). Similarly, Ibrahim et al. (2017) also reported reduced PTEs bioaccumulation in *Phaseolus vulgaris* L plants. cultivated in peanut shells biochar (PNB) and sewage sludge biochar (SSB) amended with PTEs contaminated soil. Several mechanisms could affect this decreased accumulation of PTEs in *Lactuca sativa* L. plants. One possible mechanism is the physical characteristics such as pore size, pore volume and surface area of amended biochar which could have reduced PTEs availability in the biochars amended soil. Furthermore, in-organic compounds as well as exchangeable bases in soils have also been reported to increase pore volume and surface area of amended biochars, thus assisting in decreased PTEs availability in soil and subsequent bioaccumulation in plants (Kim et al., 2013). The second mechanism may be linked with the elevated pH concentration of biochars amended soil. Elevated soil pH enhances the biochar negatively-charged surface sites that directly increase the PTEs sorption capacity (Kołodyńska et al., 2012). In-addition, improved DOC level in biochars amended soil could also be linked with the reduced PTEs availability in soil and subsequent accumulation in *Lactuca sativa* L plants. Furthermore, elevated DOC concentration creates stable complexes with PTEs molecules thus increased sorption capacity of amended biochar. A previous study (Zheng et al., 2012) explored that in biochar amended soil, DOC acts as chelator with PTEs molecules thus decreases the available concentration of PTEs. In the present findings it was investigated that in terms of PTEs sorption and biomass production, PNB was the best suitable soil amendment as compared with RHB and CCB.

3.4. *Responses of antioxidant enzymes*

In plant cells, adjacent to reactive oxygen species (ROS) sites, antioxidant enzymes system is present, which detoxify harmful effects of ROS (Corpas et al., 2015). Hydrogen peroxide (H_2O_2), hydroxyl radical (^{-}OH), superoxide radical (O_2^{-}), and singlet oxygen ($^1O_2$) are the major ROS, which are produced in mitochondria, chloroplast and peroxisomes. It has been shown that adverse environmental factors such as high and low light intensity, temperature, drought, salinity and heavy metals stress rapidly secret over production of ROS in green plants (Mittler et al., 2011; Baxter et al., 2014). Therefore, against adverse environmental factors plants have developed protective mechanisms called antioxidant enzymes that play signaling role in stress conditions (Gupta et al., 2016). Over accumulation of ROS producing intensive damage to cellular

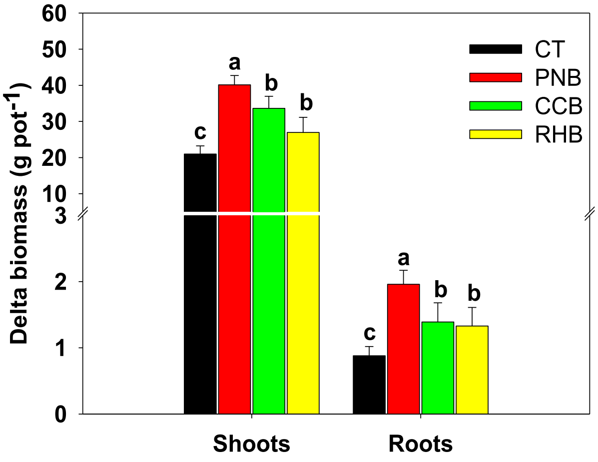

Fig. 2. Shoots and roots biomass of *Lactuca sativa* L. grown in biochars amended and non-amended soil. The error bars represent standard deviations (n=4). Different letters on the bars indicate significant difference ($P \leq 0.05$), while similar letters indicate non-significant difference between treatments.

proteins, nucleic acids and lipids (Sies et al., 2017). Accumulation of superoxide radicle (O_2^-_) in chloroplast is rapidly dismutate into hydrogen peroxide (H_2O_2) by the activity of superoxide dismutase (SOD) (Wang et al., 2016a,b). Another enzyme called peroxidase (POD) located in mitochondria can scavenge H_2O_2 into water (H_2O) and oxygen molecule (O_2) (Welinder, 1992; Passardi et al., 2007). Similarly, enzyme catalase (CAT) present in peroxisomes can eliminate over accumulation of H_2O_2 into H_2O and O_2 molecule (Reumann and Bartel, 2016).

In the present study, RHB, CCB and PNB amendments contrastingly affected the activities of antioxidant enzymes in *Lactuca sativa* L. plants. Activities of SOD and POD significantly ($P \leq 0.01$) stimulated by up to 38% and 31% with amendment of RHB however, declined by up to 53%, 69% and 22%, 31% with additions of CCB and PNB respectively. The activity of CAT significantly ($P \leq 0.01$) declined by up to 21%, 41% and 48% with amendments of RHB, CCB and PNB as compared with non-amended control (Fig. 1B).

These variations in antioxidant enzyme levels may be due to the increased or decreased PTEs bioaccumulation in *Lactuca sativa* L. plants. Previous studies (Mishra et al., 2006; Zhang et al., 2009) showed that Cd accumulation caused enhanced activity of SOD and enzyme encoding genes, thus resulting in elevated antioxidant enzyme pools. Molassiotis et al. (2006) found that increased inorganic boron (B) concentration could damage the membrane and induced stress in the peroxidation of lipids, which might slow down SOD enzyme activity. Another antioxidant enzyme POD also plays a key role in oxidative stress conditions. POD enzyme can convert H_2O_2 molecules which is toxic to plants into non-toxic H_2O and O_2 molecule. Hasan et al. (2009) showed that POD enzyme could be assessed as a possible biomarker for sublethal inorganic Cd metal toxicity in various plants species. Furthermore, in plant cells enzyme CAT also play a key role in scavenging the excessive concentration of H_2O_2 and converts it into H_2O and O_2 molecules (Wu et al., 2013). Thus the enhanced CAT activity, scavenge un-necessary accumulation of H_2O_2 molecules in the peroxisomes of plant cells, thus maintaining a dynamic equilibrium between H_2O_2 synthesis and elimination. The decreased CAT activity in plant cells is caused by less oxidative stress produced by decreased metal stress, resulting in the inhibition of enzyme synthesis (Alscher et al., 1997). Furthermore, in the present study the decreased CAT activity with amendments of RHB, CCB and PNB may be due to the lower H_2O_2 synthesis by SOD enzyme during dismutation of reactive oxygen free radical O_2^- in the *Lactuca sativa* L. plant cells. Another, reason may be the decreased accumulations of As, Cd and Pb in plant tissues causing less oxidative stress and their higher sorption capacity by RHB, CCB and PNB in amended soils. Usually, CAT enzyme activity stimulated with elevated stress in plant cells (Gong et al., 2013).

In the current study, the bioaccumulation of Ni and Cr in RHB amended plant shoots increased, due to which the levels of antioxidant enzymes SOD and POD were also elevated accordingly. Increased bioaccumulation of Ni and Cr caused enhanced production of ROS thus activate antioxidant enzyme system thereby, protecting *Lactuca sativa* L. plants from oxidative damage. It was reported previously that upregulation of antioxidant enzymes was implicated in combating oxidative stress in plant cells (Gill and Tuteja, 2010; Nadgórska-Socha et al., 2013).

4. Conclusions

In conclusion, amendments of RHB, CCB and PNB significantly ($P \leq 0.05$) decreased the bioavailable concentrations of As, Cd and Pb in soil and subsequent accumulation in *Lactuca sativa* L. plants. However, the concentrations of Cr and Ni significantly ($P \leq 0.01$) elevated with amendment of RHB. Activities of antioxidant enzymes such as SOD, POD significantly ($P \leq 0.05$) suppressed with amendments of CCB and PNB however, stimulated with amendment of RHB. In-addition, activity of CAT significantly ($P \leq 0.01$) declined with amendments of all three biochars. This up and down regulation in antioxidant enzymes may be biochar dependent. Highest significant effects on PTEs soil availability, plants bioaccumulation as well as biomass production were found with amendment of PNB as compared with RHB and CCB. This may be due to larger pore size and surface area of PNB. Current findings showed that how RHB, CCB and PNB reduced the available concentrations of PTEs in amended soil, its bioaccumulation in *Lactuca sativa* L. plants. This approach presented here can be applied to other biochar feed stocks and vegetable plants grown in multi-metals contaminated soils on global scale. Furthermore, present results proved that PNB was best soil amendment. However, applications of present outcomes require further investigations under long-term field trials.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eti.2019.100427.

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Opportunities for biochar production and use in Florida citrus

By Arnold Schumann and Timothy Spann

Biochar is a solid material derived from the carbonization of organic matter — charcoal. It has been used as a soil amendment in agricultural production for centuries to improve soil structure and cation exchange capacity. Perhaps the best-known example of biochar use in agriculture is the "terra preta" (dark earth) soils of the Amazon. Scientists have found that these rich loam soils were created by pre-Columbian civilizations by incorporating charcoal and fish bones into the soil. The result is soil nine times more fertile than the surrounding unamended soil; the amended soil was capable of supporting agriculture to feed populations in the millions. Today biochar is receiving renewed interest in agriculture, both for its soil-building properties and for its use in carbon sequestration to combat climate change.

Fig. 1. Closeup of biochar soil aggregates and plant roots, which form mycorrhizal fungal associations

(Photo from http://biocharfarms.org/farming/, by Richard Haard)

BIOCHAR PRODUCTION

As mentioned above, biochar is produced from organic matter — wood, leaves, manure, etc. — that is heated with little to no available oxygen and at relatively low temperature (<1,000 °F). This process, called pyrolysis, results in the thermochemical decomposition of the organic matter. Unlike normal microbial decomposition of organic matter that produces water and carbon dioxide, pyrolysis of organic matter produces biochar and biogas; both processes also release mineral nutrients. The biogas is generally a mix of hydrogen, carbon monoxide and light hydrocarbons (methane, acetylene, ethylene, etc.), depending on the feedstock. These can be captured and used as fuel for heating or power generation. The biochar, which is virtually pure carbon, can then be used as an agricultural soil amendment.

BIOCHAR AS A SOIL AMENDMENT

The carbon in biochar is highly resistant to decomposition and therefore can hold carbon in soils from hundreds to thousands of years. Thus, biochar can be viewed as a permanent addition to soils, making it particularly advantageous in perennial crop systems like citrus.

Biochar is naturally found in soils around the world as a result of vegetation fires as well as historical soil management practices (e.g., terra preta soils). Biochar can be an important tool in areas with highly depleted soils, scarce organic resource availability, or inadequate water and/or chemical fertilizer supplies. In highly depleted or leaching-prone soils, biochar can be an important tool for preventing groundwater contamination by increasing soil retention of fertilizer nutrients and agrochemicals. Biochar itself is not a fertilizer; it is a stable form of carbon and a permanent soil amendment.

One of biochar's important effects on soil comes through improving the number and diversity of beneficial soil

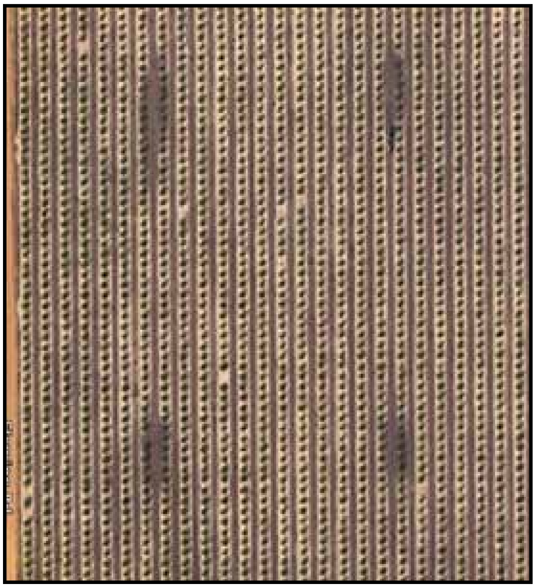


Fig. 2 (above). *Aerial view of a portion of a citrus grove showing the effects of four burn piles on tree growth*
(Photo from Google Earth)

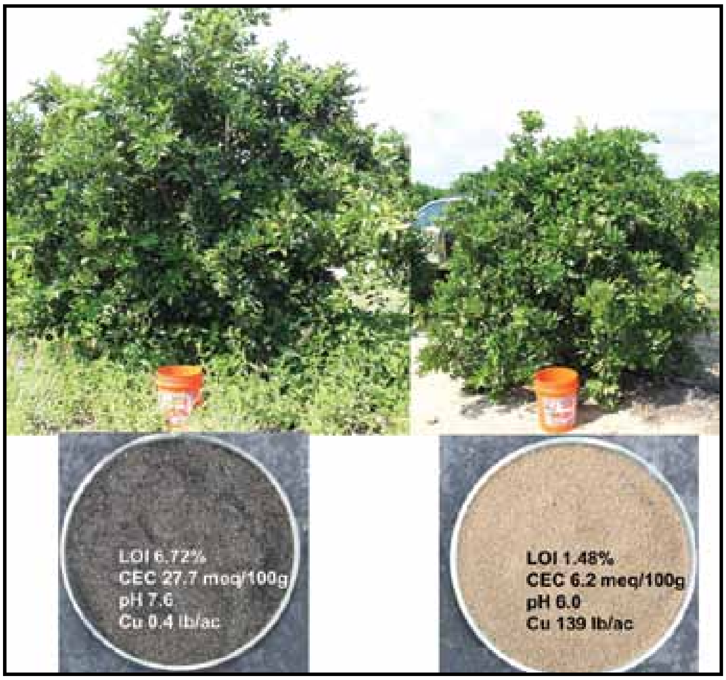


Fig. 3 (right). *Close-up view of individual trees in the grove shown in Figure 2. The tree on the left is growing on the burn pile-amended soil and the tree on the right is growing in the unamended soil (note the 5-gallon bucket for scale). The images of the soil samples show the difference in soil color and other characteristics.*

microbes (Fig. 1, page 6). The fine porous structure of biochar serves as a habitat for microbes, protecting them from drought and predation as well as providing for some of their carbon, energy and mineral needs. Understanding specifically how biochar affects the soil ecology is a very active area of research.

Biochar has a negative charge, which allows it to buffer soil pH. In addition, the negative charge gives biochar a high cation exchange capacity (CEC), allowing it to hold plant nutrients in the soil. Cations are positively charged ions, with calcium (Ca^{2+}), potassium (K^{+}) and magnesium (Mg^{2+}), among others, being particularly important to agriculture. These basic forms of mineral nutrients are those that plants take up through their roots. Soils high in organic matter or clay content have naturally high CECs and retain mineral nutrients well, making them available to plants as they are needed. However, highly leached sandy soils like those throughout much of Florida have very low CEC, and mineral nutrients can be easily leached with rain or irrigation water.

Although biochar itself does not contain any appreciable amounts of nutrients, its addition to poor soils can greatly enhance their nutrient-holding capacity and potentially reduce fertilizer inputs. Cited benefits of biochar on soil properties include a 50 percent increase in CEC, a 10 percent to 30 percent increase in fertilizer efficiency, 18 percent higher soil moisture retention, 20 percent to 120 percent increased crop productivity, 40 percent increase in beneficial mycorrhizal fungi, and a 50 percent to 72 percent increase in biological nitrogen fixation. Biochar has also been tested for remediating toxic chemicals in contaminated soils, and one study reported a tenfold reduction of cadmium in soil after application of biochar, with subsequent reduction of phytotoxicity.

SOIL AMENDMENT IN FLORIDA CITRUS

Florida citrus soils can be highly variable. In an article published in the April 2010 issue of *Citrus Industry* ("Citrus Tree Health and HLB Incidence," page 14), we presented data on how very small changes in soil composition, particularly organic matter, can have huge impacts on tree growth, productivity and health. A more in-depth presentation of these data was recently published and is available on the EDIS website (http://edis.ifas.ufl.edu/pdffiles/SS/SS55700.pdf). In addition to demonstrating the potentially huge benefits from amending our poor soils, these data show that such amendments are not required over an entire grove, but only on the weakest soils. Targeting amendment efforts at the weakest areas makes soil amendment an affordable management tool.

BURN PILES: POTENTIAL BENEFITS FROM BIOCHAR AMENDMENTS TO CITRUS SOILS

Many growers have observed the effects of burn piles on subsequent citrus growth. Initially the transplanted trees may perform poorly on burn-pile locations, and then after some months or years, the trend may reverse and they grow exceptionally well thereafter. Burn piles actually produce mostly ash from aerobic combustion, and very

little biochar. The ash tends to oversupply nutrients and especially alkalinity, thus stunting initial growth until the excess soluble components are weathered and leached from the soil, leaving mostly the insoluble biochar.

We have been collecting data to understand the growth differences of 4-year-old citrus trees growing on burn pile-affected soil and surrounding unaffected soil (Fig. 2, page 8). The trees that grew on the dark carbon-enriched soil had 67 percent more canopy volume than trees in adjacent unamended soil (Fig. 3, page 8). The soil carbon, measured by loss-on-ignition (LOI), and the CEC were 4.5 times higher in the burn-pile area, compared to the native soil levels. Also, extractable soil copper concentration in the grove soil was high (139 lb./acre), but was reduced to negligible levels (0.4 lb./acre) in the burn pile, biochar-amended soil.

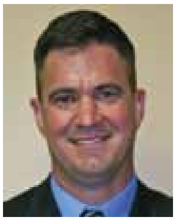
More research is needed to fully understand the burn-pile phenomenon, but, more importantly, studies testing the effects of biochar sources, rates and application methods on citrus are required to develop reliable recommendations for Florida. Ideally, biochar should be produced on location with citrus trees removed from groves, thus reducing the high cost of transporting a bulky material. Biochar yield from citrus trees would depend on the standing biomass in the grove, probably in the range of a few tons per acre.

Currently, the Florida citrus industry can be considered carbon positive because the trees are ultimately burned. That is, the carbon dioxide released to the atmosphere during the growing and then burning of the trees exceeds the carbon dioxide that is sequestered by the trees through photosynthesis and biomass storage. The conversion of dead trees to biochar can permanently improve our citrus soils for better production and store carbon long-term. In so doing, the Florida citrus industry could become carbon neutral or even carbon negative (a process that removes carbon dioxide from Earth's atmosphere).

Biochar is a soil amendment with proven benefits to many crops, including citrus, based on observations of tree growth in burn pile-affected soil. Biochar improves nutrient retention and soil structure, leading to improved crop productivity and health. And all of these benefits can be obtained from locally produced biochar made from normal agricultural waste material.

Arnold Schumann is an associate professor and Tim Spann is an assistant professor, both at the University of Florida-IFAS' Citrus Research and Education Center in Lake Alfred.

FDOC Increases Orange Juice Marketing Activities



By Douglas Ackerman

The Florida Department of Citrus (FDOC) strives to maintain market share for Florida citrus in spite of ongoing, external challenges including slow economic recovery, higher prices, increased competition from other beverages and reduced promotional activity. This year, we are also combating negative news, which has created consumer confusion about the safety of orange juice. Ensuring quality and safety of Florida citrus has always been, and will continue to be, a priority of the citrus industry. FDOC is committed to promoting our great Florida citrus products and ensuring that orange juice remains relevant to today's consumer.

The Florida Citrus Commission, in support of FDOC's leadership role as the marketing agency for the Florida citrus industry, provided an additional $2 million to increase current domestic marketing activities and reinforce positive messages about Florida orange juice. This increase was funded by a cost savings of $1.5 million that will not be used for disease research this fiscal year, as well as uncommitted reserves.

In addition to the fully integrated 2011-2012 marketing plan already under way, the FDOC marketing team identified new areas of opportunity to surround consumers with messages about Florida orange juice throughout their day via traditional and social media channels.

A 15-second TV commercial launched in early March features the eye-catching visual of orange juice pouring into a glass. The script emphasizes the pure, natural goodness of delicious, 100 percent Florida orange juice. You can view the commercial at http://www.floridajuice.com/videos.php. With this increased budget, we've purchased three additional weeks of television to increase consumer reach and frequency.

Because our target customers spend a great deal of time online, we've secured partnerships with trusted, influential websites to provide nutrition-related information, interactive content and recipes on WebMD.com, LadiesHomeJournal.com, FitnessMagazine.com and EatingWell.com.

Florida orange juice banner ads will break through the clutter and gain attention on other strategically targeted websites including Women's Health, Men's Health, Shape, Self, Food Network and All Recipes.

Innovative social media applications allow us to reach consumers in new ways, such as a Florida orange juice mood board on the hot, new Pinterest site and an interactive Twitter party.

All marketing activities drive traffic to our Florida orange juice Facebook page where we deliver positive, robust information and reinforce the value of orange juice.

Incremental marketing activities will be carefully monitored and measured to determine their ability to influence consumer attitudes, consumption intent and purchases. Results will help strengthen the marketing program currently under development for fiscal year 2012-2013. Our goal is to ensure that orange juice remains a staple in nearly 70 percent of American households and consumers continue to take on the day with a daily glass of Florida orange juice.

The mission of the Florida Department of Citrus is to grow the market for the Florida citrus industry to enhance the economic well-being of the Florida citrus grower, citrus industry and the state of Florida. Douglas Ackerman, executive director, can be reached at (863) 537-3999. For more information, visit www.FDOCGrower.com

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Phosphorus and Nitrogen Removal in Modified Biochar Filters

Ylva Stenström

ABSTRACT

Phosphorus and Nitrogen Removal in Modified Biochar Filters

Ylva Stenström

Onsite wastewater treatment systems in Sweden are getting old and many of them lack sufficient phosphorus, nitrogen and organic carbon reduction. Biochar is a material that has been suggested as an alternative to the common sand or soil used in onsite wastewater treatment systems. The objective of this study was to compare the phosphorus removal capacity between three different modified biochars and one untreated biochar in a batch adsorption and column filter experiment. The modifications included impregnation of ferric chloride ($FeCl_3$), calcium oxide (CaO) and untreated biochar mixed with the commercial phosphorus removal product Polonite. To further study nitrogen removal a filter with one vertical unsaturated section followed by one saturated horizontal flow section was installed.

The batch adsorption experiment showed that CaO impregnated biochar had the highest phosphorus adsorption, i.e. of 0.30 ± 0.03 mg/g in a 3.3 mg/L phosphorus solution. However, the maximum adsorption capacity was calculated to be higher for the $FeCl_3$ impregnated biochar (3.21 ± 0.01 mg/g) than the other biochar types. The pseudo 2^{nd} order kinetic model proved better fit than the pseudo 1^{st} order model for all biochars which suggest that chemical adsorption was important. Phosphorus adsorption to the untreated and $FeCl_3$ impregnated biochar fitted the Langmuir adsorption isotherm model best. This indicates that the adsorption can be modeled as a homogenous monolayer process. The CaO impregnated and Polonite mixed biochars fitted the Freundlich adsorption model best which is an indicative of heterogenic adsorption.

CaO and $FeCl_3$ impregnated biochars had the highest total phosphorus (Tot-P) reduction of 90 ± 8 % and 92 ± 4 % respectively. The Polonite mixed biochar had a Tot-P reduction of 65 ± 14 % and the untreated biochar had a reduction of 43 ± 24 %. However, the effluent of the CaO impregnated biochar filter acquired a red-brown tint and a precipitation that might be an indication of incomplete impregnation of the biochar. The $FeCl_3$ effluent had a very low pH. This can be a problem if the material is to be used in full-scale treatment system together with biological treatment for nitrogen that require a higher pH.

The nitrogen removal filter showed a total nitrogen removal of 62 ± 16 % which is high compared to conventional onsite wastewater treatment systems. Batch adsorption and filter experiment confirms impregnated biochar as a promising replacement or addition to onsite wastewater treatment systems for phosphorus removal. However the removal of organic carbon (as chemical oxygen demand COD) in the filters was lower than expected and further investigation of organic carbon removal needs to be studied to see if these four biochars are suitable in real onsite wastewater treatment systems.

Keywords: biochar, modified biochar, phosphorus filter, wastewater, batch adsorption experiment, nitrogen filter, COD, Tot-P, Tot-N

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REFERAT

Fosfor och kväverening i modifierade biokolsfilter

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Många av Sveriges små avloppssystem är gamla och saknar tillräcklig rening av fosfor, kväve och organiskt material. Följden är förorenat grundvatten samt övergödning i hav, sjöar och vattendrag. Lösningar för att förbättra fosfor- och kvävereningen finns på marknaden men många har visat brister i rening och robusthet. Biokol är ett material som har föreslagits som ersättare till jord eller sand i mark och infiltrationsbäddar. Denna studie syftade till att i skak- och kolonnfilterexperiment jämföra fosforreduktion mellan tre modifierade biokol och ett obehandlat biokol. Modifieringen av biokolet innebar impregnering med järnklorid ($FeCl_3$), kalciumoxid (CaO) samt blandning med Polonite som är en kommersiell produkt för fosforrening. För att undersöka förbättring av kväverening installerades även ett filter med obehandlat biokol där en vertikal aerob modul kombinerades med en efterföljande horisontell anaerob modul.

Skakstudien där biokolen skakades i 3.3 mg/L fosforlösning visade att adsorptionen var högst i det CaO-impregnerade biokolet, 0.3 ± 0.03 mg/g. Den maximala potentiella fosforadsorptionen beräknades dock vara högst för biokolet som impregnerats med $FeCl_3$, 3.21 ± 0.01 mg/g. Skakförsöket visade också att fosforadsorptionen var främst kemisk då adsorptionen passade bättre med pseudo andra ordningens modell än pseudo första. Adsorption av fosfor på obehandlat biokol och $FeCl_3$ impregnerat biokol modellerades bäst med Langmuir modellen, vilket tyder på en homogen adsorption. Det Polonite-blandade biokolet och CaO-impregnerade biokolet modellerades bäst med Freundlich modellen vilket är en indikation på en heterogen adsorptionsprocess.

Biokol impregnerat med CaO och $FeCl_3$ gav de högsta totalfosforreduktionerna på 90 ± 8 % respektive 92 ± 4 %. Biokolet som var blandat med Polonite hade en reduktion på 65 ± 14 % och det obehandlade biokolet 43 ± 24 %. Ett problem med filtratet från CaO-filtret var att det fick en rödbrun färg samt en fällning vilket kan ha berott på ofullständig pyrolysering och impregnering. Filtratet från det $FeCl_3$ impregnerade biokolet hade mycket lågt pH vilket kan vara problematiskt om mikrobiologisk tillväxt i filtret för rening av kväve och organiskt material vill uppnås.

Filtret för kväverening gav en total kvävereduktion på 62 ± 16 % vilket är högre än kommersiella system. Resultaten från skak och filterstudien visade på att impregnerade biokol kan ge en förbättrad fosforrening om de skulle användas i små avloppssystem. Rening av organiskt material, kemisk syreförbrukning (COD), var dock låg i alla filter och behöver studeras ytterligare för att avgöra om dessa biokol är lämpliga för småskalig avloppsvattenrening.

Nyckelord: biokol, impregnerat biokol, fosforfilter, avloppsvatten, skakexperiment, kvävefilter, COD, Tot-P, Tot-N

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PREFACE

This project is the final thesis for the Master's Program in Environmental and Water Engineering at Uppsala University (UU) and the Swedish University of Agricultural Science (SLU). It corresponds to 30 ETCS. The project was financed by the Swedish Agency for Marine and Water Management. I would like to give thanks to my supervisor and biochar expert Sahar Dalahmeh, researcher at the Department of Energy and Technology at SLU, for helping me with everything throughout the project. I would also like to thank the subject reviewer Mikael Pell, professor at the Department of Molecular Sciences at SLU for help with the experiments and with thorough reviewing of the report.

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POPULÄRVETENSKAPLIG SAMANFATTNING

Kväve och fosforrening i modifierade biokolsfilter

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Till små avloppsanläggningar räknas de anläggningar som renar avloppsvatten för upp till ca 200 personer. De flesta anläggningarna som används idag byggdes på 1970 och 80-talet. Många av dem har börjat tappa funktionen och renar avloppsvattnet allt sämre. De flesta små avlopp är markbaserade där avloppsvatten renas genom att filtreras genom en bädd med sand eller direkt ner i jorden. I marken eller sanden börjar det växa bakterier som konsumerar kväve och organiskt material (COD). Fosfor i avloppsvattnet fastnar också i marken genom bindning till markpartiklarna. Då avloppsanläggningar inte fungerar som avsett släpps kväve, fosfor och COD ut i grundvatten eller ytvatten. Orenat avloppsvatten i grundvatten är inte önskvärt eftersom många hämtar sitt dricksvatten därifrån. Näringsämnen som hamnar i ytvatten skapar övergödning och algblomningar vilket förstör vattenmiljöer, badplatser och förutsättningar för fisk. I Östersjön märks det att de små avloppen har stor påverkan. Även fast bara 10 % av Sveriges befolkning renar sitt avloppsvatten i små avlopp står de för 15 % av det totala fosfortillskottet. Resten av Sveriges befolkning (ca 90 %) som renar sitt vatten i större reningsverk står för endast 18 % av fosforbelastningen. För att förbättra reningen i små avlopp har nya prefabricerade lösningar introducerats på marknaden. Ett problem med dessa är dock att de behöver omfattande tillsyn och underhåll och inte är särskilt robusta.

Ett material som har visat sig vara intressant för avloppsvattensrening är biokol. Biokol är egentligen samma material som grillkol men som tillverkats med miljömässigt eller agronomiskt syfte. Biokol är mest känt för sina jordförbättrande egenskaper inom odling, men materialets stora yta och bindningsförmåga gör det lämpligt för kväve och fosforrening. Om man jämför ett gram biokol med ett gram sand finns det i biokolen 100 gånger så stor yta där fosfor kan fastna. Den större ytan gör även biokol till ett bra material för tillväxt av mikroorganismer. I tidigare studier har det kommit fram att biokol är väldigt bra på att ta bort organiskt material (> 90 % COD borttagning). Dock finns fortfarande brister i fosfor- och kvävereduktion. I denna studie undersöktes därför modifierade biokol för att se om en modifiering kunde öka reningsgraden.

För att undersöka fosforreduktion impregnerades biokol gjort av pilbark med järnklorid och kalciumoxid som är två kemikalier som används för fosforbindning. Ett tredje biokol blandades med det fosforbindande materialet Polonite som innehåller mycket kalk. De impregnerade biokolen och polonitkolet jämfördes med obehandlat pilbarkskol i ett skakförsök. I skakförsöket skakades de i olika koncentrationer av fosforlösningar för att se hur mycket som kunde bindas. Biokolen testades också i ett kolonnförsök där de packades i kolonner för att filtrera riktigt avloppsvatten.

För att undersöka kvävereningsförmågan byggdes ett avloppsvattenfilter med två delar, en del med vertikalt flöde följt av en vattenfylld del med horisontellt flöde. Detta skapade ett filter med en syresatt del följt av en syrefattig vilket är gynnsamt för de bakterier som renar kväve.

Resultatet från skakstudien visade att det kalciumoxidimpregnerade biokolet hade störst kapacitet att avlägsna fosfor. Det framgick också att järnkloridimpregnerat biokol har stor potential att binda fosfor men att bindningen tar längre tid. Från kolonnexperimentet var det klart att de kalciumoxid-och järnkloridimprgnerade biokolen hade högst fosforreduktion på mer än 90 %. Inget av de två kolen visade tecken på minskad fosforreningsförmåga under studien. Ett problem med de impregnerade biokolsfiltrena var att utflödet från det kalciumoxidbehandlade materialet fick en gul-brunaktig färg samt en fällning vilket kan betyda att kolet inte hade blivit helt förkolnat vid tillverkningen. En bättre impregnering av kalciumoxid hade möjligen resulterat i en bättre karaktär på vattnet. Vatten filtrerat i järnkloridfiltret hade väldigt lågt pH vilket kan vara ett problem om man vill använda materialet som fosfor och kvävefilter, då de kvävereducerande bakterierna trivs i ett högre pH. Det polonitblandade biokolet hade en fosforreduktion på ca 65 % medan det obehandlade biokolet bara tog bort ca 43 %. Både Polonite-biokolsfiltret och det obehandlade biokolsfiltret tappade i effektivitet under försökets gång. Kvävefiltret visade hög kvävereningsförmåga på ca 60 %.

Denna studie visar att biokol tillverkat av pilbark inte var bättre att rena avloppsvatten från kväve och fosfor än konventionella små avloppsanläggningar. Men om biokolet modifieras med impregnering kan materialet ses som lovande för fosforrening. Om en syrefri del läggs till i ett biokolsfilter kan kvävereningen också förbättras väsentligt. Dock krävs vidare studier för att undersöka hur biokolfilter bäst kan användas. Intressant var även att alla biokolfilter visade en låg COD borttagningsförmåga jämfört med tidigare studier vilket även det skulle behöva undersökas vidare.

1. INTRODUCTION

It is estimated that there are about 750 000 onsite wastewater treatment systems (OWTSs) in Sweden. Out of these, only 400 000 have a treatment process that goes beyond primary sedimentation. Most existing sites were built in the 1970s and 1980s (Ridderstolpe, 2009), and today many systems are getting old and lack sufficient pollution reduction. This leads to discharge of nitrogen (N) and phosphorus (P) into the environment causing eutrophication in downstream water bodies (Hjelmqvist, 2012; Ejhed et al., 2004; Naturvårdsverket, 2014). Another problem is that drilled drinking water wells risk contamination from nearby malfunctioning OWTSs (Miljömålsrådet, 2010).

P has been suggested as a major concern regarding small wastewater treatment systems (Ridderstolpe, 2009). Only a small fraction (about 10 %) of Sweden's population uses OWTS, yet they represent 15 % of the total net anthropogenic load of P on the Baltic Sea. This can be compared with the load from larger wastewater treatment plants (WWTPs) treating the water of 90 % of the population, but is responsible for only 18 % of the P load (HaV, 2016a). For eutrophication to decrease in Swedish waters the level of P emissions have to decline (Boesch et al., 2006). The N load to the Baltic sea from OWTS is small relative other anthropogenic sources (HaV, 2016a). Nevertheless it is still important that the systems have a sufficient N treatment to prevent eutrophication close to them and inadvertent pollution of ground water reservoirs that are used as drinking water resources.

1.1 ONSITE WASTWATER TREATMENT SYSTEMS

OWTSs are defined as systems treating wastewater for up to 200 population equivalents and most OWTSs in Sweden are built as vertical soil filters. The filters are installed with a septic tank in which heavy particles in the wastewater undergo sedimentation. The water is then either led by gravity or pumped into an infiltration unit. The effluent from infiltration units with closed bottoms is collected and conveyed to a ditch or river. Effluent from infiltration systems with open bottom is discharged directly to the ground water. In the latter the water percolates the underlying natural soil. The vertical distance from the filter bottom to the ground water table is crucial and needs to be at least 1 m (Ridderstolpe, 2009). The recommended hydraulic load for a Swedish OWTS is 30 – 60 L/m^2 and day (Olshammar et al., 2015).

The main mechanism behind P removal in vertical soil filters is adsorption or precipitation to the soil or bed material. The phosphate ions (PO_4^{3+}) adsorbed to the surface of the material can also react with iron (Fe), aluminum (Al) or calcium (Ca) minerals to form strong precipitates or surface complexes. The pH in the soil affects the reaction. At low pH, the phosphate reacts with Fe and Al more easily forming e.g. $FePO_4 \cdot H_2O$. At higher pH the PO_4^{3+} forms complexes with Ca ions more easily, such as $CaHPO_4 \cdot 2H_2O$ and $Ca_4H(PO_4) \cdot 3H_2O$ (US EPA, 2002). Some of the P bound in organic particles can be removed physically by the filtration through the soil. Initially the P reduction can be very high. But the capacity to remove P will successively decrease and at some point the bed material will reach saturation. At this time the efficiency of the P removal will be essentially lowered or even cease (Olshammar et al., 2015). It has also been shown that P may be released (desorbed) from the material in the event of heavy rains (Eveborn et al., 2012). This has made it difficult to estimate the lifetime of P removal in soil infiltration beds.

N in vertical soil filters is removed partly by adsorption by ammonium (NH_4^+). However, the main removal mechanism is through bacterial mediated processes. Bacterial growth is favored in soils and materials with large pore volume and specific surface area (US EPA, 2002). By consuming organic material (measured as chemical oxygen demand, COD, or biochemical oxygen demand, BOD) in the wastewater, the bacteria will grow and create an active biofilm. Some parts of the biofilm will be exposed to air and other parts will not. Nitrifying bacteria in the biofilm derive their energy from oxidation of NH_4^+ to nitrite (NO_2^-) in a first step and then further to nitrate (NO_3^-). This process called nitrification is aerobic and the bacteria derive their carbon from carbon dioxide fixation. Under anaerobic conditions, another group of bacteria called denitrifying bacteria reduces NO_3^- or other nitrogen oxides to form nitrous oxide (N_2O) and nitrogen gas (N_2) in a process called denitrification. When denitrifying the NO_3^- is used instead of oxygen for respiration. In addition, denitrifying bacteria must be supplied with a readily available energy and carbon source to denitrify. The combined nitrification-denitrification will lower the total content of N (Tot-N) in the water (US EPA, 2002).

The rate of rebuilding and improving older OWTSs is low. Even some newly built systems have shown poor pollutant reduction and do not pass the regulations on nutrient reduction. The Swedish Agency for Marine and Water Management (Havs och Vattenmyndigheten) issued a proposition in 2016 during the time that this thesis was being written. The proposition was to decrease the required total P (Tot-P) removal from 70 % to be 40 % for general sites. However, for areas classified as sensitive to wastewater the required Tot-P reduction was to be increased to 90 % (HaV, 2016b). Furthermore, the reduction of organic material was suggested to be at least 90 % for all sites. It was also suggested that requirements for N reduction should be removed completely for general OWTS. However requirements for N removal was suggested to be put to 50 % if the area is classified as sensitive. A soil based wastewater system built according to present recommendations has the capability to remove 30 ± 10 %, 70 ± 20 % and 80 ± 10 % of influent N, P and COD, respectively (Olshammar et al., 2015). One problem is that many systems today have not been built according to the recommended guidelines. A common mistake is to locate the soil filter too close to the ground water, less than one meter. If the distance is too short the water does not get treated. N and P removal also show large variations depending on soil, placement and load.

To improve the P and N removal in vertical soil filters, alternative solutions and upgrades have become available on the market. An example is precipitation in the septic tank using iron or aluminum salts that significantly improves the P removal rate. Other popular but not as common upgrades are prefabricated treatment systems such as separate phosphor filters. Phosphor filters are commonly made from material with high calcite content and are placed after a closed sand bed to polish the effluent water. They are said to be able to remove up to 90 % of the P (Avloppsguiden, 2009). Polonite is an example of a material used in P filters. It is produced by heating the sedimentary rock opoka that has a high silica and CaO content. Opoka also contains MgO, Al_2O_3 and Fe_2O_3 that helps improve P removal (Brogowski & Renman, 2004). Solutions for improving N removal also exist. They can for instance be compact mini-treatment plants, mimicking large-scale WWTPs. There are many different versions of mini treatment plants but most are built with sedimentation, biological and chemical treatment. All mini-treatment plants use nitrification-denitrification for the reduction of N and can remove around 30 – 60 % of total N. Artificial bed material with large specific surface area is also a method to ensure good microbial development yielding N and BOD removal rates of about 20 – 40 and 90 %, respectively (Avloppsguiden, 2009).

Alternative treatment methods, like the ones mentioned, have shown higher P, N and BOD removal rates than vertical soil filters, but as of today require much supervision and service (HaV, 2016b). A treatment system based on infiltration requires minimal attention and is robust to changes in both load and temperature (Ridderstolpe, 2009). A robust system with high removal capacity is desirable. However, the lack of quality in vertical soil filters makes it necessary to look for new solutions for a secure reduction on P and N.

1.2 BIOCHAR

Char is the product of pyrolysis, where biomass is heated at high temperatures with no access to oxygen. Char is known for its ability to improve soil quality and plant growth. It has also proven itself useful for energy production, climate change mitigation and water treatment. Biochar is defined as char specifically produced for agronomic and environmental management applications (Joseph & Lehman, 2009). The char created after pyrolysis does not degrade over time, but is still a reactive material. The material is similar to activated carbon but does not undergo any activation process, making it a less expensive alternative. Yet biochar has twice the porosity of sand and has a specific surface area more than a 100 times higher than sand or soil with corresponding particle size (Dalahmeh, 2016). This gives biochar an excellent adsorption potential and can create a good environment for microbiological growth which could be beneficial for P, N and COD removal.

P adsorption to biochar is physical and/or chemical. The physical adsorption constitutes weak van der Waals forces between the phosphate ions and the surface. The large pore volume and specific surface area of biochar increases the potential for physical adsorption (Lehmann & Joseph, 2009). What chemical reaction that binds the P depends on the biochar surface and its chemical composition.

A review of several different biochar experiments showed that P removal was not affected much by hydraulic loading rate or particle size (Dalahmeh, 2016). However, to reach an optimal removal of COD and pathogens, a particle size of 1.4 mm and hydraulic load of less than 50 L/m^2 and day was recommended. In the results of the review it was clear that biochar had the capacity to remove 62 – 88 % of the total nitrogen (Tot-N). Biochar also had the capacity to remove 32 – 89 % of the total P (Tot-P), highly depending on its mother material. COD and BOD removal in biochar filters was proven to be high (> 90%) and consistent while it was suggested that the P and N removal processes in biochar filters needed further investigation to reach sufficient and reliable reduction (Dalahmeh, 2016).

1.3 IMPREGNATED BIOCHAR

Recent studies of modified biochar have focused on removal of several different substances; from reduction of heavy metals to carbon dioxide emissions. To impregnate or modify biochar with different elements as a method to improve the removal of specific substances is a growing research field (Rajapaksha et al., 2016). Modifications may occur before or after the biomass undergoes pyrolysis and can include heat treatment, impregnation of different substances and acid or base treatment to change and improve structure and removal properties. Modification of biochar with the objective to remove P has been investigated in a few studies by preforming sorption experiments with P solutions. In a study by Chen et al. (2011), biochar powder for P removal was produced at different temperatures and impregnated with magnetite (Fe_2O_3) with a biochar to Fe ratio of 0.9. The modified biochar showed higher P adsorption (up to 99 % removal) compared to unmodified replicates. Adding iron oxides to the biochar can also have structural benefits producing larger pore volume and specific surface area (Ren et al., 2015). Ferric chloride biochar has been studied by Li et al. (2016) where a Fe to biochar ratio of 0.7 in the biochar resulted in a P adoption as high as 16.58 mg P/g biochar which could be compared to natural sand that can have an adsorption less than 1 mg/g P (Del Bubba et al., 2003). When Liu et al. (2015) tested column filters with Fe modified biochar, 99 % of the Tot-P concentration was removed. Ca modified biochar filters have been studied for the removal of arsenic and chromium (Agrafioti et al., 2014) but is not as common for P removal. However Seo et al. (2005) impregnated and compared construction aggregate quarry with CaO, Al and Fe and found that the CaO impregnated material had superior P removal. Jung et al. (2016) analyzed fine biochar material produced by algae, drained and dried in calcium-alginate beads to investigate P removal and found that the biochar had the capacity to remove 100 mg P/g biochar.

1.4 OBJECTIVES

The overall goal of the project was to investigate the potential of biochar as filter media for removal of wastewater pollutants. Biochar filter materials were tested in a batch adsorption experiment with various phosphate concentrations and in filters for removal of P, N and COD from municipal wastewater. Specific objectives were to:

(i) Evaluate P removal capacity using biochar modified by impregnation with ferric chloride, calcium oxide and biochar mixed with Polonite in a batch adsorption experiment using increasing concentrations of phosphate solutions.

(ii) Evaluate P removal capacity using the same biochar types as in (i) but in a column filters fed with wastewater.

(iii) Investigate N transformation and removal in a biochar filter unit consisting of a vertical flow non-saturated section followed by a horizontal flow saturated section.

2. MATERIALS AND METHOD

2.1 BIOCHAR PREPERATION

Pine bark of particle size of 1 – 7 mm was saturated with solutions of ferric chloride ($FeCl_3$), calcium oxide (CaO) before pyrolysis. $FeCl_3$ and CaO are two common precipitation chemicals used for P removal (US EPA, 2002). After being mixed in the solutions for 24 hours in room temperature, the bark was dried in 100 ºC for another 24 hours. Finally the biochars were pyrolysed in 350 ºC for 3.5 hours. The ratio between ion and biochar was 0.3 for both impregnated biochars. The third biochar type was produced without any impregnation before pyrolysis but also had the pine bark as mother material. After pyrolysis, it was mixed with granular Polonite at a ratio of 0.3. The four different types of modified biochar used in the batch experiment and column filter experiment were named as follows:

UBC – untreated biochar
FBC – biochar impregnated with ferric chloride ($FeCl_3$)
CBC –biochar impregnated with calcium oxide (CaO)
PBC–biochar mixed with Polonite

The biochar used in the N removal filter originated from mixture of hard wood biomass and was obtained from Vildelkol AB (Vindelkol, 2017).

2.2 BATCH ADSORPTION EXPERIMENT

A batch experiment was carried out to assess and compare the adsorption capacity of P for the different types of biochar. One gram of each biochar type was added to 500 mL E-flasks containing 100 mL of phosphate solution of the concentrations 0.5, 3.3, 6.5, 13 and 26 mg PO_4-P/L (labeled C1-C5). The concentration were prepared by diluting 1000 mg PO_4/L stock solution based on monopotassium phosphate (KH_2PO_4) with distilled water (Table 1). The PO_4-P concentrations were selected based on what can be expected in an OWTS and diluted according to Table 1 (Palm et al., 2002). Three replicates (n=3) were prepared for each concentration except for C1 having only one replicate (n=1). The beakers were shaken on a rotary table for 24 hours at 130 rpm and constant room temperature 20 ± 2 ºC. Samples of the adsorbate solution (6 mL) from each of the beakers were extracted after 0 min, 15 min, 75 min, 4 h and 24 h using a pipette. The sorbate samples were filtered through a 0.45 µm filter and their PO_4-P concentration was determined according to method given in Table 2. The pH of the P solutions with biochar was measured during the experiment using pH strips (Table 2). After 24 hours the residual solids were washed with deionized water and then oven dried 80 ºC for 4 hours. The solids were finally stored in plastic bags for later analysis using Scanning Electron Microscopy (SEM) and Fourier Transform- Infrared Spectroscopy (FTIR), but this analysis was not performed during this thesis and was thus not included in the report.

Table 1 Dilution scheme for preparation of different concentrations of P solutions used in biochar adsorption batch experiment. Stock KH_2PO_4 solution of 1000 mg PO_4/L was mixed with distilled water into 100 mL beakers.

Label	PO_4 stock solution (mL)	Volume of beaker (mL)	Final concentration (mg P/L)
C1	0.15	100	0.5
C2	1	100	3.3
C3	2	100	6.5
C4	4	100	13.0
C5	8	100	26.08

2.2.1 Adsorption isotherm

An adsorption isotherm is the relationship between the equilibrium concentration in a solution (Ce) and the amount of adsorbate adsorbed on the surface of the material (Q) at constant temperature. The adsorption of phosphate (Q) from the batch adsorption experiment was calculated using Equation 1:

$$Q = (C_0 - C_e)\frac{V}{m} \qquad (1)$$

where Q is the mass P adsorbed per mass biochar (mg/g), C_0 the initial concentration of the solution (mg/L), C_e the concentration (mg/L) after 24 hours of the batch equilibrium experiment, V the volume of the solution (mL) and m the mass of the adsorbent (g).

The adsorption isotherm is often modelled with a Langmuir or Freundlich equation model (Messing, 2013). Langmuir and Freundlich adsorption isotherms were calculated for each biochar type with data used from the batch adsorption experiment. The Langmuir isotherm (Equation 2) models a monolayer adsorption on a uniform surface, while the Freundlich isotherm (Equation 3) models non-uniform adsorption on a non-uniform surface.

$$Q_e = \frac{k_L Q_m C_e}{1 + k_L C_e} \qquad (2)$$

Q_e (mg/g) Equilibrium adsorption capacity
C_e (mg/L) Concentration at equilibrium
k_L (L/mg) Langmuir adsorption constant
Q_m (mg/g) Maximum adsorption capacity

$$Q_e = k_F C_e^{1/n} \qquad (3)$$

k_F (L/g) Freundlich constant
n Dimensionless Freundlich heterogeneity exponent

In order to explore what model best described the batch experimental data, the parameters k_L, Q_m, k_F and n were determined for the models. This was done by linearizing the model Equations (2) and (3). The linear equation of the Langmuir (Equation 4) and Freundlich (Equation 5) was expressed on the form y = kx + m.

$$\frac{C_e}{Q_e} = \frac{Ce}{Q_m} + \frac{1}{k_L Q_m} \quad (4) \qquad \ln(Q_e) = \frac{1}{n} lnC_e + \ln(k_F) \quad (5)$$

Linear plots of the Langmuir Equation (4) were created with Ce as x-axis vs C_e/Q_e as y-axis. This provided the Langmuir parameters Q_m and k_L were $1/k_LQ_m$ is the intercept and $1/Q_m$ as the slope. Graphing Equation (5) with ln(Ce) on the x-axis and $\ln(Q_e)$ on the y-axis provided the Freundlich parameters k_F and n where $\ln(k_F)$ was the intercept and 1/n the slope. This was done for all biochar types.

After obtaining all the parameters, Q_e was calculated for each C_e with the Langmuir and Freundlich Equations (2) and (3). The model that calculated Q_e correlated best with the experimental Q_e was considered the best model to describe the P adsorption on each biochar type.

2.2.2 Kinetic isotherm

A kinetic isotherm describes the adsorption (Q) over time (t). The concentrations analyzed after 0 min, 15 min, 75 min, 4 h and 24 h in the batch adsorption experiment were used to calculate Q_t with Equation (1). The pseudo first (Equation 6) and second (Equation 7) order kinetic models are commonly used to describe the adsorption over time:

$$\frac{dQ_t}{dt} = k_1(Q_e - Q_t) \quad (6) \qquad \frac{dQ_t}{dt} = k_2(Q_e - Q_t)^2 \quad (7)$$

Q_t (mg/L) Amount adsorbed at time t
k_1 (min^{-1}) Pseudo 1st rate constant
k_2 (g/mg/min) Pseudo 2nd rate constant

In order to see which of pseudo 1st and pseudo 2nd order kinetic models best described the adsorption experiment their linear forms Equation (8) and (9) were used:

$$\ln(Q_e - Q_t) = lnQ_e - k_1 t \quad (8) \qquad \frac{t}{Q_t} = \frac{1}{k_2 Q_e} + \frac{t}{Q_e} \quad (9)$$

The pseudo 1st order equation was graphed on linear form with $\ln(Q_e – Q_t)$ on the y-axis and t on the x-axis. From the linear plot the rate constant k_1 (slope of the graph) and correlation coefficient R^2 was determined. Pseudo 2nd order equation was linearly graphed with t/Q_t on the y-axis and t on the x-axis with the intercept of the graph being $1/k_2Q_e$ and the slope $1/Q_e$. By plotting data this way the k_2 and R^2 for the pseudo 2nd order equation was determined. The linear plot of the two models with the highest correlation coefficient (R^2) was considered the best model to describe the P adsorption of the biochar types over time.

2.3 COLUMN FILTERS

To investigate the removal of P from real wastewater the four biochar types were tested in a 14 week long column filter experiment. Four 60 cm tall acrylic glass columns with diameter 4.25 cm were filled separately with untreated biochar (UBC), biochar impregnated with calcium oxide (CBC), biochar impregnated with ferric chloride (FBC), and biochar mixed with Polonite (PBC). Underneath and on top of the main biochar layer, 5 cm coarser untreated biochar (8 mm in diameter) was filled to prevent clogging on the very top of the filter and facilitate drainage on the bottom (Figure 1). The filters received 71 mL wastewater per day divided equally between the times 24:00, 08:30 and 16:00 to mimic the load of a real vertical soil infiltration system with 50 L/m^2 and day (Olshammar et al., 2015). Peristaltic pumps regulated with timers were used to feed the filters with wastewater stored in a fridge (2 – 4 ^{o}C). Before feeding, the wastewater was left outside the fridge for 20 minutes to reach room temperature. The wastewater was collected twice a week on Mondays and Thursdays mornings from the municipal wastewater treatment plant in Uppsala (Kungsängsverket). The water was collected directly from the primary sedimentation step of the plant and had to be filtered through a 0.8 mm mesh to remove particles to prevent clogging of the pipe of the pumps.

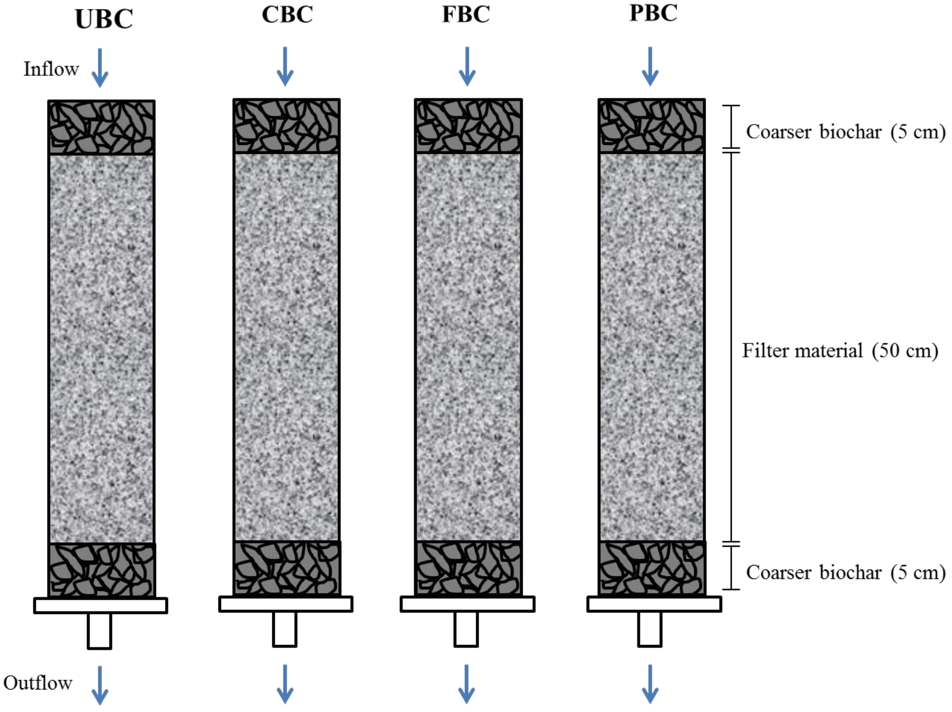


Figure 1 Experimental set-up for column filters filled with untreated biochar (UBC), biochar impregnated with calcium oxide (CBC), biochar impregnated with ferric chloride (FBC) and biochar mixed with Polonite (PBC).

Sampling of the inflow and outflow was done once a week, on Wednesdays, starting on the third week of the experiment. The following parameters were determined weekly: Tot-P, PO_4-P, Tot-N, NO_3-N, NH_4-N and pH and every second week COD was analyzed. The main objective was to investigate P but N measurements took place too. All analysis was conducted using chemical kits (Table 2).

Table 2 Analytical kits, analytical concentration ranges and instruments used for analyzing pollutants in wastewater used in the column filter and lab-scale filter unit experiments.

Substance	**Kit name/Method**	**Range mg/L**	**Instruments**
Tot-N	Spectroquant Crack Set 20 1.14963.0001	0.1-25.0	Spectroquant NOVA 60, VWR International Sverige Thermal reactor TR420, Merck
NH4-N	Spectroquant Ammonium Test 1.00683.0001	2.0-150	Spectroquant NOVA 60 and Aquamate, VWR International Sverige
NO3-N	Spectroquant Nitrate Test 1.09713.0002	0.1-25.0	Spectroquant NOVA 60 and Aquamate, VWR International Sverige
Tot-P	Spectroquant Crack set 10 1.14687.0001	0.0025-5	Spectroquant NOVA 60 and Aquamate, VWR International Sverige Thermal reactor TR420, Merck
PO4-P	Spectroquant Phosphate test 1.14848.0002	0.0025-5	Spectroquant NOVA 60 and Aquamate, VWR International Sverige
COD	Spectroquant COD Cell test 1.09772.0001 and 1.09773.0001	10-100 and 100 - 1500	Spectroquant NOVA 60
pH	pH strips	7-14, 1-7 and 1-14	Papier dosatest, VWR MColorptest, Merck

Removal efficiency was calculated from the difference in concentrations of inflow and outflow of the filters (Equation 10):

$$E = 100 \frac{C_{in} - C_{out}}{C_{in}} \qquad (10)$$

where E is the removal efficiency (%); C_{in} the concentration of the influent (mg/L); and C_{out} the concentration of the effluent (mg/L).

2.4 NITROGEN REMOVAL FILTER

A biochar filter with an aerobic vertical flow section combined with an anaerobic horizontal flow section was installed at Kungsängsverket and operated for 14 weeks. The biochar used originated from mixture of hard wood biomass and was obtained from Vildelkol AB (Vindelkol, 2017). The horizontal and vertical flow sections were installed using two boxes each with the size of 74×40×29 cm placed on top of each other (Figure 2). In the vertical flow section, a 3 cm drainage layer was prepared with coarse biochar (8 - 16 mm in diameter) at the bottom which had a slope of (1.5: 60; i.e. 2.5%). The section was then filled up to 30 cm with biochar of a particle size that varied between 2.5 and 5 mm. A second 3 cm layer of coarse biochar was placed on the top of the main filter to prevent clogging on the surface.

The horizontal flow biochar section was prepared by filling the box with coarse biochar (25 - 40 mm in diameter) in two 10 cm layers at the inlet and outlet sides. The main 54 cm part of the section was then filled with biochar (1.6 - 2.5 mm in diameter). The depth of the biochar in the horizontal flow section was 30 cm. The outlet of the horizontal flow section was located at a level 4 cm below the inlet level. Before the start of the experiment the filter was gently washed with distilled water. During the experiment, pumps fed the filter with 3 L three times a day, at 9:00, 16:00 and 01:00. This gave a flow of around 42 L/m^2 and day. The wastewater was initially pumped from after primary sedimentation in the plant. However, $FeCl_3$ added directly after the primary sedimentation in the plant interfered with N analysis so the filter with sampling point was relocated in week 7 to a location before the actual $FeCl_3$ dosing in the middle of the primary sedimentation. The water pumped from the primary sedimentation was filtered through a 0.8 mm sieve and the flow was lowered to 1.5 L/day giving a load of 21 L/m^2 to prevent clogging.

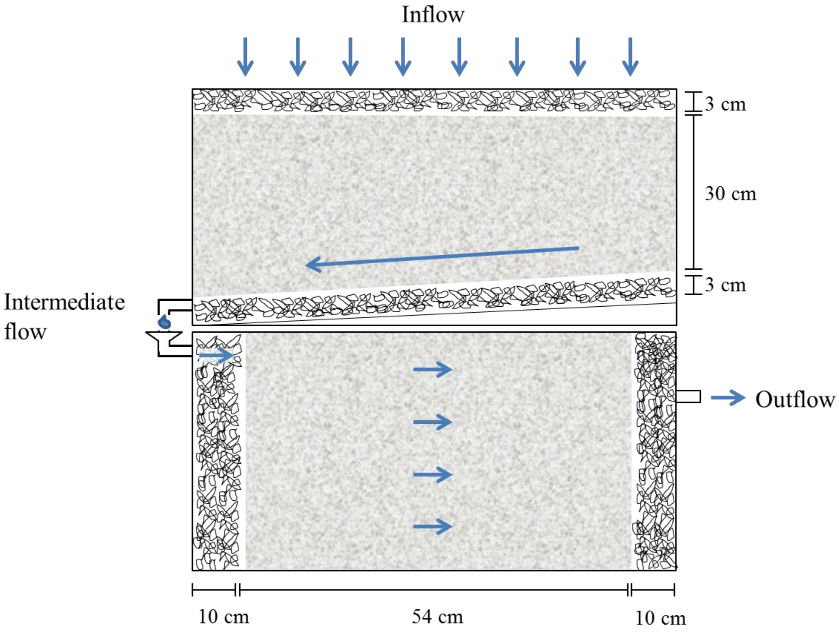


Figure 2 Combined aerobic vertical flow and anaerobic horizontal flow biochar filter unit for wastewater nitrogen removal. The material in the filter was biochar made from hardwood biomass.

Samples were taken from the inflow, intermediate flow and outflow of the filter once a week and N transformation and concentration was measured as Tot-N, NH_4-N and NO_3-N. Even though N was the main investigation objective for this filter P concentrations were also analyzed as Tot-P and PO_4-P. COD concentrations were also analyzed and all analysis was made according to methods given in Table 2. Removal efficiency was calculated according to Equation 10.

3. RESULTS

3.1 BATCH ADSORPTION EXPERIMENT

The mean concentration of P in all solutions (C1 – C5) of the batch adsorption experiment decreased with time for all biochars, except for PBC in C1, where the mean PO_4-P concentrations fluctuated with time and was higher than at start after 24 hours of shaking (Table 3 & Table 10-AI).

The untreated biochar showed low adsorption in the concentration range 0.5 - 13 mg/L (C1-C4) and it was never tested for the highest concentration (26 mg P/L, i.e. C5). The achieved PO_4-P reductions were 16 ± 3 (mean ± standard deviation; n=3) % for UBC, 80 ± 24 % for CBC, 63 ± 22 % for FBC and 50 ± 52 % for PBC after 24 hours of shaking.

Table 3 The average PO_4-P concentrations from shaking experiment where 1 g of untreated biochar (UBC), CaO biochar (CBC), $FeCl_3$ biochar (FBC) and Polonite biochar (PBC) were shaken in five P concentrations C1 – C5 (mg/L) for 24 h.

Biochar	**Time**	**C1**	**C2**	**C3**	**C4**	**C5**
UBC	t_0 (0min)	0.57	3.26	5.87	12.77	X
	t_1 (15min)	0.49	3.25	6.53	12.77	X
	t_2 (1h 15min)	0.53	2.65	5.30	11.59	X
	t_3 (4 h)	0.51	2.90	4.90	10.77	X
	t_4 (24 h)	0.48	2.57	5.00	10.82	X
CBC	t_0 (0min)	0.57	3.48	6.43	13.00	26.30
	t_1 (15min)	0.45	1.27	1.93	8.17	21.80
	t_2 (1h 15min)	0.32	0.48	0.44	1.18	8.66
	t_3 (4 h)	0.33	0.40	0.40	0.81	1.95
	t_4 (24 h)	0.32	0.42	0.50	0.63	0.66
FBC	t_0 (0min)	0.51	3.38	6.72	12.67	25.85
	t_1 (15min)	0.70	2.77	3.78	10.93	23.30
	t_2 (1h 15min)	0.67	2.18	3.07	8.68	20.68
	t_3 (4 h)	0.55	1.75	3.20	6.49	16.79
	t_4 (24 h)	0.36	0.81	1.78	3.52	9.91
PBC	t_0 (0min)	0.46	3.51	6.27	13.07	25.95
	t_1 (15min)	0.67	1.44	2.68	10.37	24.85
	t_2 (1h 15min)	0.49	0.52	0.98	4.82	21.87
	t_3 (4 h)	0.47	0.58	1.10	3.84	16.65
	t_4 (24 h)	0.59	0.74	1.58	3.59	11.06

At the end of the 24 h shaking period the UBC, FBC and PBC biochars were still intact but CBC had disintegrated into fine particles more noticeable than the other biochar types. Beakers with CBC got a red-brown and FBC yellow color while UBC and PBC stayed uncolored.

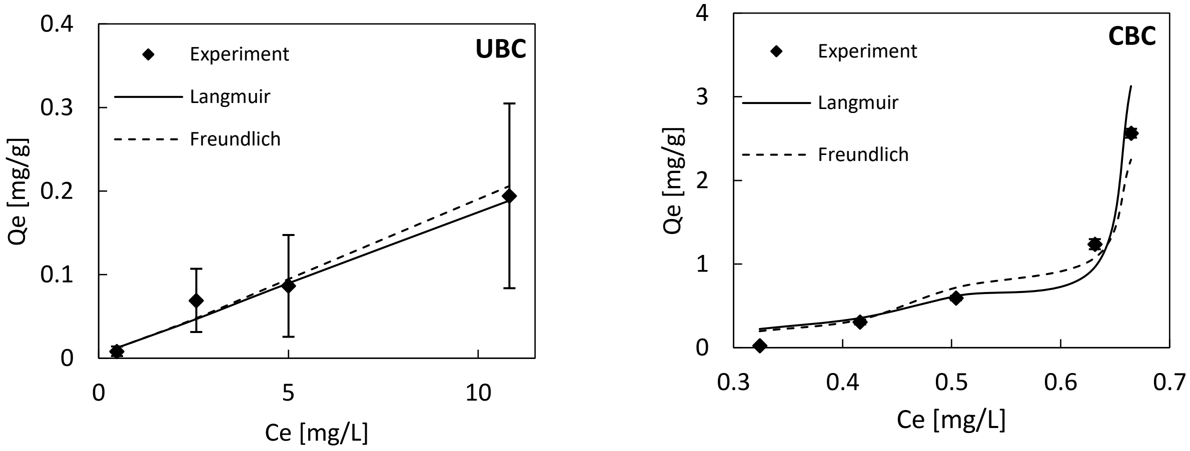
The pH in the PO_4 solution at the start of the shaking (t_0) was 7.0, but it changed with time (Table 4). In the flasks with UBC, CBC and PBC, pH increased to 7.5, 8.5 and 8.8 while the solution with FBC's pH was lowered to 3.0.

Table 4 Mean pH in the different solution concentrations during the batch adsorption experiment for untreated biochar (UBC), calcium oxide impregnated biochar (CBC), ferric chloride impregnated biochar (FBC) and untreated biochar mixed with Polonite (PBC).

Time	UBC	CBC	FBC	PBC
t_0 (0min)	7.0	7.0	7.0	7.0
t_1 (15min)	x	8.7	4.7	9.2
t_2 (1h 15min)	7.0	9.0	4.5	9.5
t_3 (4 h)	7.3	8.8	4.3	9.3
t_4 (24 h)	7.5	8.5	3.0	8.8

3.1.1 Adsorption isotherm

All adsorption isotherm curves show that increasing equilibrium concentrations (C_e) gave an increase in P adsorbed on the surface (Q_e) (Figure 3). The UBC isotherm showed linear behavior, where an increase in concentration (C_e) gave a constant increase in the P concentration on the biochar surface (Q_e). However, the standard deviations of the replicates were high and hence observed trends can only be considered indicative as error bars overlapped to a large extent. Adsorption isotherm curves for FBC and PBC were linear in lower concentrations but at higher equilibrium concentrations, Q_e increased less. CBC showed the opposite with a small increase of Q_e in lower concentrations but higher Q_e when the concentration became higher.



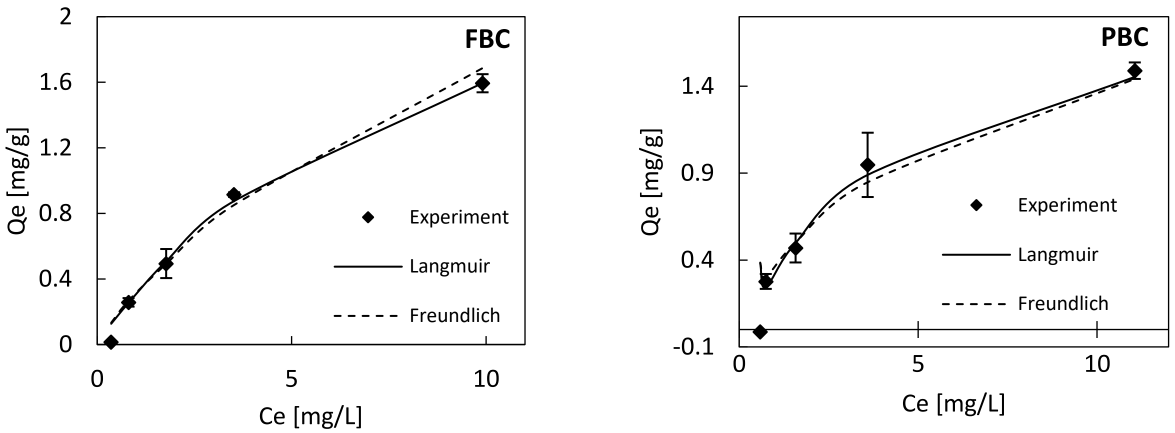


Figure 3 Relation between the concentration of P in the solutions from the batch adsorption experiment at the end of the shaking experiment (C_e) and the concentration of P adsorbed on to the biochar (Qe). Diamond symbols represent measured mean ± standard deviation, n=3.The Langmuir and Freundlish adsorption isotherm models calculated from the data are expressed as solid or dashed lines, respectively. This was done for untreated biochar (UBC), CaO impregnated biochar (CBC), $FeCl_3$ impregnated biochar and untreated biochar mixed with Polonite (PBC) was shaken in initial P solutions of 0.5-26 mg/L.

The correlation coefficients (R^2) were in the range of 0.957 - 0.997 for Langmuir isotherm and 0.960 - 0.993 for Freundlich isotherm for the adsorption of PO_4-P to the biochar types (Table 5). The Langmuir had a higher correlation for UBC and FBC and Freundlich for CBC and PBC. The parameters were calculated from liner plots of the two equations as presented in Figure 11-A2 & Figure 12-A2. FBC had the highest maximum adsorption capacity (Q_m) according the Langmuir (3.21 ± 0.01 mg/g) while Q_m for CBC was negative. CBC also had a negative mean Langmuir adsorption constant k_F. PBC had the highest k_F but also a high standard deviation of 0.21 ± 0.17 L/mg.

Table 5 Model parameters (mean ± standard deviation, n=3) for the Langmuir equation and Freundlich equation calculated from linear plots presented in Figure 11 & Figure 12-A2 for untreated biochar (UBC), CaO impregnated biochar (CBC), $FeCl_3$ impregnated biochar and untreated biochar mixed with Polonite (PBC). A higher R^2 value means a better fit.

Material	**Langmuir model parameters**			**Freundlich model parameters**		
	Q_m (mg/g)	**k_L** (L/mg)	**R^2**	**n**	**k_F** (L/g)	**R^2**
UBC	1.53±2.4	0.004±0.04	0.973±0.48	0.98±0.12	0.02±0.01	0.964±0.17
CBC	-0.41±0.19	-1.18±0.33	0.975±0.48	0.34±0.14	9.04±8.50	0.997±0.49
FBC	3.21±0.01	0.11±0.01	0.997±0.09	1.29±0.13	0.32±0.02	0.993±0.49
PBC	2.42±0.47	0.21±0.17	0.957±0.27	1.68±0.36	0.40±0.13	0.959±0.47

3.1.2 Kinetic isotherms

The UBC reached equilibrium adsorption (Q_e) after 3 hours in all PO_4-P concentrations tested for (Figure 4) with Q_e varying between 0.05 and 0.2 mg/g. This was lower than for the other biochar types. The Q is said to have reached equilibrium when the curve stops increasing and is then named Q_e. The adsorption rate for FBC was faster during the first three hours (240 min) and then slowed down. FBC did however not reach adsorption equilibrium Q in any of the concentrations C2 - C5. PBC reached a stable Q in C2, C3 and C4 but in C5 the biochar never reached equilibrium displaying a final adsorption of around 1.5 mg/g. The CBC reached stable adsorption capacities of 0.3, 0.6 and 1.2 mg/g after 1 hour in C2, C3 and C4 and these were higher than the other biochar types at corresponding concentrations. In C5 the equilibrium occurred first after 3 hours and was around 2.5 mg/g.

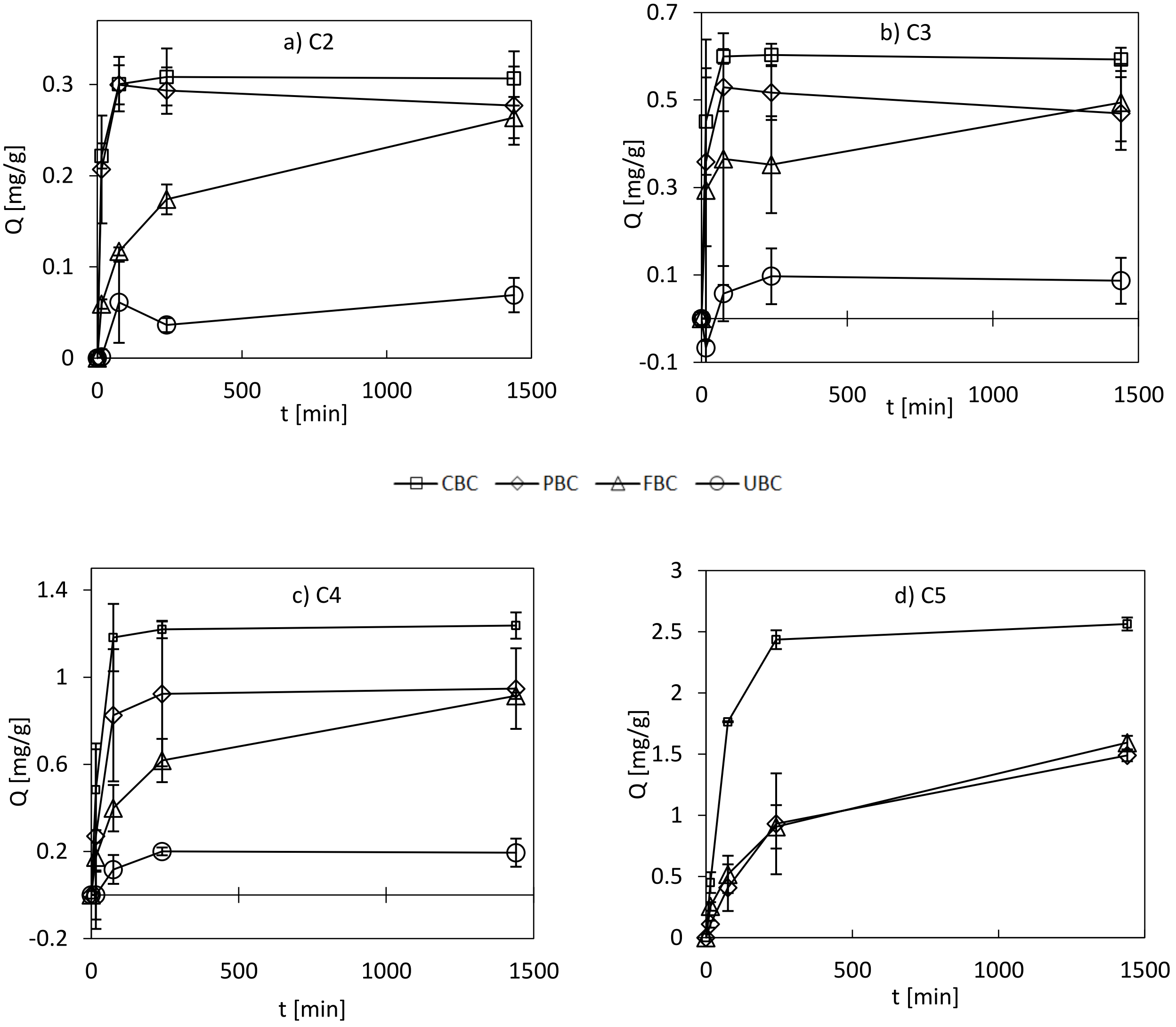


Figure 4 Adsorption of P (Q) onto four biochar types at four P solution concentrations, **a)** 3.3 mg P/L (C2) **b)** 6.5 mg P/L (C3) **c)** 13 mgP/L (C4) and **d)** 26 mg P/L (C5) over 24 hours. Symbols are mean values and error bars the standard deviation.

Higher adsorption capacities were achieved at higher P concentrations for CBC, FBC and PBC (Figure 5). Even if some biochars did not reach equilibrium, their final Q is presented as their equilibrium adsorption Q_e in Figure 5. UBC had the least amount adsorbed P per gram biochar, with around 0.07 - 0.2 mg/g for all concentrations. FBC and PBC displayed similar equilibrium adsorptions of 0.2 and 0.26 mg/g for C2, 0.49 and 0.46 mg/g for C3, 0.91 and 0.95 for C4 and 1.6 and 1.5 mg/g in C5. CBC had the highest equilibrium adsorption in all concentrations with around 0.3 mg/g in C2, 0.6 mg/g in C3, 1.2 mg/g in C4 and 2.6 mg/g in C5. At higher concentrations the gap to the other biochars became wider.

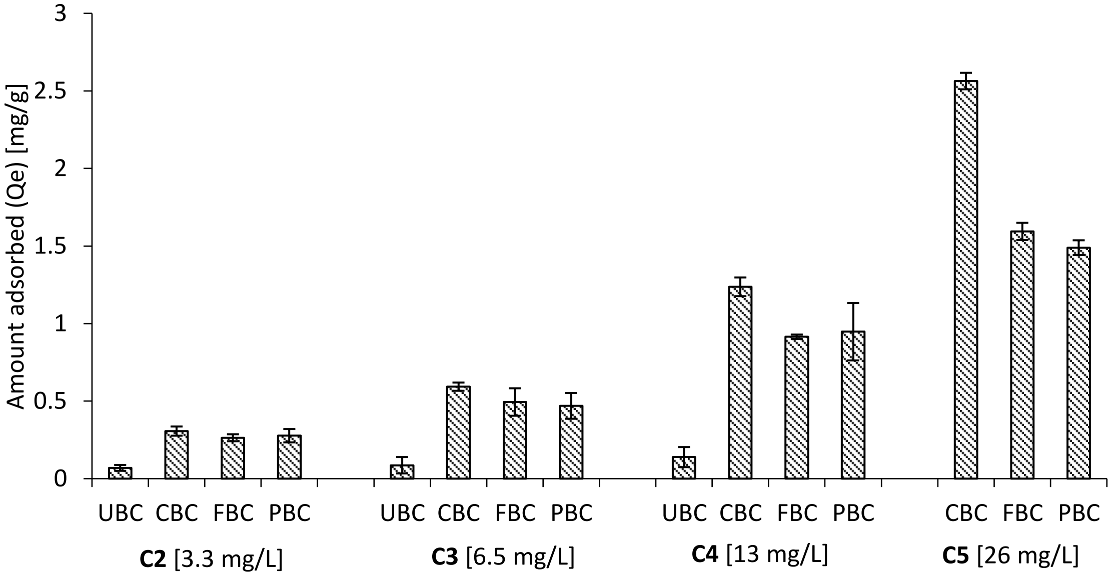


Figure 5 Amount P adsorbed in mg per g biochar after 24 hours of shaking four different biochar types in solutions of 3.3 (C2), 6.5 (C3), 13 (C4) and 26 (C5) mg PO_4^{3-}-P/L. Error bars are mean values ± standard deviations, n =3.

The pseudo 2nd order model had higher R^2 values (0.9102 - 0.9999) than the 1st order model (0.7785 - 0.997) for all biochar types shaken in the PO_4-P concentration 3.3 mg/L (Table 6). This difference was also the case for all other concentrations except for PBC shaken in C5 (26 mg/L) Table 11-A3. Kinetic model parameters for all concentrations and biochars and the linear plots providing the parameters can be found in Table 11-A3 and Figure 13-A3. The Q_e calculated for the 2nd order models were all close to the experimental Q_e. The k_1 value was highest for PBC, 0.097 ± 0.01 min^{-1} and lowest for UBC and PBC, 0.004 min^{-1}. CBC had the highest k_2 at 1.717 ± 1.13 L/mg.

Table 6 Pseudo 1st and pseudo 2nd order model parameters and the experimental value of equilibrium adsorption (Qe) from batch adsorption experiment where four different types of biochar were shaken in 3.3 mg P/L (C2). All parameters are presented as mean ± standard deviation, n=3 and they were calculated by linearization of pseudo 1st and pseudo 2nd order kinetic models (Figure 13-A3).

Material	**Pseudo first order model**			**Pseudo second order model**			**Experimental**
	$\mathbf{Q_e}$ [mg/g]	$\mathbf{R^2}$	$\mathbf{k_1}$ [min^{-1}]	$\mathbf{Q_e}$ [mg/g]	$\mathbf{R^2}$	$\mathbf{k_2}$ [L/mg]	$\mathbf{Q_e}$ [mg/g]
UBC	0.064±0.03	0.779±0.26	0.004±0.02	0.068±0.02	0.911±0.081	-0.021±0.37	0.069±0.01
CBC	0.156±0.09	0.836±0.14	0.028±0.02	0.307±0.03	0.999±0.0001	1.717±1.13	0.307±0.03
FBC	0.229±0.03	0.919±0.07	0.004±0.00	0.281±0.03	0.997±0.002	0.036±0.01	0.264±0.02
PBC	0.266±0.04	0.997±0.01	0.097±0.05	0.264±0.04	0.999±0.001	-0.499±1.35	0.277±0.04

3.2 COLUMN FILTERS

The concentration of the Tot-P in the influent to the column filters fluctuated between 2.3 and 6.2 mg/L during the experimental period (Figure 6a), with a mean of 3.84 ± 1.14 mg/L (Table 7). The Tot-P concentrations in all effluents were around or below 1 mg/L during the 5 first weeks of the experiment. After week 5 the concentrations in UBC and PBC gradually increased and reached stable effluent concentrations after week 10 of about 2.6 ± 0.1 and 1.5 ± 0.1 mg/L, respectively. Effluent concentrations of CBC and FBC started above 0.5 mg/L but after week 4 they decreased and remained below < 0.5 mg/L until the end of the experiment. The removal efficiencies of UBC and PBC fluctuated and decreased from about 60 and 80 % initially to around 20 and 55 % after week 10. The removal of Tot-P in CBC and FBC filters increased early in the experiment and then remained high at around 90 % (Figure 6b).

During the whole experiment the UBC and PBC filters had higher mean Tot-P effluent concentrations (2.09 ± 0.74 and 1.25 ± 0.37 mg/L) and lower removal efficiencies (43 ± 24 and 65 ± 14 %) compared to the CBC and PBC filters (Table 7). In contrast CBC and FBC had low outflowing concentration of Tot-P (0.37 ± 0.27 and 0.30 ± 0.18 mg/L) and displayed high removal efficiency (90 ± 8 and 92 ± 4 %).

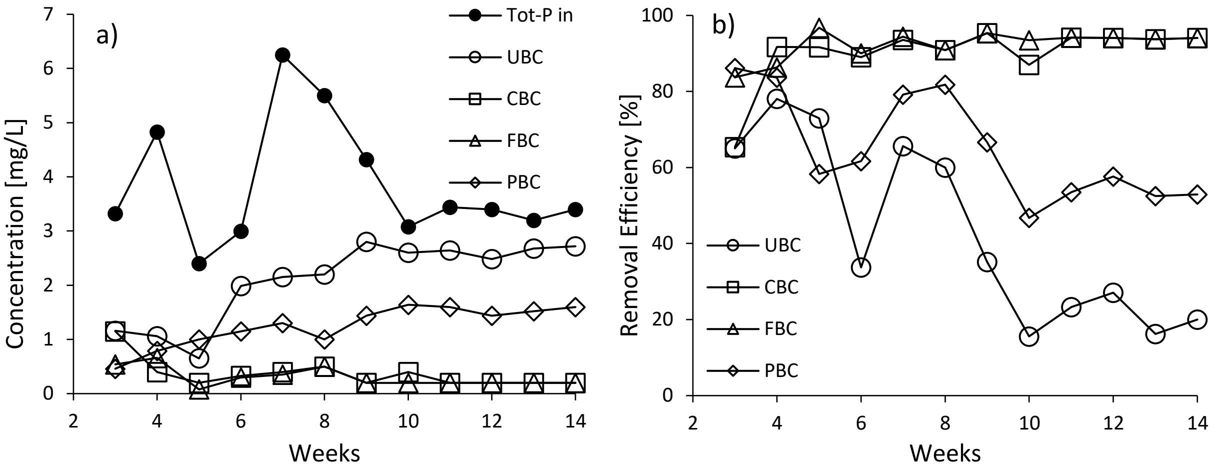


Figure 6 a) The Tot-P concentrations in the influent and in the effluent and **b)** the removal efficiency of the untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC).

The PO_4-P concentration were lower than the Tot-P concentrations and varied in the influent between 1.5 and 5.2 mg/L throughout the experiment with a mean value of 3.18 ± 1.04 mg/L (Figure 7). The concentration and removal efficiency of PO_4-P showed a similar trend to Tot-P. CBC and FBC did however display a higher removal of PO_4-P than Tot-P while UBC and PBC had higher removal efficiency of Tot-P than PO_4-P.

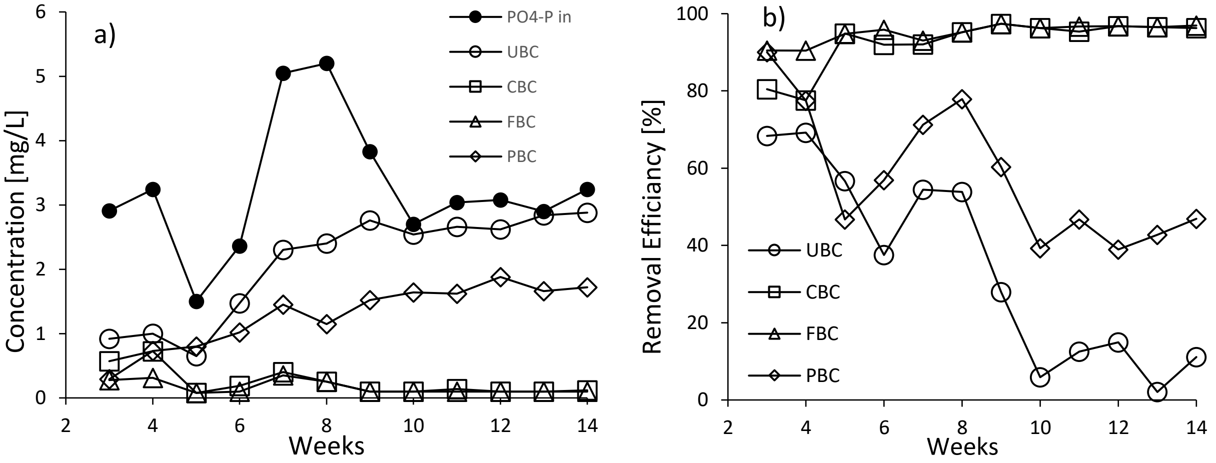


Figure 7 a) The PO_4-P concentrations in the inflow and in the outflow from four different biochar filters and **b)** corresponding PO_4-P removal efficiencies. Untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC).

The COD analysis showed that UBC removed 36 ± 22% of the COD and PBC removed 30 ± 30 %. No clear trend could be red from those data points taken once every second week and the standard deviations were high (Table 7). In average the CBC and FBC had a higher concentration of COD in the effluent than in the influent, resulting in negative removal efficiencies -122 ± 186 % and -100 ± 141 %.

The pH varied in filter effluents. The influent to the filters was neutral with pH 7.1 ± 0.4. The UBC filter effluent was just below neutral (pH 6.7 ± 0.5) while effluents from CBC and PBC discharged an effluent with higher pH (7.8 ± 0.4). The largest pH change was observed for FBC which had an average effluent pH of 2.6 ± 0.9 over the experimental period (Table 7).

The appearance of the effluent from the filters differed from each other and changed over time. Initially the UBC and PBC effluents were turbid and greyish. The CBC effluent had a red-brown color and the FBC effluent was yellow, both turbid. Over time the color and turbidity of UBC, PBC and FBC disappeared but CBC kept its red-brown color. On the surface of the effluent beaker of CBC a precipitate formed and kept forming during the whole experiment**.**

Table 7 The influent and effluent mean concentration (Conc) ± standard deviation and corresponding removal efficiencies (E) of Tot-P, PO_4-P, COD and pH for the untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC).

Type of water	**Tot-P**		**PO_4-P**		**COD**		**pH**
	Conc (mg/L)	**E** (%)	**Conc** (mg/L)	**E** (%)	**Conc** (mg/L)	**E** (%)	
Influent	3.84±1.14	-	3.18±1.04	-	320.8±116.4	-	7.1±0.4
UBC	2.09±0.74	43±24	2.09±0.83	32±25	206.2±113.5	36±22	6.7±0.5
CBC	0.37±0.27	90±8	0.24±0.21	93±7	710.6±480.6	-122±186	7.8±0.4
FBC	0.30±0.18	92±4	0.16±0.10	95±2	641.0±453.5	-100±141	2.6±0.9
PBC	1.25±0.37	65±14	1.29±0.49	58±17	223.4±116.7	30±30	7.8±0.7

The influent Tot-P and PO_4-P displayed a relatively wide variation in concentrations which was also the case for the effluent from the untreated biochar filter (UBC) (Figure 8). Concentrations in the effluent of the PBC filter also fluctuated but varied less than that of the UBC. In contrast CBC and FBC effluent concentrations were low and did not vary much during the experiment.

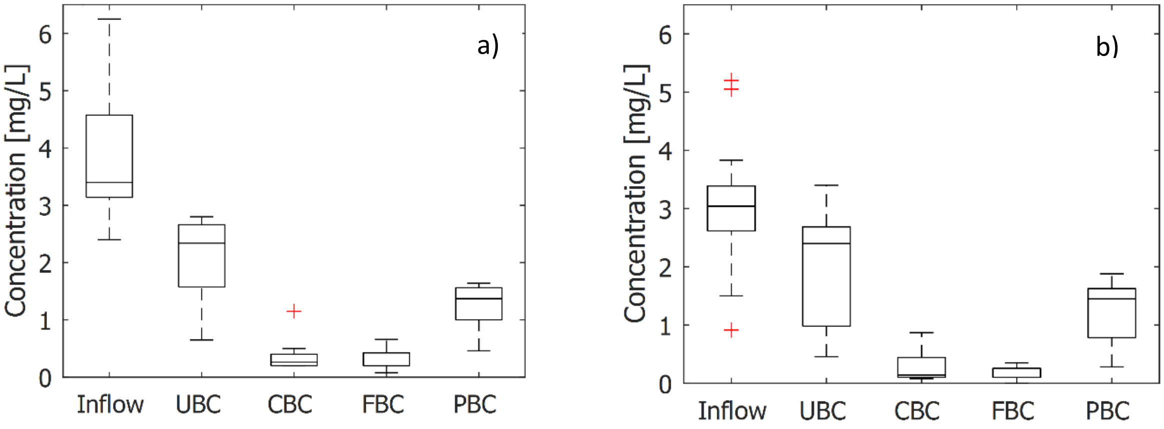


Figure 8 Boxplots of the **a)** Tot-P concentrations and **b)** the PO_4-P concentrations of the untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC). The box is the quartiles of the data set and the medians are shown as a straight line in the box. Max and min values are the whiskers and outliers are shown as red crosses.

3.3 NITROGEN REMOVAL FILTER

The mean concentration of Tot-N in the influent to the vertical aerobic section of the N removal filter was 39.54 ± 8.26 mg/L (Table 8). After the vertical section the effluent concentration of Tot-N had dropped to 21.23 ± 3.36 mg/L. The reduction of Tot-N was stable at around 40 % between week 8 and 14 of the experiment (Figure 9a), resulting in an average removal rate of 42 ± 10 % (Table 8). The influent concentration of Tot-P to the vertical section was stable at 4.62 ± 0.54 mg/L between week 9 and week 14 of the experiment (Table 8). The Tot-P was on average removed by 13 ± 23 % leading to mean concentration in the effluent wastewater of 3.98 ± 0.95 mg/L. The removal of Tot-P in the vertical section was not stable and low points occurred in week 8 and 14 (Figure 9a).

The effluent water from the vertical section became the influent water to the horizontal anaerobic section (Figure 2). The concentration of Tot-N decreased from 21.23 ± 3.36 mg/L in the influent to 12.90 ± 1.45 mg/L in the effluent (Table 8). This corresponded to a reduction of Tot-N of 35 ± 16 %, which was lower than in the vertical section. The Tot-P in the influent to the horizontal filter section, 3.98 ± 0.95 mg/L, decreased to 3.30 ± 0.60 in the effluent. In average, 14 ± 25 % of the Tot-P was removed. Removal rates of Tot-P fluctuated between removal and release during the experiment (Figure 9b).

Together, the two sections removed 62 ± 16 % of Tot-N and 29 ± 8 % of Tot-P during the experiment (Table 8). In week 8, Tot-P concentrations in the effluent was higher than in the influent for both the vertical and horizontal sections (Figure 9a & b). This resulted in large negative removal rates for the total filter during week 8 (Figure 9c). This is why the P results are presented only from week 9 in Table 8.

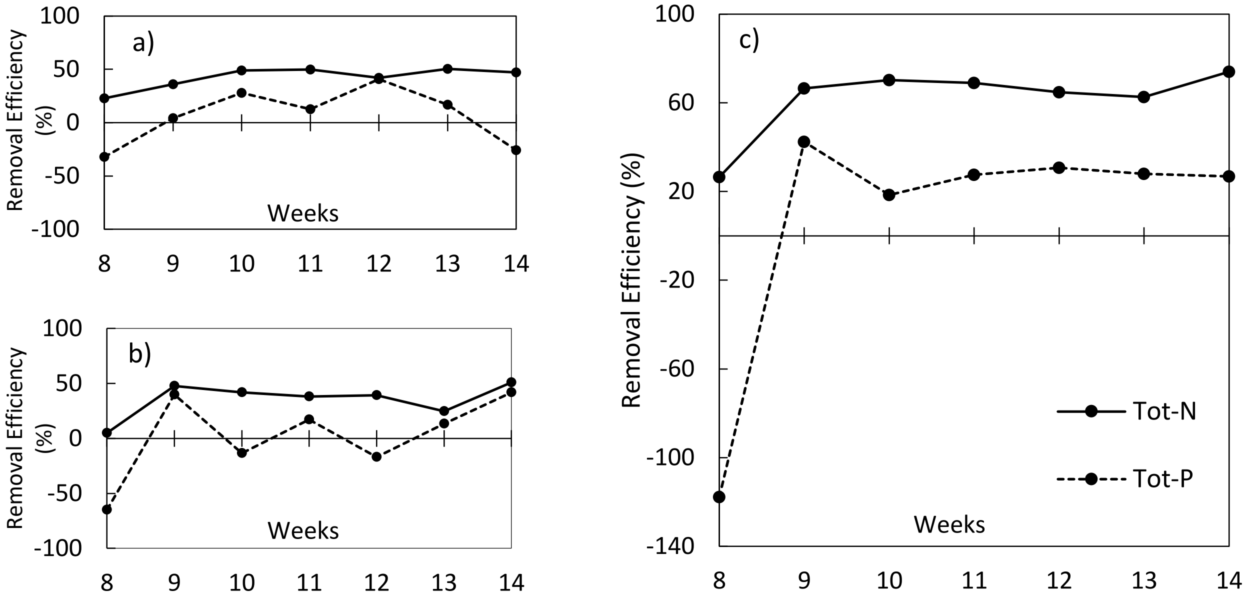


Figure 9 The removal efficiencies of Tot-N and Tot-P in % from **a)** the vertical aerobic section, **b)** the horizontal saturated section and **c)** total nitrogen removal of a two-section biochar filter.

NH_4-N and NO_3-N was also analyzed in the influents and effluents to the vertical and horizontal sections. NH_4-N in the influent to the vertical filter had a higher average concentration than Tot-N (Table 8). It was also clear that NO_3-N concentration increased from 1.60 ± 0.35 mg/L to 6.91 ± 2.23 mg/L while passing the vertical section and thereafter decreased in the horizontal section. The formation of NO_3-N in the vertical section increased between week 8 and 14. This is presented in Figure 14-A4, where the complete dynamics of the N is presented. pH decreased slightly in the whole filter and the two sections removed COD equally well, 30 ± 23 and 30 ± 36 %, respectively. Average removal efficiency of COD was 45 ± 68 % for the entire filter.

Table 8 The average removal efficiencies (%) and concentrations (mg/L) ± standard deviation for all for pollutants measured in the N removal filter. The filter had an aerobic vertical flow section followed by an anaerobic horizontal flow section.

Pollutant	**Concertration (mg/L)**			**Removal efficiency (%)**		
	Inflow	**Vertical section effluent**	**Horizontal section effluent**	**Vertical section**	**Horizontal flow section**	**Total Removal efficiency**
pH	7.1±0.1	6.7±0.4	6.8±0.4			
Tot-N	39.54±8.26	21.23±3.36	12.90±1.45	42±10	35±16	62±16
Tot-P*	4.62±0.54	3.98±0.95	3.30±0.60	13±23	14±25	29±8
NH_4-N	42.67±8.55	14.67±2.66	11.00±1.10	65±8	23±17	74±5
NO_3-N	1.60±0.35	6.91±2.23	2.66±0.98	-341±131	58±23	-64±53
PO_4-P*	4.05±0.74	3.79±0.96	2.97±0.56	3±29	19±23	27±10
COD	286.20±116.35	197.80±100.52	152.00±96.43	30±23	30±36	45±68

* Means calculated from week 9

The N removal filter recived wastewater with a verying Tot-N and NH_4-N concentration and more N was removed in the first section than in the second. However, the concentrations in the effluent had smaller variation (Figure 10). The NO_3-N concentration in the intermediate flow varied more than the NO_3-N concentrations in inflow and outflow of the filter. The Tot-P and PO_4-P concentrations in inflow and intermediate flow had a similar variation. The Tot-P concentrations in the outflow was however less varied than the PO_4-P concentraions. COD concentration data had the largest variation of all analyzed pollutants.

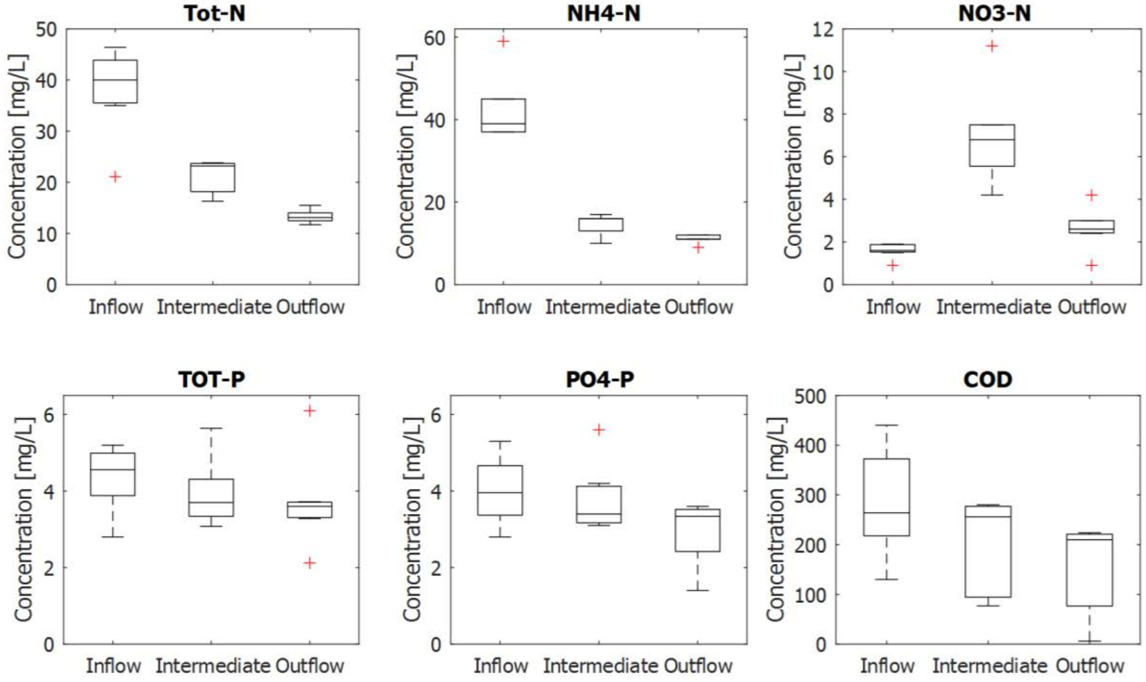


Figure 10 Boxplots showing the change of N and P concentration in the the inflow, intermediate flowand outflow of a two-step biochar filter. The first section of the filter was aerobic and had vertical flow and the second section had horizontal saturated flow.The box is the quartiles with horizontal line in the box showing the median. Max and min values are the whiskers and outliers are presented as red crosses

4. DISCUSSION

4.1 BATCH ADSOPTION EXPERIMENT

In the batch adsorption experiment, four biochar types were shaken with solutions of five different PO_4-P concentrations. CBC had the best P adsorption capacity. PBC and FBC both had a lower but similar adsorption while untreated biochar (UBC) adsorbed the least P. The shape of the adsorption isotherm for CBC (Figure 3) shows that when the equilibrium concentrations are low the increase in equilibrium adsorption was also low. This could indicate dissolved organic compounds being involved in the adsorption at low concentrations (Essington, 2004). The Freundlich model best fitted the PO_4-P adsorption to CBC and PBC biochars which means that the adsorption to these materials was best described as non-uniform. Adsorption to FBC biochar correlated better with the Langmuir adsorption model which indicates that their adsorption can be modeled as homogenous and in a monolayer over the biochar surface. This is in agreement with Li at al. (2016) who found that P removal using wheat straw biochar impregnated with $FeCl_3$ fitted the Langmuir model well. Contrastingly, Chen et al. (2011) reported that P adsorption by untreated and magnetite coated biochar made from orange peel fitted the Freundlich model better. The large standard deviation of the P adsorption on UBC makes it difficult to compare it to the equation models (Figure 3).

The Langmuir adsorption constant k_F was higher for adsorption on PBC than for the other biochar types. This indicates that the affinity between P and PBC was the highest. The Langmuir maximum adsorption Q_m for CBC was negative which is not realistic indicating that this model was not suitable for describing adsorption on CBC (Table 5). FBC had the highest Q_m at 3.2 mg/g but this is still lower than that reported by Liu et al. (2015) who demonstrated an adsorption capacity of 16.58 mg/g for a Fe impregnated biochar made from wheat straw. The biochar in the study by Li et al. (2016) had a smaller diameter than the biochar in this experiment (< 1 mm *vs* 1 - 7 mm) and higher iron to biochar ratio, 0.7 *vs* 0.3, which can explain the difference.

Looking at the Q_e for the kinetic adsorption experiment it is clear that the CBC had the highest equilibrium adsorption at all concentrations tested (Figure 5). In C2 (3.3 mgP/L), i.e. the concentration closest to the average influent wastewater concentration of PO_4-P in the column filters, CBC had the highest Q_e of 0.3 ± 0.03 mg/g after 24 h of shaking. Jung et al. (2016) received a Q_e of 100 mg/g on their Ca modified biochar in a batch sorption experiment. However, the concentration in the experiment by Jung et al. (2016) was 326 mg/L PO_4-P, which makes it inappropriate to compare between the experiments since the concentrations in this study were lower. The higher concentration of P in the solution the more obvious difference between the adsorption characteristics of the different biochar types could be seen (Figure 5). Twenty-four hours was not enough for the FBC biochar to reach an equilibrium adsorption (Figure 4) which means that the Q_e for FBC of 0.264 ± 0.02 mg/g in C2 would most likely be higher and even pass that of PBC (0.277 ± 0.04 mg/g) if longer time would have been given. Alternatively, it could have continued and never reached equilibrium due to a continuous formation of complexes as discussed by Essington (2004). The pseudo second order model was the better fit compared to pseudo first for most biochar types and concentrations (Table 6). This means that the adsorption can be assumed to be mainly chemical as suggested by Ho & McKay (1999 & 1998). The calculated Q_e from the pseudo second order equation was close to the experimental Q_e which implies the accuracy of the model. In previous studies, the second order kinetic model was proven to be the best model for describing P adsorption on magnesium modified biochar. However, $FeCl_3$ modified biochar has shown a better fit for the pseudo first order model by Zhang et al. (2013).

Adsorption and kinetic isotherms behave very different for different types of materials and chemicals, hence, results are difficult to compare. Experimental conditions like beaker size, material properties and preparation, temperature, reaction time etc. have a large influence on the results and these conditions are rarely the same in different studies. Therefore, batch adsorptions experiments are more suitable in comparing adsorption characteristics between materials in the same study (Essington, 2004).

4.2 COLUMN FILTER EXPERIMNET

The inflowing PO_4-P and Tot-P concentrations to the column filters varied considerably as can be seen in Figure 7 and Figure 6 and also in the box plot in Figure 8. The concentration probably varied because the quality of the wastewater from the WWTP differs between days and even changes during the day. These variations can also explain why the average concentration of the inflowing Tot-P, 3.84 mg/L (Table 7) was lower than yearly average of 6 mg/L for WWTP (Kungsängsverket, 2016).

The untreated biochar (UBC) filter had the smallest removal efficiency of Tot-P (43 ± 24 %) of all filters (Table 7). This is lower than what could be expected from a fully functioning vertical soil filter having an estimated Tot-P removal of 70 ± 20 % (Olshammar et al., 2015). The Tot-P reduction in UBC was also in the lower range of what have been shown possible (32 - 89 %) in other filters using untreated biochar (Table 9) (Dalahmeh, 2016). PBC had an average removal of 65 ± 14 % of Tot-P which is comparable of what could be expected from vertical soil filters and also of previously studied biochars. P concentration in the effluent of the UBC and PBC filters continued to increase during the experiment but seemed to become stabilized towards the end. It is difficult to recognize if they would have continued to decrease in efficiency given longer time. The Tot-P removal in CBC and FBC were 90 ± 8 % and 92 ± 4 % respectively and their PO_4-P removal rates were even higher. This is similar to previous batch adsorption studies where Fe modified biochar has been shown to remove of up to 99 % of P (Chen et al., 2011; Liu et al., 2015).

When comparing the Tot-P and PO_4-P removal, both UBC and Polonite biochar removed more Tot-P than PO_4-P (Table 7). The CBC and FBC showed the opposite trend. This means that UBC and PBC removed organic P better while CBC and FBC were more efficient in removing inorganic P. The impregnation in CBC and FBC probably created different surface structures compared to UBC and PBC. PBC should have similar surface to that of UBC since they had the same untreated biochar, which possibly could explain the grouping in the two Tot-P and PO_4-P characteristics.

The initial yellow color of the FBC filter effluent, also seen in the shaking solutions from the batch adsorption experiment, can most likely be explained by $FeCl_3$ treatment that carries a yellow color when dissolved in water. $FeCl_3$ also lowers the pH which can explain the drop in pH seen in the effluent water from the filter and in the PO_4-P solution of the batch adsorption experiment. An average pH of 2.6 ± 0.9 from the FBC filter effluent (Table 7) most likely created unfavorable environment for nitrifying and denitrifying bacteria which must be considered undesirable for wastewater treatment even if low pH favors precipitation reactions between P and iron (US EPA 2002). In contrast, CaO and Polonite increase the pH in aqueous solutions which explains the pH increase in the beakers during the batch sorption experiment (Table 4). The red-brown color of the CBC effluent probably originated from the mother material – willow tree bark. Water that is filtered through bark receives a red-brown color due to the release of organic acids (Dalahmeh et al., 2012). If the color comes from the bark it indicates that the pyrolysis of the biochar was never fully completed as the biochar itself would not release any color. Organic acids present in bark would lower the pH, meaning that the pH might have been even higher in the CBC effluent if the pyrolysis had been complete. Presence of organic acids can explain the shape of CBCs adsorption isotherm and can also be an explanation to the high COD content in the CBC effluent. Ca and Fe ions were most likely released from the CBC and FBC filter materials to the effluents which possibly could explain their high COD contents as calcium and iron compounds can be chemically oxidized in the analysis procedure. To investigate the removal of organic matter it would have been more appropriate to measure biochemical oxygen demand (BOD) or total organic carbon (TOC). TOC sampling occurred but lack of proper equipment and time stopped the analysis. Ca and Fe ions are not likely to affect the COD of PBC and UBC filter effluents to the same extent, yet these filters had lower COD removal rates (36 and 22 %, respectively) than shown in most previous biochar studies (90 %) as reported in Table 9 (Dalahmeh, 2016).

Another problem except for the color of the CBC effluent was the precipitate adding to the effluent beaker surface. It is likely that the precipitate is some calcium phosphate mineral which might lead to problems with clogging in the long run in a full-scale system.

4.3 NITROGEN REMOVAL FILTER

The two sections of the N removal filter removed 62 ± 16 % of the influent N (Figure 9 & Table 9). This was higher than conventional vertical soil filers where removal rates of 30 ± 10 % can be expected (Olshammar et al., 2015) and also higher than alternative OWTP solutions in general (Avloppsguiden, 2009) (Tabel 9). The average total N concentration was lower than that of NH_4-N in the influent which is not realistic. This is likely due to error in analysis during week 11, 12 and 13 (Figure 14c-A4). The increase in NO_3-N concentration in the first and decrease in the second section show that nitrification and denitrification took place (Figure 9a & b). However it was not until the end of the experiment the nitrate removal was high enough to remove almost of the NO_3-N created in the vertical section. The average outflow concentration from the horizontal filer was 2.66 ± 0.98 mg/L. It is likely that the NO_3-N and Tot-N removal capacity would have continued to increase as the biofilm in the filter continued to grow and mature. The P removal in the N removal filter was 29 ± 8 % which was lower than the removal rate observed for UBC in the column experiment and what can be expected from vertical soil filers (Table 9). The relocation of the filter in week 7 seemed to negatively affect the filter performance the following week. When moving the filter some of the water from the lower section had to be emptied and particles were released from the biochar. The disturbance of the microbial community in the biofilm and loose particles was probably the reason why P was released during week 8. After this the removal of Tot-P became more stable (Figure 9c). Moving the filter to the primary sedimentation also meant that the water entering the filter from week 8 was more turbid and contained more particles than before. This could explain why the overall COD removal was relatively low (45 ± 68 %) and varied more compared to vertical soil filters (80 ± 10 %) (Olshammar et al., 2015).

4.4 COMPARING BIOCHARS AND FILTERS

To compare adsorption of P in a batch sorption experiments to a real life systems can be misleading (Brix et al., 2001). Hedstöm (2006) argued that batch sorption experiments may overestimate the P sorption capacity because it is an ideal system with the material saturated in P solutions. Another aspect that was stressed was that biochar pieces can break during the experiment which increases the adsorption surface. Others claim that a shaking experiment severely underestimates the adsorption capacity because it does not take slow reactions of regenerated sorption sites into consideration (USEPA, 2002). In order to fully investigate materials adsorption, a combination between shaking studies and filter studies is recommended (Essington, 2004).

From the shaking experiment it was clear that the CBC had the highest adsorption of P (Table 10). This is in agreement with Seo et al. (2005) who in comparing Fe and Ca treated filter media found that Ca impregnation had the better P removal capacity. However, results from the filter experiment in the present study showed that the CBC is good but not better than FBC (Table 9). One explanation to this can be that the CBC biochar fragmented more than the other biochar types during the batch adsorption experiment. The risk of overestimating adsorption capacity as the biochar is breaking in a batch sorption experiment has been stressed by Hedström (2006). Also if the pyrolysis and impregnation of the CBC biochar was not complete as discussed above, loose CaO particles on the material surfaces might have overestimated the CBC adsorption. If the shaking experiment had been longer the FBC most likely would have reached a higher equilibrium adsorption and the difference in P adsorption capacity between CBC and FBC would have been smaller. It is also difficult to know how the CBC would perform if it had been produced differently.

Both the filter experiment and the batch adsorption experiment concordantly showed that PBC had a better P removal than UBC. The filter experiment showed that by mixing untreated biochar with Polonite, the Tot-P removal became 1.5 times higher compared to the mother material. Batch sorption experiment also showed that the PBC had three times higher P removal than UBC.

Table 9 Comparison between the results of pollutant removal (%) from filter experiments and literature for biochar filters Dalahmeh (2016)* and vertical soil filters Olshammar et al., (2015)** (mean ± standard deviation). The filter experiments comprised column with untreated biochar (UBC), biochar impregnated with calcium oxide (CBC) or ferric chloride (FBC) and untreated biochar mixed with Polonite (PBC). The N removal filter was constructed with a vertical unsaturated flow section followed by a vertical saturated flow section.

Chemical	**Results**					**Literature**	
	UBC	**CBC**	**FBC**	**PBC**	**N-Removal filter**	**Removal in Biochar Filters***	**Removal in Vertical Soil Filters ****
COD	36 ± 22	-122 ± 186	-100 ± 141	30 ± 30	45 ± 68	> 90	80 ± 10
Tot-P	43 ± 24	90 ± 8	92 ± 4	65 ± 14	29 ± 8	32 – 66	70 ± 20
Tot-N					62 ± 16	62 – 88	30 ± 10

A factor that affects the P and N removal is the volume and depth of the filters. The column filters were 50 cm tall which is similar to the 55 and 60 cm biochar filters compared with (Dalahmeh, 2016). The unsaturated filter section in the N removal filter was 30 cm deep which is smaller than the vertical soil filters (Olshammar et al., 2015). It is possible that a larger N removal filter might have had a better N removal.

If for instance the CBC or FBC would be used in real-scale filters the amount of filter material do not need to be high since the removal efficiency is high. It is possible that impregnated biochar in a filter would be more suitable as a separate P filter module connected to a larger system such as the N removal filter. To use the N filter in larger scale would require some planning on where to locate the filter. Alternately the unsaturated section or the whole filter system could be installed on top of a soil profile with a pump feeding the filter with wastewater from a septic tank.

4.4 POSSIBLE SUORCES OF EXPERIMENTAL ERROR

In the second week of the column experiment large hydrophobic (dry) areas in the column filters were observed and the filters were therefore washed with distilled water which enabled wastewater to flow through the entire filter volume. It could not be excluded that the washing could have removed some of the impregnation on FBC and CBC lowering their removal capacity.

The N removal filter was relocated due to interference of $FeCl_3$ on the N samples. After that the N removal filter had been relocated analysis results became more stable. However it is possible that some residual $FeCl_3$, used as P precipitation chemical, from the wastewater got adsorbed and stayed in the filter and further influenced the analysis. Initially, N parameters were also measured in the influent and effluent of the column filters. However, it soon became clear that ions and high COD from the filters themselves interfered with the kits for chemical analyses, giving unrealistic and highly fluctuating results. It was therefore decided to stop the N measurements in week 5 and to only present P data as the analysis kit for P was not as affected by high COD. In conclusion, there is a risk that some of the results in this report might be affected by intrinsic COD and ions from the filter materials. In future studies, when sampling water from impregnated filters, it is important to consider the potential problems the impregnation itself might cause on the analysis.

5. CONCLUSIONS

The batch adsorption and filter experiments in this study demonstrates that modification of biochar made from hard wood bark can improve phosphorus removal capacity. Especially modification by impregnation before pyrolysis can improve the phosphorus removal compared to unmodified biochar or biochar mixed with Polonite. These materials are promising replacements or additions to vertical soil filters.

The column filters with biochar impregnated with ferric chloride and calcium oxide showed phosphorus removal rates of 93 ± 7 % and 95 ± 2 % which was higher than untreated biochar and biochar mixed with Polonite which removed 32 ± 25 % and 58 ± 17 %, respectively.

The Freundlich adsorption model best fitted the P adsorption onto CaO impregnated and Polonite mixed biochar. Adsorption to untreated and $FeCl_3$ biochar correlated better with the Langmuir adsorption model. The adsorption over time for all biochar types was best described by pseudo 2^{nd} order kinetic model.

The effluent from ferric chloride impregnated biochar had low pH. The effluent from the calcium oxide impregnated biochar had some precipitation in it and a brown-red color and the biochar was probably not completely prepared. The low pH, color and precipitation can be a problem if the materials are to be used in full-scale treatment system.

Biochar filter consisting of a vertical flow aerobic section followed by a horizontal section with saturated flow reached a high total nitrogen removal rate of 62 ± 16 %, a removal rate higher than that of conventional vertical soil filters as well as most alternative onsite wastewater treatment systems.

5.1 SUGGESTIONS FOR FURTHER EXPERIMENTS

For further studies it would be interesting to see how impregnated biochar filters and N removal units will perform in a long-term column study. Improved filtration or sedimentation of the inflowing wastewater to the N removal filter would make a more realistic set up and possible better COD treatment. Clogging effects, not investigated in this study, and changes in flow patterns through the filters caused by clogging would be another important area to investigate in order to evaluate the life time of filter materials. It would be worth considering redoing the calcium oxide impregnation of the biochar to see if the observed color and precipitation effects would disappear. It would also be interesting to expose calcium oxide biochar to higher P concentration in a batch adsorption experiment to see if the adsorption isotherm will show signs of a decreasing equilibrium adsorption (Q_e). A longer batch adsorption experiment to investigate the $FeCl_3$ equilibrium adsorption would also be interesting.

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7. APPENDIX

APPENDIX I - Shaking experiment

All the data from the shaking experiment can be seen in Table 8. The concentrations in this table were then adjusted for the volume chance of the beakers when sampling took place. The mean concentrations adjusted for the volume change can be found in Table 3 in the Result section. The UBC did not get exposed or C5 because it showed little adsorption. CBC, FBC and PBC did not get more than one replicate for C1 because the concentration were considered too low to give interesting data.

Table 10 Results from the shaking experiment with all replicated (R1-R3), concentrations (mg/L) (C1-C5) and biochar types UBC, CBC, FBC and PBC. The concentrations in the table have not been adjusted for the change of volume that took place at each sampling time.

		R1					R2					R3				
Biochar	Time	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
UBC	t_0 (0m)	0.65	3.29	6.3	12.6	x	0.58	3.3	6.1	13.5	x	0.47	3.2	5.2	12.2	x
	t_1 (15m)	0.5	3.18	6.6	11.9	x	0.49	3.34	6.6	12.9	x	0.48	3.23	6.4	13.5	x
	t_2 (1h15)	0.65	3.01	5.7	12.6	x	0.54	3.23	5.5	12.3	x	0.51	2.22	5.7	12.1	x
	t3 (4 h)	0.54	3.25	5.9	11.9	x	0.57	3.32	5.2	13.3	x	0.63	3.32	5.6	11.5	x
	t4 (24 h)	0.65	3.34	6.1	13.3	x	0.58	2.92	6.2	13.2	x	0.54	3.15	6	13.1	x
CBC	t_0 (0m)	0.57	3.2	6.2	13.8	x	x	3.519	6.4	12.3	26.7	x	3.727	6.7	12.9	25.9
	t_1 (15m)	0.447	1.07	0.318	8.8	x	x	1.374	2.842	9.4	22.8	x	1.351	2.617	6.3	20.8
	t_2 (1h15)	0.336	0.551	0.252	0.485	x	x	0.49	0.587	2.18	9.6	x	0.484	0.553	1.113	8.816
	t3 (4 h)	0.375	0.54	0.506	1.498	x	x	0.339	0.368	0.646	2.05	x	0.483	0.499	0.628	2.374
	t4 (24 h)	0.395	0.557	0.562	1.013	x	x	0.479	0.713	0.655	0.841	x	0.486	0.569	0.642	0.78
FBC	t_0 (0m)	0.51	3.22	7.4	12.9	x	x	3.22	5.95	12.3	25.8	x	3.704	6.8	12.8	25.9
	t_1 (15m)	0.7	2.57	0.497	10.4	x	x	2.57	5.288	11	23	x	3.155	5.559	11.4	23.6
	t_2 (1h15)	0.718	2.14	0.5	8.2	x	x	2.14	4.684	9.7	20.8	x	2.685	4.606	9.81	23.2
	t3 (4 h)	0.625	1.892	3.16	6.342	x	x	1.892	4.031	7.6	17.6	x	2.165	3.703	8.196	20.565
	t4 (24 h)	0.44	0.971	1.965	4.447	x	x	0.971	2.353	3.779	12.5	x	1.012	2.18	4.659	11.668
PBC	t_0 (0m)	0.46	3.27	6.2	14.3	x	x	3.523	5.9	12.1	26.3	x	3.746	6.7	12.8	25.6
	t_1 (15m)	0.67	1.65	0.417	6.9	x	x	0.785	3.739	13	25.4	x	1.899	3.886	11.2	24.3
	t_2 (1h15)	0.52	0.554	0.56	2.86	x	x	0.415	1.316	6.795	22.2	x	0.68	1.236	5.714	24.325
	t3 (4 h)	0.536	0.395	0.836	1.551	x	x	0.376	1.647	6.359	16	x	1.207	1.251	5.167	21.83
	t4 (24 h)	0.717	0.429	1.31	3.698	x	x	0.514	2.644	5.521	13.5	x	1.782	1.811	3.923	13.466

APPENDIX II - Adsorption isotherms

The graphs that provided all Langmuir and Freundlich parameters are shown in Figure 12 & Figure 13. The linear equation of Langmuir model (Equation 4) is Ce plotted vs Ce/Qe. The linear plot provided the parameters Q_m and k_L where the slope was $1/Q_m$ and the intercept $1/Q_mk_L$ and they are presented in Table 5.

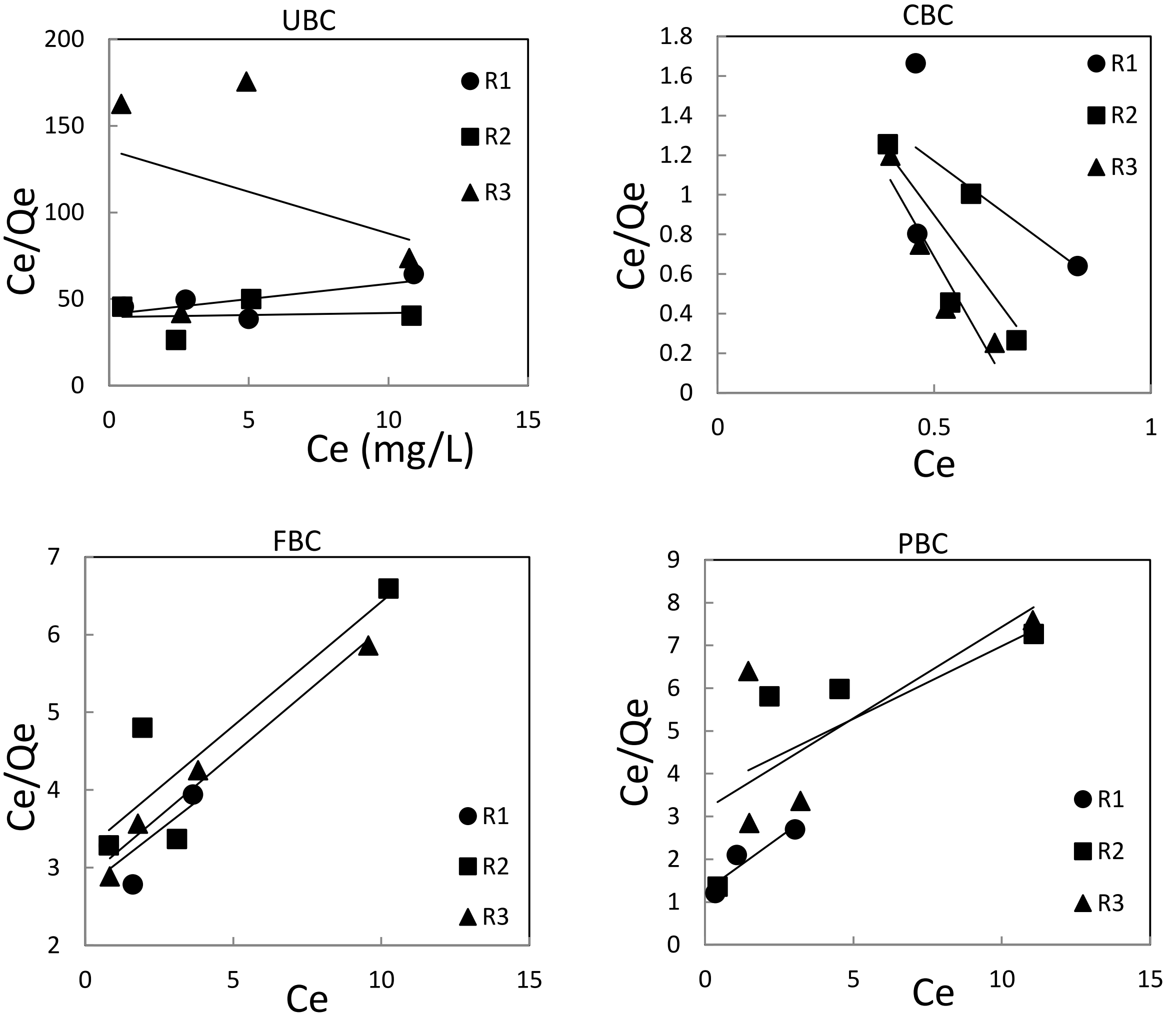

Figure 11 Linear plots of the linearization of the Langmuir equation.

The linear equation of the Freundlich model (Equation 5) is expressed as lnQ_e vs lnC_e. The slope is 1/n and intercepts in lnk_F. The parameters are all presented in Table 5 in the result section.

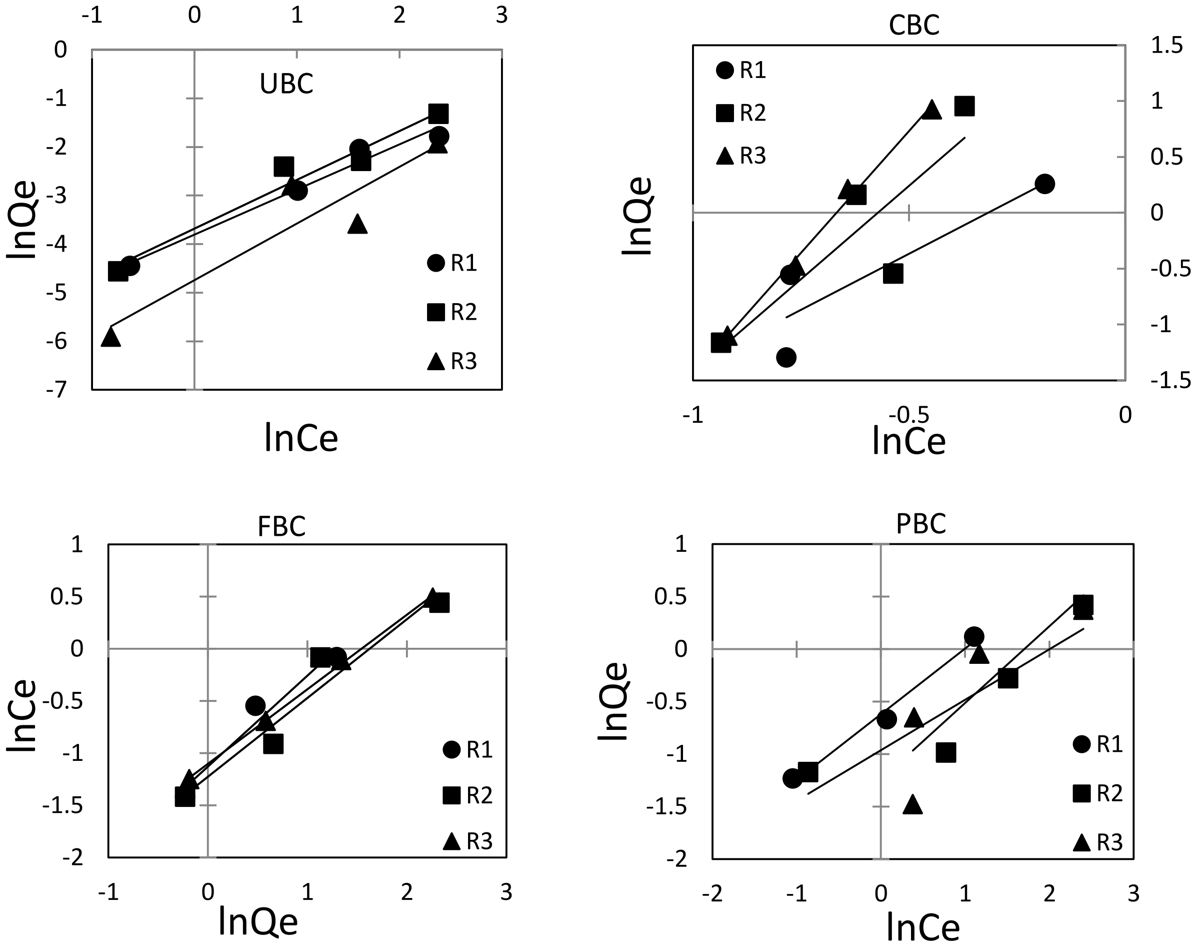

Figure 12 Plots of the linear version of Freundlich model for all biochar types.

APPENDIX III - Kinetic isotherms

Model parameters derived from calculated pseudo first and second order equation 6 & 7 (Table 11).

Table 11 All the calculated parameters for the kinetic isotherms

Concentration	**Biochar type**	**Pseudo 1st order model parameters**			**Pseudo 2nd order model parameters**			**Experimental**
		Q_e (mg/g)	R^2	k_1 (min^{-1})	Q_e (mg/g)	R^2	k_2 (g/mg/min)	Qe (mg/g)
C2	**UBC**	0.064	0.77850	0.004	0.068	0.9107	-0.021	0.069
	CBC	0.156	0.83597	0.028	0.307	1.0000	1.717	0.307
	FBC	0.229	0.91907	0.004	0.281	0.9965	0.036	0.264
	PBC	0.266	0.99700	0.097	0.264	0.9998	-0.499	0.277
C3	**UBC**	0.123	0.85430	0.021	0.085	0.9913	-0.593	0.086
	CBC	0.586	0.99970	0.063	0.594	1.0000	1.657	0.593
	FBC	0.456	0.95767	0.005	0.516	0.9970	0.055	0.494
	PBC	0.385	0.99700	0.049	0.468	0.9995	-0.496	0.469
C4	**UBC**	0.182	0.55703	0.664	0.199	0.9940	-0.081	0.194
	CBC	1.015	0.98263	0.021	1.250	0.9997	0.075	1.237
	FBC	0.815	0.95843	0.005	0.916	0.9978	0.014	0.914
	PBC	0.847	0.87223	0.029	0.950	0.9951	-0.047	0.947
C5	**UBC**	-	-	-	-	-	-	-
	CBC	2.409	0.99200	0.013	2.654	0.9988	0.008	2.564
	FBC	1.467	0.96665	0.003	1.774	0.9887	0.004	1.594
	PBC	1.494	0.99450	0.005	1.756	0.9814	0.002	1.489

Linearization of pseudo 2^{nd} order equation gave liner plots with t/Q as y-axis and t as x-axis (Figure 13a-d). The plots have the slope $1/Q_e$ and intercept $1/k_2Qe$ and the parameters Q_e, k_2 and correlation R^2 are presented in Table 6 in and Table 11. Pseudo 2^{nd} had the best fit for all biochar and concentrations except for PBC and C5 (Figure 13e). Pseudo 1^{st} equation gave a linear plot with $\ln(Q_e\text{-}Q_t)$ as y-axis. The slope is k_1 and intercept $\ln(Q_e)$ and k_1 and Q_e are presented in Table 6 in the Result section and in Table 11.

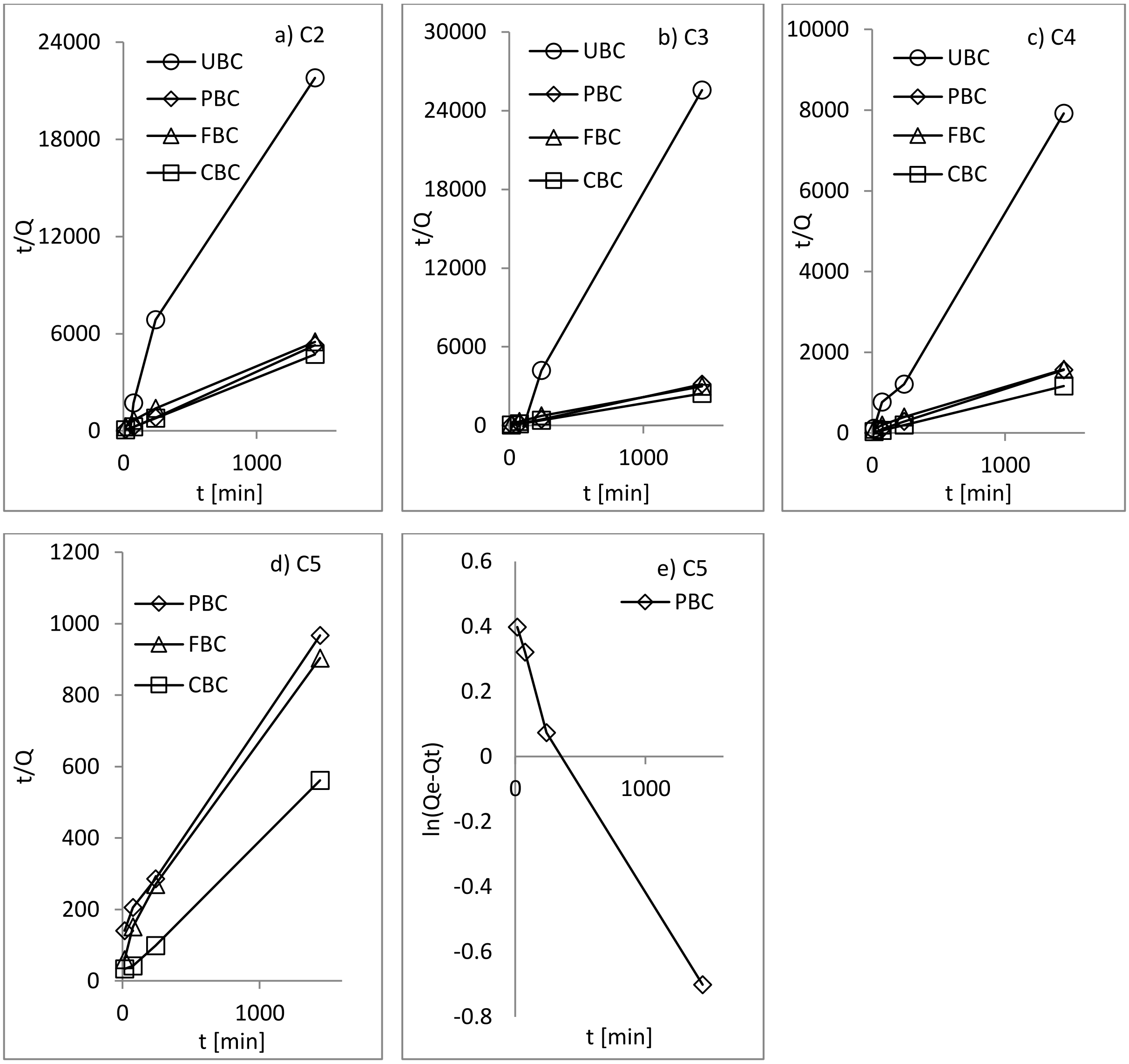

Figure 13 a-d) The linear plots of pseudo 2nd order kinetic model for C1, C2, C3, C4 and C5 where t/Q has the unit min/mg/g. **e)** The pseudo 1st order kinetic model linear plot for C5 and Polonite (PBC) with y-axis ln(Qe-Qt) (mg/g).

APPENDIX VI - Filter experiments

The removal efficiency of NH_4-N in the vertical section of the N removal filter was stable around 50 % from week 9 to 14 of the experiment (Figure 14a). In the same filter section, NO_3-N was not removed but created. As the experiment proceeded higher NO_3-N were measures in the outflow of the vertical filter section. In the Horizontal section, the NH_4-N removal varied more than in the previous section but had an average removal around 40 % (Figure 14b). The NO_3-N removal was not stable and increased during the experiment (Figure 14b). In the whole filter (Figure 14c), NH_4-N and Tot-N displayed stable removal whereas the filter had an increasing removal of NO_3-N. Tot-N removal is also presented in the result section (Figure 9).

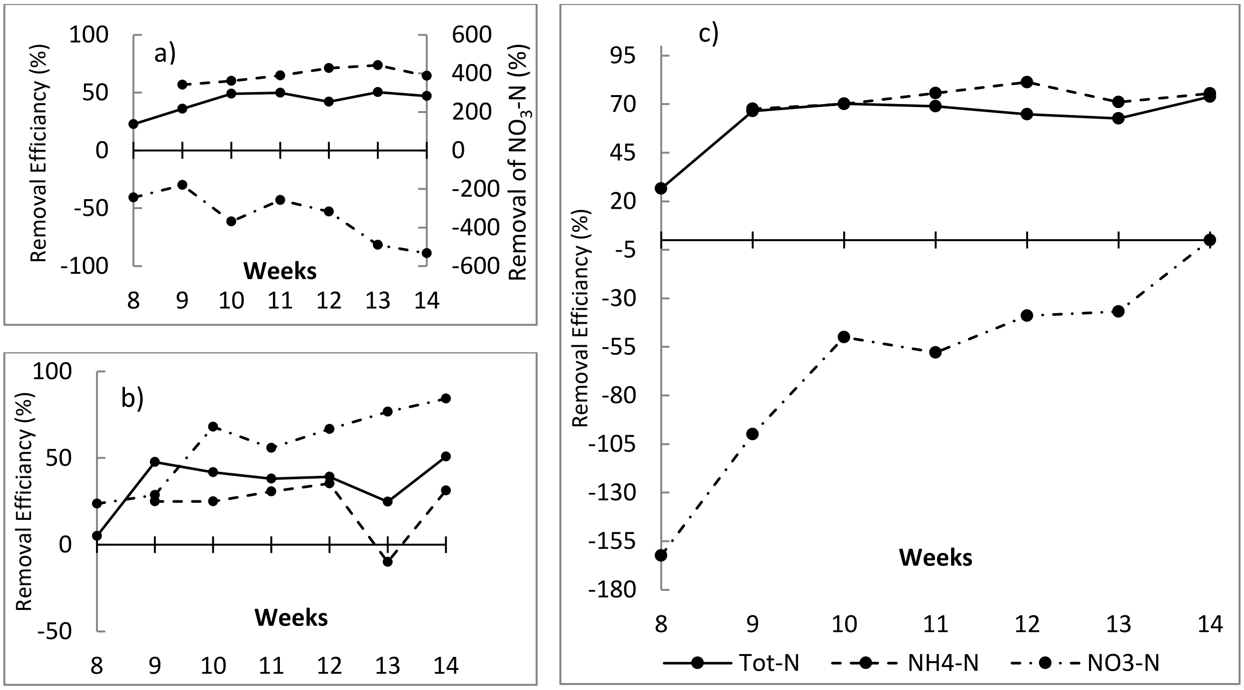

Figure 14 The variation of the removal of NH_4-N, NO_3-N and Tot-N in the nitrogen removal filters **a)** First unsaturated section with vertical flow, **b)** second saturated section with horizontal flow and **c)** total filter with both sections combined.

SL383

An Introduction to Biochars and Their Uses in Agriculture[1]

Rao Mylavarapu, Vimala Nair, and Kelly Morgan[2]

Biochar, also known as *black carbon,* is a product derived from organic materials rich in carbon (C) and is found in soils in very stable solid forms, often as deposits. Biochars can persist for long periods of time in the soil at various depths, typically thousands of years. The most common example is charcoal, derived from wood. Similarly, the *Terra Preta* soils of the Amazon Basin are one of the more widely known examples of biochar.

In recent years, considerable research has focused on biochar, its nature, and its properties to explore its potential benefits and negative impacts, particularly for applying to agricultural fields as amendments. This publication provides a general description of biochar, as well as technical details, benefits, and disadvantages of biochar for agricultural and environmental uses. The intended audiences for this factsheet are agricultural producers, crop professionals, state agencies, researchers, resource conservationists, Extension educators, high school teachers, students, and the general public.

How are biochars made?

The benefical effects of biochar were discovered more than 2,000 years ago when the "slash-and-burn" agricultural method was in practice. Natural forest fires and historical cultural practices also resulted in the formation of biochars that are stable over thousands of years as soil deposits. There are numerous types of biochars depending on the original material from which they are derived. Each specific type of carbon-rich material results in a very specific and different type of biochar, reflecting the physical and chemical properties of the parent material. For example, biochars derived from different types of trees (wood) or plant species result in different types of biochars.

Biochar can also be created artificially. Typically, biochars are formed by heating biomass or wastes containing C through a process called *pyrolysis*. *Pyrolysis* involves thermal and chemical decomposition of biomass, in limited or zero supply of oxygen. Biochar is typically produced at temperatures between 300°C–1000ºC (Glaser et al. 2001). The absence of oxygen prevents complete combustion of the material and the amount of biochar and other by-products obtained depends on the temperature. Lower temperatures (300°C–600°C) yield more solid *char* material and temperatures above 700°C result in more liquid/gas components. Typical waste-to-energy projects involve *pyrolysis* at high temperatures and result in gasification of biomass yielding approximately 20% *Syngas*, a combustible gas used in internal combustion engines, composed of primarily carbon monoxide and hydrogen, along with bio-oil and biochar.

Various types of biomass have been used on a commercial scale for biochar production successfully, including agricultural and forestry by-products (such as straw, nut shells, rice hulls, wood chips, wood pellets, tree bark, and switch grass), industrial by-products (such as bagasse from the sugarcane industry, paper sludge, and pulp), animal

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wastes (such as chicken litter, dairy and swine manure), and sewage sludge. Converting biomass to biochars offers an excellent method for reducing waste and using these byproducts. Biochars can also be engineered to have specific physical and chemical properties by selecting appropriate feedstock and pyrolyisis conditions. Engineering biochars to have specific properties can increase the ability of biochars to serve as a soil amendment and/or as a low-cost sorbent for organic and inorganic pollutants (Chen, Chen, and Lv 2011; Novak et al. 2009).

Uses of Biochars

When applied as soil amendments, biochars are known to improve soil physical and chemical properties, such as increasing soil fertility and productivity. Current research is focused on understanding the physics and chemistry of soil-applied biochars by studying the methods and rates of applications and documenting benefits for use as agricultural amendments. Many recent studies are also focusing on broader impacts of biochars, such as the potential for climate change mitigation at a global scale. These studies are evaluating increases in soil carbon storage at regional scales. An estimated 2.2 gigatons of C can be stored in the soil by 2050 using biochar conversion technologies, according to the International Biochar Initiative (http://www.biochar-international.org/biochar). Other benefits from amending soils with biochars include minimizing nitrous oxide and methane emissions, minimizing leaching of nutrients to groundwater, and reducing contaminant levels in soils, among others.

Impacts on Agriculture

The characteristics of biochars and its potential benefits when applied to the land are both influenced by the specific material of the biochar and the processing technique used. Biochars can retain applied fertilizer and nutrients and release them to agronomic crops over time. Biochars' ability to retain water and nutrients in the surface soil horizons for long periods benefits agriculture by reducing nutrients leaching from the crop root zone, potentially improving crop yields, and reducing fertilizer requirements. Thus, using biochars in production agriculture should improve yields and reduce negative impacts on the environment. A distinction between biochars and composts should be made here for clarity. Biochars differ from composts commonly added to soils for agricultural production in that compost is a direct source of nutrients through further decomposition of organic materials. However, biochars do not decompose with time and so additional applications should not be necessary.

A recent review of biochar articles by Spokas et al. (2012) concluded that while application of biochars can lead to positive results in agricultural production, there have been some reports of no crop yield benefits (Schnell et al. 2012) or even negative yield responses (Lentz and Ippolito 2012). Reported low yields could be because of reduced nutrient release for plant uptake, application of biochar on fertile soils, or a low rate of biochar application. High yields observed in some cases of biochar application could not be easily explained, but might depend on biochar properties, the soil fertility status, and the agronomic crop under consideration. Ippolito, Laird, and Busscher (2012) pointed out that most recent research on biochar has been conducted on highly weathered and infertile soils where benefits of biochar application were often noted. UF/IFAS researchers are working on determining benefits of biochars on sandy soils of Florida with low fertility and documenting any improvements in crop growth and yield.

Impacts on the Environment

As discussed earlier, biochars can have benefits for waste reduction, energy production, C-sequestration, and soil fertility. Also, different biochars (derived from a variety of feedstocks) have been recognized as highly efficient low-cost sorbents for various pollutants in the environment. Application of biochars to soils has been investigated at the laboratory and field scale as an in-situ remediation strategy for both organic and inorganic contaminants to determine their ability to increase the sorption capacity of varying soils and sediments. For example, Chun et al. (2004) reported biochars generated by pyrolyzing wheat residues at temperatures ranging from 300°C to 700°C removed benzene and nitrobenzene (organic contaminants) from wastewater. Similarly, biochars produced from greenwaste (a mixture of maple, elm, and oak woodchips and bark) removed atrazine and simazine from aqueous solution (Zheng et al. 2010). Pine needle-derived biochar removed naphthalene, nitrobenzene, and m-dinitrobenzene from water (Chen, Zhou, and Zhu 2008). Straw-derived biochar was found to be an excellent, cost-effective substitute for activated carbon to remove dyes (reactive brilliant blue and rhodamine B) from wastewater (Qiu et al. 2009). Biochar derived from dairy manures (pyrolysis from 200°C to 300°C) also removed substantial amounts of atrazine from wastewater (Uchimiya et al. 2010).

In addition to removing organic contaminants, biochars have also been shown to remove metal contaminants and nutrients from wastewater and soil. Cao et al. (2009) investigated the sorption capacities of biochars produced by the pyrolysis of dairy manures at low temperatures

(200°C and 350°C). They found that the biochar was six times more effective in removing lead (Pb) from wastewater than a commercial activated carbon. Broiler litter manure biochar enhanced the immobilization of heavy metals including cadmium (Cd), copper (Cu), nickel (Ni), and Pb in soil and water (Uchimiya et al. 2011). Yao et al. (2011) reported biochar derived from anaerobically digested sugar beet tailings (DSTC) removed 73% of phosphate from the tested water. Also, magnetic biochars were found to be effective at removing hydrophobic organic contaminants and phosphate from solution simultaneously (Chen, Chen, and Lv 2011). These results show the potential of biochars to minimize nutrient leaching in agricultural fields.

Summary

Biochars are obtained through pyrolyzing biomass at temperatures above 300°C in the absence of oxygen. Degraded, dry lands and soils with poor fertility and low organic matter can immensely benefit from biochar amendments. In documented cases, biochars have improved nutrient and water-holding capacities, increased fertility and productivity, and improved crop management efficiency. Additional benefits come from biochar's ability to sorb contaminants, including inorganic and organic pollutants in the soil and leaching waters, thus improving soil and water quality. Using biochar as a soil amendment can help sequester stable carbon in soils and combat climate change. However, responses to biochars may depend on the type of biochar used and the specific characteristics of that biochar. Because biochar characteristics determine its suitability for specific agronomic or environmental purposes, biochar production must be tailored to address such specific needs.

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Research Article

Kinetic and Thermodynamic Studies on the Phosphate Adsorption Removal by Dolomite Mineral

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The efficiency of dolomite to remove phosphate from aqueous solutions was investigated. The experimental results showed that the removal of phosphate by dolomite was rapid (the removal rate over 95% in 60 min) when the initial phosphate concentration is at the range of 10–50 mg/L. Several kinetic models including intraparticle diffusion model, pseudo-first-order model, Elovich model, and pseudo-second-order model were employed to evaluate the kinetics data of phosphate adsorption onto dolomite and pseudo-second-order model was recommended to describe the adsorption kinetics characteristics. Further analysis of the adsorption kinetics indicated that the phosphate removal process was mainly controlled by chemical bonding or chemisorption. Moreover, both Freundlich and Langmuir adsorption isotherms were used to evaluate the experimental data. The results indicated that Langmuir isotherm was more suitable to describe the adsorption characteristics of dolomite. Maximum adsorption capacity of phosphate by dolomite was found to be 4.76 mg phosphorous/g dolomite. Thermodynamic studies showed that phosphate adsorption was exothermic. The study implies that dolomite is an excellent low cost material for phosphate removal in wastewater treatment process.

1. Introduction

Phosphorus is an indispensable element for animals and plants on the earth. However, excessive phosphorus in water bodies can cause eutrophication. When the concentration of phosphorus in water bodies is higher than 0.02 mg/L, the eutrophication would happen [1]. So it is necessary to eliminate phosphate ions from water.

Several techniques have been applied to the removal of phosphate from wastewater, and the frequently used methods include chemical precipitation [2], biological treatments [3], and adsorption [4]. Among these, adsorption is considered to be a reliable and effective technique for phosphate removal. To choose the adsorption method, both high adsorption capacity and low cost are key issues to be considered. A great attention has been paid to low-cost adsorbents over past years, especially to the natural mineral and industrial waste, such as limestone [5], iron based compounds [6], aluminum based compounds [7], natural zeolite [8], iron oxide tailing [9], ferric sludge [10], blast furnace slag [11], and other materials.

It is well recognized that dolomite is an effective and low-cost adsorbent for phosphate. However, related studies of adsorption mechanism of dolomite, such as the kinetic and thermodynamic adsorption of phosphate by dolomite minerals, had not been reported yet. It is of great importance to study the adsorption mechanism of phosphate by dolomite to clarify the absorption phenomena and reaction processes and to determine the optimal adsorption conditions in practical production. Dolomite contains Ca^{2+}, which can be dissolved in the solution and can then react with phosphate anions to form phosphate precipitates, such as $Ca_{10}(PO_4)_6(OH)_2$ [12]. In a previous paper [13], the effects of initial phosphate concentration, reaction time, reaction temperature, and adsorbent dosage on the phosphate removal rates were investigated. The experiments of phosphate adsorption removal results show that the phosphate removal rates exceed 99%; the equilibrium phosphate concentrations after phosphate removal reaction completely accord with the requirement of national discharge standards of the second category pollution GB 1A (TP = 0.5 mg/L) in China.

The objective of the present study was focused on the phosphate adsorption kinetics and thermodynamics of dolomite. Several kinetic models including intraparticle diffusion model, pseudo-first-order model, Elovich model, and pseudo-second-order model were used to fit the kinetic experimental data and the corresponding kinetic parameters were calculated. The isotherm models of Langmuir and Freundlich equations were applied to evaluate the adsorption equilibrium.

2. Materials and Methods

2.1. Materials. Dolomite used in this research (mass percent CaO 29.68%, SiO_2 5.13%, and MgO 16.55%) was obtained from Daye, Hubei, China; dolomite was crushed and sieved to smaller than 0.15 mm in particle size before it was used. An appropriate volume of 0.1 mol/L HCl (AR, Chemical Reagent Factory, Chongqing Chuandong Chemical (Group) Co., Ltd) or 0.1 mol/L NaOH (AR, Shanghai Fengxian Fengcheng Reagent Factory) was used to adjust the pH of the solution.

2.2. Experimental Methods. Adsorption experiments were carried out as the following procedure. Firstly, a defined volume of phosphate stock solution was diluted to the experimental concentration by adding deionized water in 100 mL glass round-bottom flasks immersed in a thermostatic shaker bath. The pH of the solution was then adjusted to the desired value and a defined amount of adsorbent was added. The mixture was stirred at 250 rpm for a defined period, using a potentiometer to regulate the stirring speed. Then the liquid samples were collected and filtering process was applied to separate solid from liquid, and the filtrate was taken for P analysis.

To investigate the influence of pH on the phosphate adsorption by dolomite, experiments were carried out on the conditions of reaction temperature 20°C, stirring speed 250 rpm, dolomite dosage 10 g/L, initial phosphate concentration 50 mg/L, and reaction time 60 min. Phosphate adsorption kinetics studies were evaluated in the conditions with different adsorption time, different initial phosphate concentrations, and fixed dolomite dosage (10 g/L) and pH 9.5 at 20°C. Five levels of initial phosphate concentrations (10, 30, 50, 70, and 100 mg P/L) and adsorption time (20, 40, 60, 80, and 100 min) were used. The effect of adsorption temperature on phosphate removal was performed at four different temperatures (20, 40, 60, and 80°C) for 60 min with fixed dolomite dosage (10 g/L) and pH (9.5), and the initial phosphate concentration varies from 10 to 90 mg P/L.

The pH of solutions was measured by pH meter (Model Delta 320, METTLER-TOLED Instruments (Shanghai) Co., China). The phosphate concentration of all samples including wastewater was analyzed by bismuth phosphor molybdenum blue spectrophotometric method (Model TU-1810, Beijing Puxi Science and Technology Instrument Co. Ltd., China). Phase analyses of dolomite before and after phosphate adsorption were conducted by X-ray diffraction (XRD) (Model D/max 2500 PC, Rigaku, Japan) with Cu Ka radiation.

2.3. Data Evaluation. In order to investigate the potential rate-controlling step of the phosphate adsorption process, several kinetics models, including intraparticle diffusion model, pseudo-first-order model, Elovich model, and pseudo-second-order model were employed to evaluate phosphate adsorption kinetics performance. The following equations were applied for describing the four kinetics models, respectively, [14–17]:

intraparticle diffusion model:

$$Q_t = c + k_m t^{1/2}, \tag{1}$$

pseudo-first-order model:

$$\frac{1}{Q_t} = \frac{k_1}{Q_e t} + \frac{1}{Q_e}, \tag{2}$$

Elovich model:

$$Q_t = \frac{1}{\beta \ln(\alpha\beta)} + \frac{1}{\beta}\ln t, \tag{3}$$

pseudo-second-order model:

$$\frac{t}{Q_t} = \frac{1}{k_2 Q_e^2} + \frac{t}{Q_e}, \tag{4}$$

where t (h) is the contact time of adsorption experiment, Q_e (mg/g) and Q_t (mg/g) are, respectively, the adsorption capacity at equilibrium and at any time t, α (mg/(g·min)) is the initial adsorption rate constant and the parameter β (g/mg) is related to the extent of surface coverage and activation energy for chemisorption, k_1 (1/min) is the rate constant of the pseudo-first-order model, k_m (mg/(g·min$^{1/2}$)) is the rate constant of the intraparticle diffusion model and c is obtained from the intercept, and k_2 (g/(mg·min)) is the rate constant of the pseudo-second-order model. The initial adsorption rate is $k_2 Q_e^2$ (mg/(g·min)).

Adsorption isotherms data were evaluated using the Langmuir and Freundlich equations, respectively, expressed in the following equations [18, 19]:

$$Q_e = \frac{C_e b Q_{\max}}{(1 + bC_e)}, \tag{5}$$

$$Q_e = kC_e^{1/n}. \tag{6}$$

The linear equations of these two experiential models are as follows:

$$\frac{C_e}{Q_e} = \frac{1}{(bQ_{\max})} + \frac{C_e}{Q_{\max}}, \tag{7}$$

$$\log Q_e = \log k + \frac{(\log C_e)}{n}, \tag{8}$$

Table 1: Influence of pH value on phosphate removal by dolomite.

Initial pH	Residual phosphate concentration/(mg/L)	Phosphate removal rate/%
3.52	3.75	92.50
5.56	3.65	92.70
7.39	2.98	94.04
9.50	1.46	97.08
10.39	1.53	96.40
11.35	1.69	96.20
12.37	3.02	93.96

where C_e is the equilibrium concentration of phosphate in the solution (mg/L), Q_e is the phosphate concentrations in the solid adsorbent (mg/g), $Q_{\max}$ is the maximum adsorption capacity (mg/g), k is a constant related to the adsorption capacity ($\mathrm{mg}^{1-1/n}\mathrm{L}^{1/n}\mathrm{g}$), b is a constant related to the energy of adsorption (L/g), and n is a constant related to the energy of adsorption.

3. Results and Discussion

3.1. Influence of pH. The result of the influence of pH on the phosphate adsorption by dolomite was listed in Table 1. As can be seen from Table 1, the phosphate removal rate increases rapidly with pH value increasing when the pH value is lower than 9.5. This may be explained by the fact that the phosphate removal is related both to the dissolution of Ca^{2+} ions from adsorbent and to the polyprotic nature of phosphate [20]. For KH_2PO_4 solution, the main orthophosphate compound is changed with the pH value (i.e., conversion of $H_3PO_4 \Rightarrow H_2PO_4{}^{-} \Rightarrow HPO_4{}^{2-} \Rightarrow PO_4{}^{3-}$ with increasing pH). When pH value is about 9.5, $HPO_4{}^{2-}$ is the dominant compound in the solution. It is known that calcium phosphate precipitation is the predominant mechanism in phosphorus immobilization at higher pH value [21]. Therefore, dolomite dissolves to emerge partial Ca^{2+}, and Ca^{2+} reacts with $HPO_4{}^{2-}$ and $PO_4{}^{3-}$ to form calcium phosphate. The dolomite samples before and after reactions have been checked by XRD and the result was shown in Figure 1. The main components of the sample after reaction include dolomite, quartz, and hydroxyl apatite; the maximum diffraction peak intensities of dolomite, quartz, and hydroxyl apatite are 16393, 622, and 279, respectively. It is obvious from Figure 1 that phosphate precipitated with calcium as hydroxyl apatite. However, the phosphate removal rate decreases with pH value increasing when the initial pH value is above 9.5. Obviously, the dissolved Ca^{2+} concentration will decrease with the initial pH value increasing, which causes the inhibition of calcium phosphate precipitation and thus reduces phosphate adsorption. In addition, OH^{-} concentration in solution increases with the initial pH value increasing [22]. The inhibition of phosphate adsorption could also be ascribed to the competition between hydroxyl ions (OH^{-}) and the phosphate ions on the dolomite surface. In addition, it can be seen from Table 1 that the phosphate removal rate achieves 92.50% when the pH value is 3.52. Considering the fact that the calcium phosphate precipitation can be neglected when the pH value is relatively low [21], it is clear that the considerable phosphate removal rate (92.50%) at pH = 3.52 is fulfilled by the process of phosphate adsorption to dolomite. So, it can be concluded that adsorption to dolomite is the main phosphate removal process in present work. Although dolomite contains Mg element, previous works reported that the phosphate removal by fixation with Mg^{2+} ions was not accomplished or it was low [23]. So the main effective component for phosphate adsorption on dolomite is Ca^{2+}.

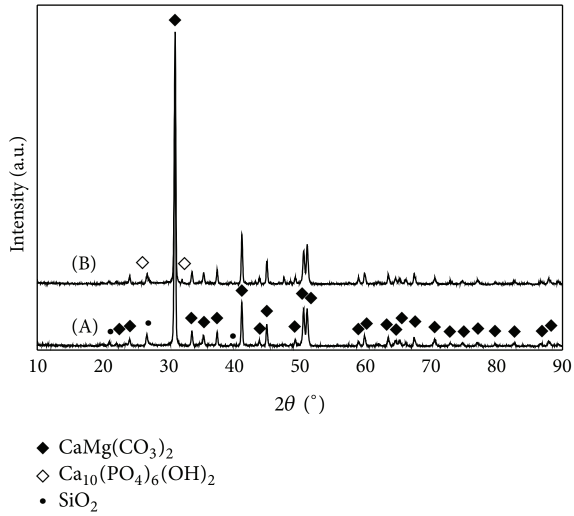


Figure 1: XRD patterns of the dolomite samples (A) before adsorption and (B) after adsorption (at pH value = 9.5).

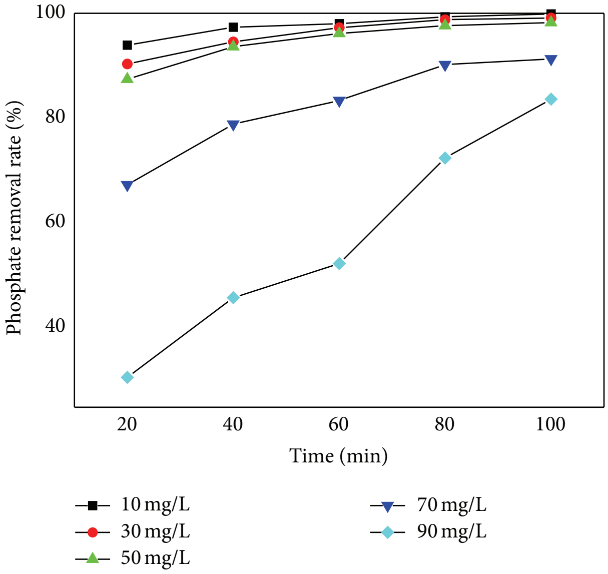
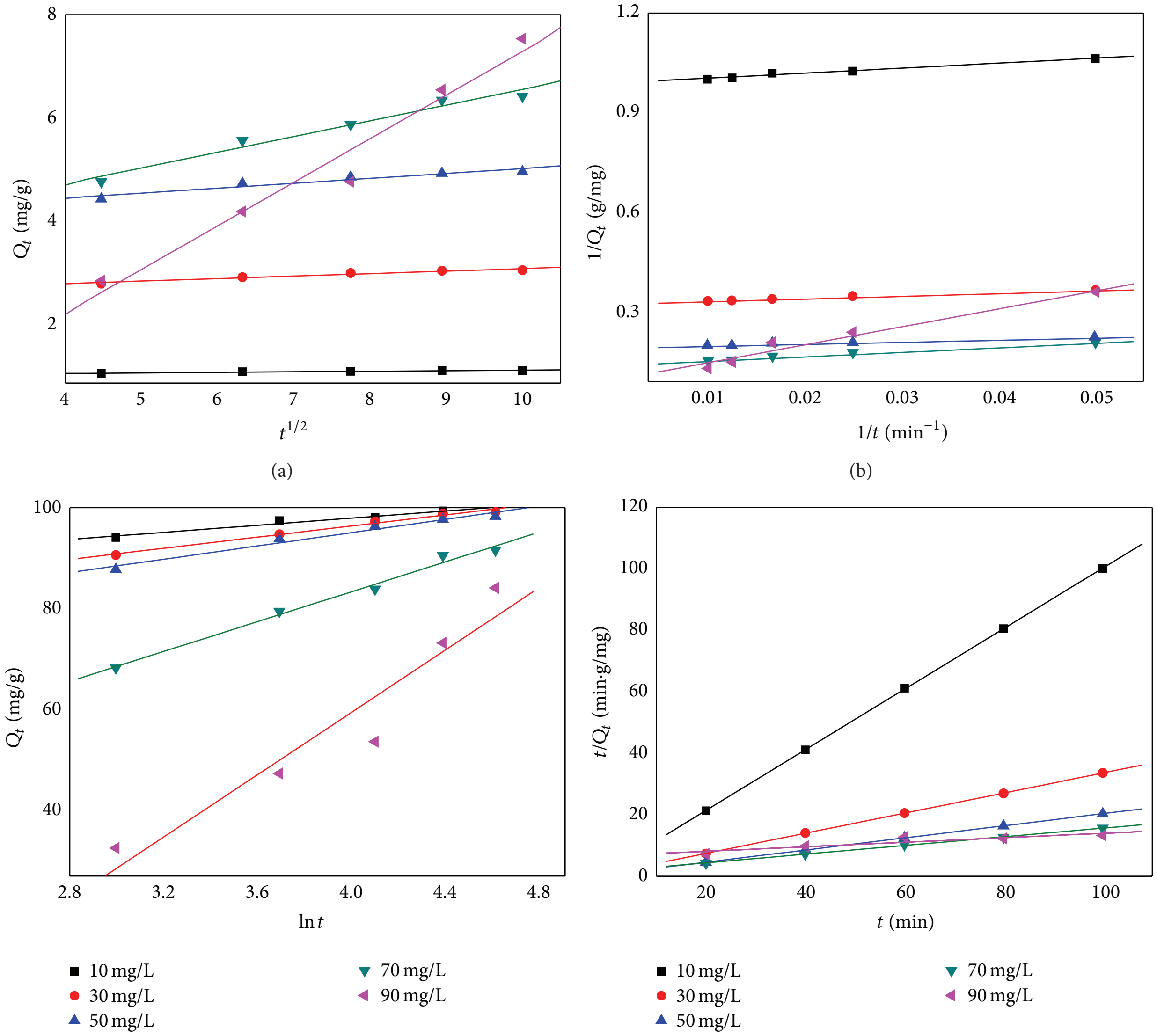


Figure 2: Kinetics of phosphate adsorption by dolomite.

3.2. Adsorption Kinetics. Figure 2 showed the kinetics results of phosphate removal by dolomite. Results indicated that



(a) (b)

(c) (d)

FIGURE 3: The kinetic plots for sorption of phosphate using different models: (a) intraparticle diffusion model; (b) pseudo-first-order model; (c) the Elovich model; and (d) pseudo-second-order model.

the rate of phosphate removal by dolomite was quite rapid. The phosphate removal rate increased rapidly before 80 min. With the adsorption time further increasing, the phosphate removal rate increased slowly.

The experimental data were employed to derive the kinetic parameters using the four different models. The fitting of the experimental data to the linear forms of the four adsorption kinetics models was shown in Figures 3(a)–3(d), respectively. The parameters obtained using these four models are listed in Table 2. It is seen that the pseudo-second-order model shows a good agreement with the experimental data; the correlation coefficients (R^2) of pseudo-second-order model in all different initial phosphate concentrations are all above 0.99, which are higher than those of Elovich model, intraparticle diffusion model, and pseudo-first-order model. In adsorption processes, a pseudo-second-order mode is generally interpreted to mean that the mechanism of the process is mainly controlled by chemical bonding or chemisorption. This would imply that the cause of phosphate adsorption onto the dolomite involves valency forces through sharing or exchanging electrons between sorbate and sorbent [24].

3.3. Adsorption Isothermal Models. Figure 4 showed the effect of adsorption temperature on phosphate removal. It can be seen from Figure 4 that the adsorption reaction nearly reached equilibrium at initial phosphate concentration at about 50 mg/L under the experimental conditions tested.

The plots of fitting the experimental data to the linear forms of Freundlich and Langmuir models were shown in Figure 5. The values of the Freundlich and Langmuir constants and the correlation coefficients for dolomite are presented in Table 3. Results showed that Langmuir equation gave a better fit than the Freundlich equation according to their correlation coefficients. In all cases, correlation

Table 2: Estimated kinetic model parameters for phosphate adsorption by dolomite.

	Intraparticle diffusion model: $Q_t = c + k_m t^{1/2}$			
Initial phosphate concentration/(mg/L)	c	$k_m/(\mathrm{mg}/(\mathrm{g}\cdot\mathrm{min}^{1/2}))$	R^2	SD
10	0.8990	0.0104	0.9401	0.00661
30	2.5134	0.0490	0.9518	0.02769
50	4.0065	0.0966	0.9222	0.07055
70	3.4407	0.3089	0.9682	0.14076
90	−1.3036	0.8581	0.9630	0.4227
	Pseudo-first-order model: $1/Q_t = k_1/Q_e t + 1/Q_e$			
Initial phosphate concentration/(mg/L)	$k_1/(\mathrm{min}^{-1})$	$Q_e/(\mathrm{mg/g})$	R^2	SD
10	1.5421	1.0110	0.9821	0.0039
30	2.5160	3.0426	0.9805	0.0022
50	3.1923	5.0669	0.9989	0.0004
70	9.5929	6.9324	0.9826	0.0035
90	57.4628	10.4811	0.9631	0.0201
	Elovich model: $Q_t = 1/\beta \ln(\alpha\beta) + (1/\beta)\ln t$			
Initial phosphate concentration/(mg/L)	$\alpha/(\mathrm{mg}/(\mathrm{g}\cdot\mathrm{min}))$	$\beta/(\mathrm{g/mg})$	R^2	SD
10	3.7975	0.2751	0.9766	0.41284
30	6.1505	0.1757	0.9866	0.48756
50	7.5168	0.1471	0.9731	0.82918
70	30.7053	0.0655	0.9886	1.20612
90	20.0906	0.0314	0.9182	0.95821
	Pseudo-second-order model: $t/Q_t = 1/k_2 Q_e^2 + t/Q_e$			
Initial phosphate concentration/(mg/L)	$k_2/(\mathrm{g}/(\mathrm{mg}\cdot\mathrm{min}))$	$Q_e/(\mathrm{mg/g})$	R^2	SD
10	0.5637	1.0148	1.0000	0.2412
30	0.1168	3.0586	0.9999	0.0901
50	0.0602	5.0743	1.0000	0.0185
70	0.0129	7.0877	0.9985	0.1978
90	0.0008	13.6519	0.9903	1.1780

Table 3: Characteristic parameters and determination coefficients of the experimental data according to Freundlich and Langmuir equations.

Temperature (°C)	Langmuir equation $C_e/Q_e = 1/(bQ_{\max}) + C_e/Q_{\max}$				Freundlich equation $\lg Q_e = \lg k + (\lg C_e)/n$			
	b (L/g)	$Q_{\max}$ (mg/g)	R^2	SD	k ($\mathrm{mg}^{1-1/n}\mathrm{L}^{1/n}\mathrm{g}$)	$1/n$	R^2	SD
20	11.56	4.76	0.9958	0.2871	2.48	0.276	0.6645	0.2096
40	9.64	4.00	0.9857	0.7333	1.67	0.326	0.6334	0.2100
60	5.83	3.71	0.9812	0.9462	1.45	0.336	0.6924	0.1856
80	3.06	3.25	0.9694	1.4949	1.20	0.345	0.6270	0.1998

coefficients corresponding to Freundlich equation were lower than those corresponding to Langmuir equation. The fact that dolomite has a relatively higher monolayer adsorption capacity supports the possibility of the adsorption mechanism. The value of the Langmuir constant $Q_{\max}$ was found to be 4.76 mg/g. Comparisons with other adsorbents indicate that the adsorption capacity of dolomite is good. For example, it was reported that adsorption capacities of hematite [25] and furnace slag [26] were 3 mg/g and 0.65 mg/g P, respectively.

The essential characteristics of the Langmuir isotherm can be expressed by a dimensionless constant called equilibrium parameter R_0 [27]:

$$R_0 = \frac{1}{(1 + bC_0)}, \tag{9}$$

where b is the Langmuir constant, C_0 is the initial concentration (mg/g), and R_0 values indicate the type of isotherm. The value of R_0 indicates the type of the isotherm to be either for unfavorable adsorption, $R_0 > 1$, for linear adsorption, $R_0 = 1$, for favorable adsorption, $0 < R_0 < 1$, or for irreversible adsorption, $R_0 = 0$.

In the present work, the R_0 values on the initial phosphate concentrations of 10 mg/L, 30 mg/L, 50 mg/L, and 90 mg/L are in Table 4. The R_0 values were found to be between 0 and 1 for all the concentrations of phosphate studied; therefore, the phosphate adsorption by dolomite belonged to favorable adsorption.

3.4. Thermodynamic Parameters of Adsorption. From Figure 4, the phosphate removal rate decreased with the

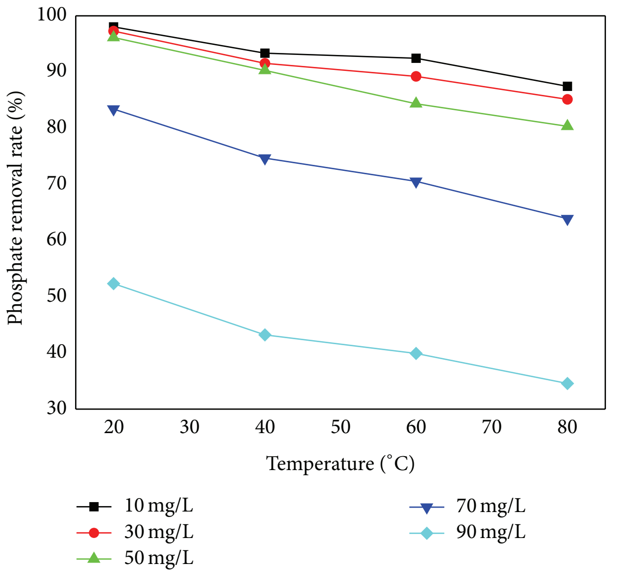


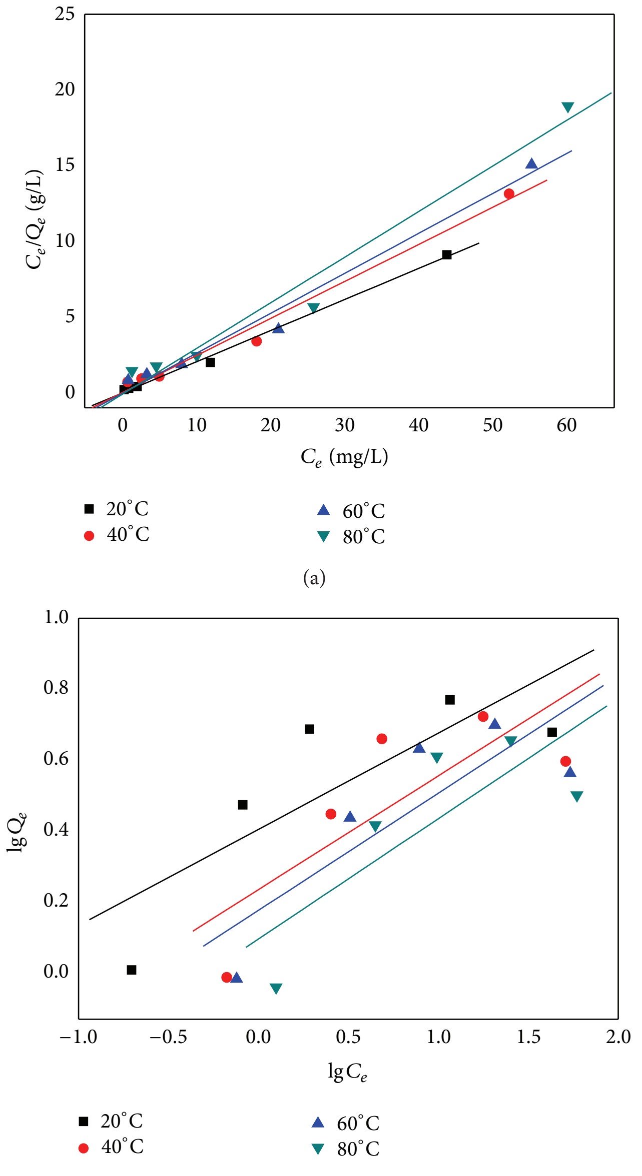
Figure 4: Effect of adsorption temperature on phosphate removal.

Table 4: Computation result of R_0.

			C_0 (mg/L)		
b (L/g)	10	30	50	70	90
			R_0		
11.56	0.0086	0.0029	0.0017	0.0012	0.0010
9.64	0.0011	0.0004	0.0002	0.0002	0.0001
5.83	0.0169	0.0057	0.0034	0.0024	0.0019
3.06	0.0316	0.0108	0.0065	0.0046	0.0036

Table 5: Thermodynamic parameters for the adsorption of phosphate on dolomite.

Temperature (K)	ΔG^θ (KJ/mol)	ΔH^θ (KJ/mol)	ΔS^θ (J/K/mol)
293	−3.06	−5.85	−10.17
313	−2.71		
333	−2.45		
353	−2.25		



(a)

(b)

Figure 5: Linearized form plots of Langmuir (a) and Freundlich (b) isotherms for phosphate adsorption by dolomite.

increase of adsorption temperature, especially for the sample with relatively high initial phosphate concentration. Which indicates that phosphate adsorption on the dolomite is exothermic reaction.

The change of Gibbs free energy is obtained using the following relationship:

$$\Delta G^\theta = -RT \ln k, \tag{10}$$

where R is the gas constant, k is the equilibrium constant (obtained from Freundlich equation), and $T(K)$ is the temperature. The negative values of ΔG^θ indicate the spontaneous nature of adsorption (Table 5). The standard Gibbs free energies (ΔG^θ) of the adsorption by dolomite were −3.06, −2.71, −2.45, and −2.25 KJ/mol at 293, 313, 333, and 353 K, respectively. The increase in ΔG^θ values for minerals with the temperature decreasing indicated that the adsorption is easier at low than at high temperature.

Other thermodynamic parameters such as enthalpy change (ΔH^θ) and entropy change (ΔS^θ) are evaluated using van't Hoff equation. The negative values of ΔG^θ indicate the spontaneous and highly favorable nature of adsorption:

$$\log k = \frac{\Delta S^\theta}{(2.303R)} - \frac{\Delta H^\theta}{(2.303RT)}. \tag{11}$$

Values of ΔH^θ and ΔS^θ were calculated from the slope and intercept of van't Hoff linear plot of $\log k$ versus $1/T$ (Figure 6) and were listed in Table 5. The negative value of ΔH^θ confirms the exothermic nature of phosphate

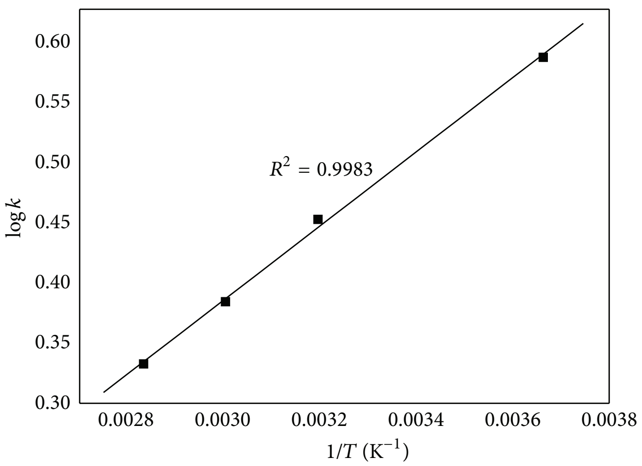


FIGURE 6: Plot of log k versus $1/T$ for phosphate adsorption by dolomite.

adsorption onto dolomite. The negative value of ΔS^{θ} suggests that the randomness at the solid/solution interface decreases during the phosphate adsorption, and it governs the possibility of chemical adsorption. Entropy of activation can be regarded as a measure of the "saddle point energy" over which reactant molecule must pass as activated complex; ΔS^{θ} conveys whether a particular reaction proceeds faster or slower than another individual reaction [28].

It is well known that phosphate adsorption reaction belongs to endothermic reaction for most adsorbents, for example, Fe(III)/Cr(III) hydroxide, red mud, and iron oxide tailings [29–31]. Considering the fact that the reaction of phosphate adsorption onto dolomite is exothermic, a relatively high phosphate removal rate is expected to be obtained at room temperature, and the energy consumed to heat up can be saved, which favors the industrial application of dolomite in phosphate removal.

4. Conclusions

(1) Dolomite removes phosphate from aqueous solution rapidly. Phosphate may be removed by adsorption and/or by precipitation of calcium phosphate.

(2) The adsorption kinetics characteristics of phosphate on dolomite were well described by pseudo-second-order model. The mechanism of the phosphate removal process is mainly controlled by chemical bonding or chemisorption.

(3) Equilibrium isotherm adsorption data obey Langmuir isotherms. The maximum adsorption capacity of dolomite is 4.76 mg/g P.

(4) Thermodynamic studies indicated that the phosphate adsorption on dolomite was exothermic.

(5) Dolomite can be used as an effective and low-cost adsorbent for the removal of phosphate.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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Based on monitoring and research analysis prepared by
The City of Casselberry, FL & Environmental Research and Design, Inc. for the
Florida Department of Environmental Protection

Baffle Box Removal Efficiency Study for Lake Jesup Watershed

PROJECT DESCRIPTION AND BACKGROUND

Lake Jesup Watershed is located in Seminole County Florida serving as the main drainage basin for residential, urban, agricultural areas and roadway land uses, where occupied by 33,570 residents (estimated from 2010 consensus year). The water body was identified by FDEP as impaired by nutrients (Phosphorus and Nitrogen) based on State of Florida TMDLs water quality standard. As a result, the Basin Management Action Plan (BMAP) was mandated statewide to restore water quality in Florida. Lake Jesup Watershed is interconnected with smaller basins and ponds/rivers that contribute to the total nutrient and sediment loading. This document provides a summary of the removal efficiency evaluation on the baffle box and CDS technologies studied in City of Casselberry in the "*Baffle Box with Media Filtration Installation, Effectiveness Evaluation, and Association Education for the Lake Jesup Watershed*". The report was prepared by the City of Casselberry in March 2014. It compares the performance of three EcoVault® baffle boxes from EcoSense® International Inc., one Nutrient Separating Baffle Box^{TM} form Suntree Technologies, one CDS® (continuous deflective separation) unit from Contech® Engineered Solutions and five inlet filter baskets. A brief analysis of the performance of each unit is presented. The study encompasses a full 6-month period of data collection; June through December 2013. The purpose of this summary is to outline key differences in removal efficiency for the three types of GPS (gross pollution separator) units. Data collected for the inlet basket filters has been purposely omitted.

DESCRIPTIONS OF THE INSTALLED GPS TECHNOLOGIES

The GPS technologies evaluated in this study include systems manufactured by Suntree Technologies, Contech Industries and EcoSense International. A brief description of each technology is given in the following sections.

Lake Concord Site: Suntree Technologies, Nutrient Separating Baffle Box™

Second Generation Baffle Box features:

- Concrete Structure, Rectangular Box
- Deflector Shields provided on both sides of the internal walls/chambers
- Floating Storm Boom and associated skimmer
- (2) Internal baffles
- Elevated Debris Collection Basket
- Shallow Excavations
- Internal Bypass

San Pablo Avenue Site: CDS unit, Contech Engineered Solutions Continuous Deflective Separator with Screening

CDS® Unit features:

- Concrete Structure, Cylindrical
- Tangential Pipe Connections
- Swirl Concentration with associated centrifugal forces
- Screening
- Oil Baffle
- Separation Slab (isolates sump area)
- Deep Excavations
- Internal Bypass

San Pablo Site: EcoSense International EcoVault®

Special Conditions: Author notes that this structure was constantly surcharged with high water levels from lake conditions. A bleeder valve was installed but found ineffective.

EcoVault® Baffle Box features:

- Concrete Structure, Rectangular Box
- Re-suspension prevention panels
- F.O.G (floatables-oil-grease) Baffle
- Elevated Debris Collection System
- Shallow Excavations
- Ported Baffle Wall
- Filter Weir
- 0448 Baffle Buddy Filter (2)
- Internal Bypass

Gee Creek Site: EcoSense International EcoVault®

EcoVault® Baffle Box features

- Concrete Structure, Rectangular Box
- Re-suspension prevention panels
- F.O.G (floatables-oil-grease) Baffle
- Elevated Debris Collection System
- Vault-Ox® Infusion System
- Internal Bypass
- Ported Baffle Wall
- Filter Weir
- 0261 Baffle Buddy Filter (2)
- Shallow Excavations

Lake Hodge Site: EcoSense International EcoVault®

EcoVault® Baffle Box features

- Concrete Structure, Rectangular Box
- Re-suspension prevention panels
- F.O.G (floatables-oil-grease) Baffle
- Elevated Debris Collection System
- Vault-Ox® Infusion System
- Internal Bypass
- Ported Baffle Wall
- Filter Weir
- 0261 Baffle Buddy Filter (2)
- Shallow Excavations

COMPARISON OF REMOVAL EFFICIENCIES
[Data taken from tables 4-16, 4-17, 4-18, 4-25, 4-26 4-33]

GPS UNIT	SITE	FLOW Mean/Max	TOTAL PHOSPHORUS	TSS	ZINC	COPPER	FECAL COLIFORM	TOTAL NITROGEN
Suntree NSBB™	Lake Concord	3/8 cfs	2.6%	66%	NA	NA	NA	1.6%
CDS®	San Pablo	2/5 cfs	9.3%	92%	NA	NA	NA	4.2%
EcoVault®	Lake Hodge	10/22 cfs	57%	91%	70%	40%	77%	14%
EcoVault®	Gee Creek	10/23 cfs	41%	78%	79%	64%	74%	2%
[1]EcoVault®	San Pablo	5/12 cfs	11%	63%	16%	15%	30%	14%

[1]High water conditions reduce effective head pressure on filters resulting in near zero flow through filters. High water conditions above debris screens result in nutrient release from captured organic debris.

Discussion from section 4.4.3

"Excellent removal efficiencies for total phosphorus were obtained in both the Lake Hodge and Gee Creek EcoVault® sites. Each of these sites was equipped with the outlet filter as well as the Vault-Ox® inserts. The level of phosphorus removal observed in these units is generally much greater than is commonly observed in typical GPS devices. The EcoVault® system without the Vault-Ox® insert, along with the Suntree baffle box and CDS unit, exhibited removal efficiencies ranging from approximately 3-9% which is typical of the range of values commonly observed for GPS units. The combination of the outlet filter system and the Vault-Ox® (concepts which are unique to the EcoVault® system) appear to substantially enhance phosphorus load reductions compared with the other devices."

Discussion from section 4.4.1.1.5

"A summary of observed mass removal efficiencies for total nitrogen, total phosphorus, and TSS in the EcoVault® units is given in Table 4-26. In general, removal efficiencies for total nitrogen were relatively low in value, ranging from approximately 2-14%. A substantially higher removal efficiency was observed for total phosphorus, ranging from 41-57% at the Osceola Trail sites, decreasing to 11% at the San Pablo EcoVault® site. The reduced mass removal for total phosphorus observed at this site is thought to be associated with the periodic flooded conditions which occurred in the unit. Mass load reductions for TSS were very good in each of the three units, ranging from 78-90%."

Discussion from sections 4.4.1.2.4

"As indicated on Table 4-25, positive mass removals were obtained in each of the three units for each of the evaluated metals based upon a comparison of inflow and outflow loadings. Relatively similar removal efficiencies for copper, iron, and zinc were obtained in the Lake Hodge and Gee Creek EcoVault® sites. However, somewhat lower removal efficiencies were obtained at the San Pablo site which was submerged during portions of the study and also did not contain the Vault-Ox® inserts. Since metals were not measured on the solids collected from the sumps, there is no way to determine if the observed removals for metals occurred as a result of sedimentation of solids or filtration of dissolved metals within the outlet filter. However, the San Pablo unit (which exhibited substantially lower metal removal efficiencies) also had an outlet filter system similar to the Gee Creek and Lake Hodge sites, suggesting that the filter system may not be a significant factor in removal. The Lake Hodge and Gee Creek sites also had the Vault-Ox® inserts which maintained oxidized conditions within the unit, and may have caused some of the metals to precipitate out as either oxides or hydroxides, accumulating into the sump. If this assumption is true, then the Vault-Ox® insert appears to substantially enhance the overall effectiveness of the system for stormwater metals."

ERD
Water Quality Engineering

DEPARTMENT OF ENVIRONMENTAL PROTECTION
FLORIDA

CITY OF CASSELBERRY
INC. 1940

ESI
EcoSense International

MICCO LAB ANALYSIS	DN in Bbin 1/14/16 mg/L	DN out Bbout 1/14/16 mg/L	% Δ	DN in Bbin 3/14/16 mg/L	DN out Bbout 3/14/16 mg/L	%Δ
TSS	5.0 U	16	220	5.0 U	5.0 U	0
TN	1.2	0.96	-20	1.1	0.87	-21
Nitrogen, Ammonia	0.43	0.5	16	0.32	0.46	44
Total Kjeldahl Nitrogen	0.87	0.78	-10	0.87	0.82L	-6
Nitrogen, Nitrate	0.29	0.094	-68	0.19	0.048 I	-75
Nitrogen, Nitrite	0.039	0.083	213	0.025 I	0.025 I	0
Nitrogen, NO2 +NO3	0.29	0.18	-38	0.19	0.048 I	-75
Orthophosphate as P	0.099	0.029	-71	0.12	0.098	-18
Total Phosphorus	0.096 I	0.050 U	-48	0.11	0.079 I	-28

I - The reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

U - Compound was analyzed for but not detected

BOARD OF COUNTY COMMISSIONERS

Final Monitoring Report

for

Micco I Stormwater Improvement Project

Prepared by:

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For

Brevard County Natural Resources Management Department
Watershed Management Program
2725 Judge Fran Jamieson Way
Building A, Room 219
Viera, Florida 32940

DEP Contract No. G0358
August 30, 2016

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List of Acronyms and Abbreviations:

BMAP- Basin Management Action Plan

BMP- Best Management Practice

FDEP- Florida Department of Environmental Protection

FAWN- Florida Automated Weather Network

Ft. - Feet

Gal. - Gallon

In. - Inches

IRL- Indian River Lagoon

MDL- Minimum Detection Limit

NELAC- National Environmental Laboratory Accreditation Conference

NH_3- Ammonia

NO_2- Nitrite

NO_3- Nitrate

QAPP- Quality Assurance and Protection

PLSM- Pollutant Loading Screening Model

SOP- Standard Operating Procedure

TMDL- Total Maximum Daily Load

TN- Total Nitrogen

TKN- Total Kjeldahl Nitrogen

TP- Total Phosphorous

TSS- Total Suspended Solids

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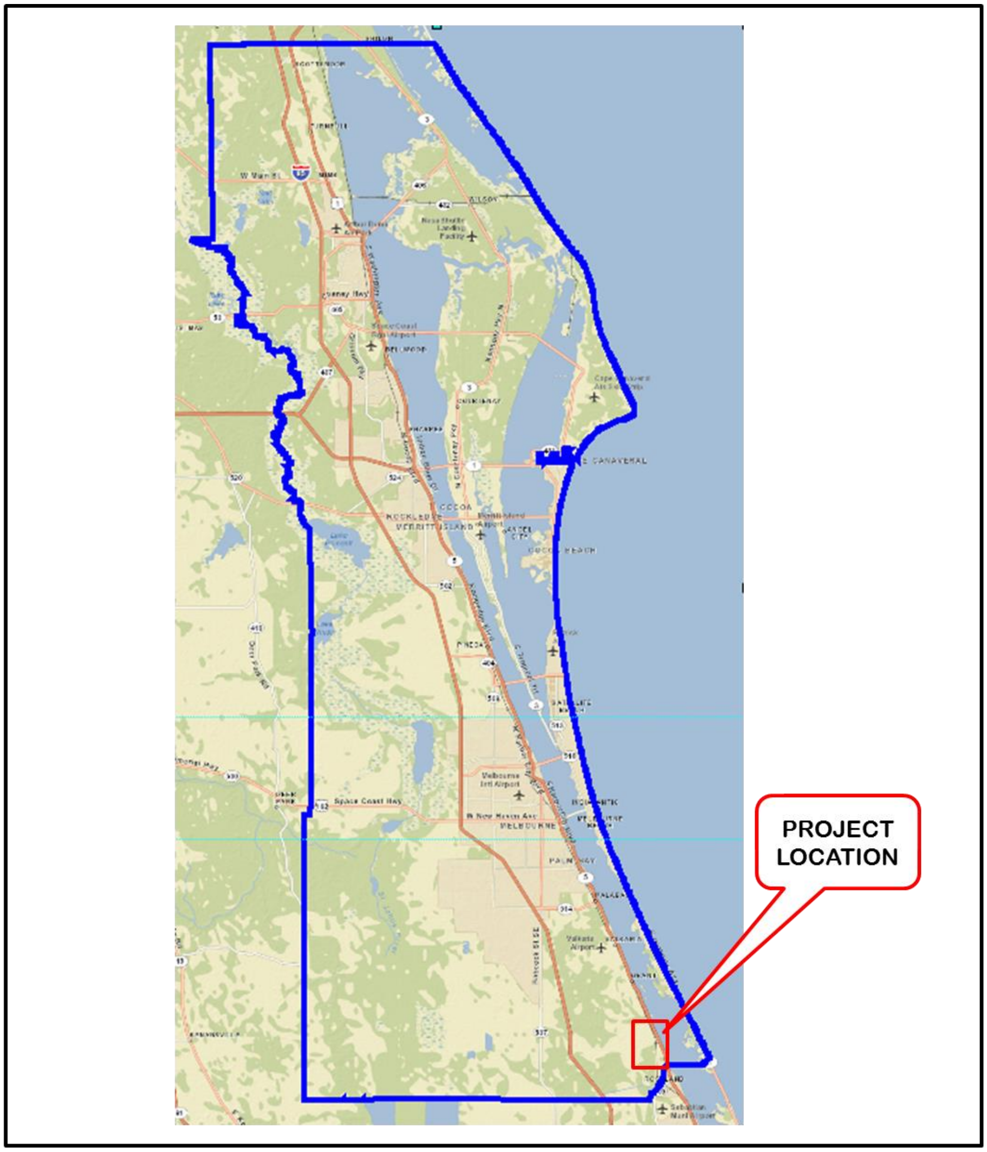
Section 1: Background

1.1 Project Location

The Micco I Stormwater Improvement project is located in southern Brevard County, FL. As shown in Figure 1.

Figure 1- Location and basin delineation for Micco I stormwater Improvement Project.



Brevard County Natural Resources Watershed Management Program 2725 Judge Fran Jamieson Way Viera, Florida 32940 (321)633-2014 Fax: (321)633-2029	Micco I Storm Water Improvements	MAP IS NOT TO SCALE Date: 4-17-2015

1.2 Project Description

The Micco I stormwater improvement encompasses 52-acres and provides treatment for two separate basins. In the north basin, an exfiltration system with a denitrification wall provides treatment to a 14.78-acre region that previously had no treatment. In the south basin, a baffle box and a denitrification box provide treatment for a 37.43-acre region that previously had very limited stormwater treatment. The project components of each basin are detailed in Figures 2 (north) and 3 (south).

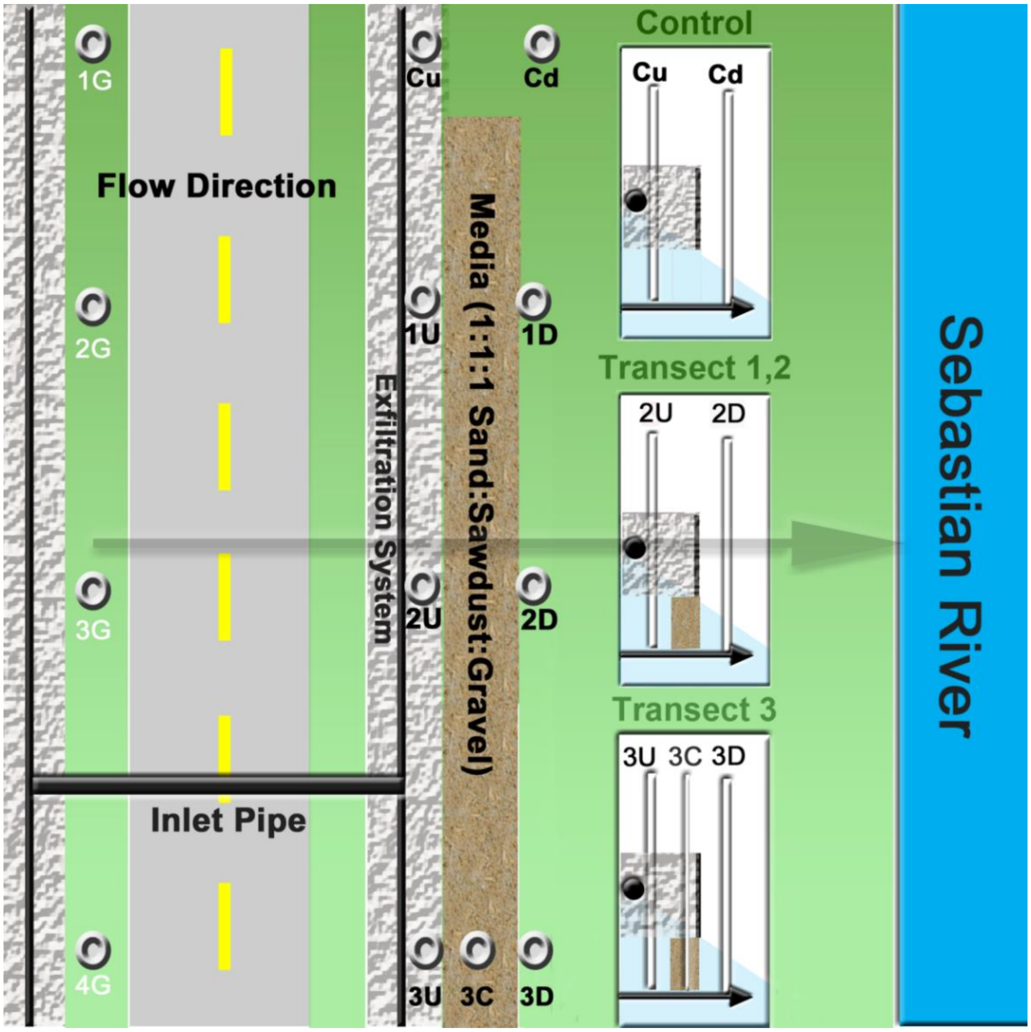


Figure 2- Micco I Stormwater Improvement Project, North Basin Monitoring Details : Stormwater is directed to an inlet pipe through the exfiltration system (grey) through the denitrification media (tan). Transect lines of groundwater wells are shown as circles with a control transect (Cu-Cd) north of the denitrification media, and 3 transects (1U-1D, 2U-2D, 3U-3D) throughout the media. Wells 1G-4G monitor the baseflow groundwater flux downstream of the project. An Autosampler (A) was installed in the inlet pipe where it meets the exfiltration system.

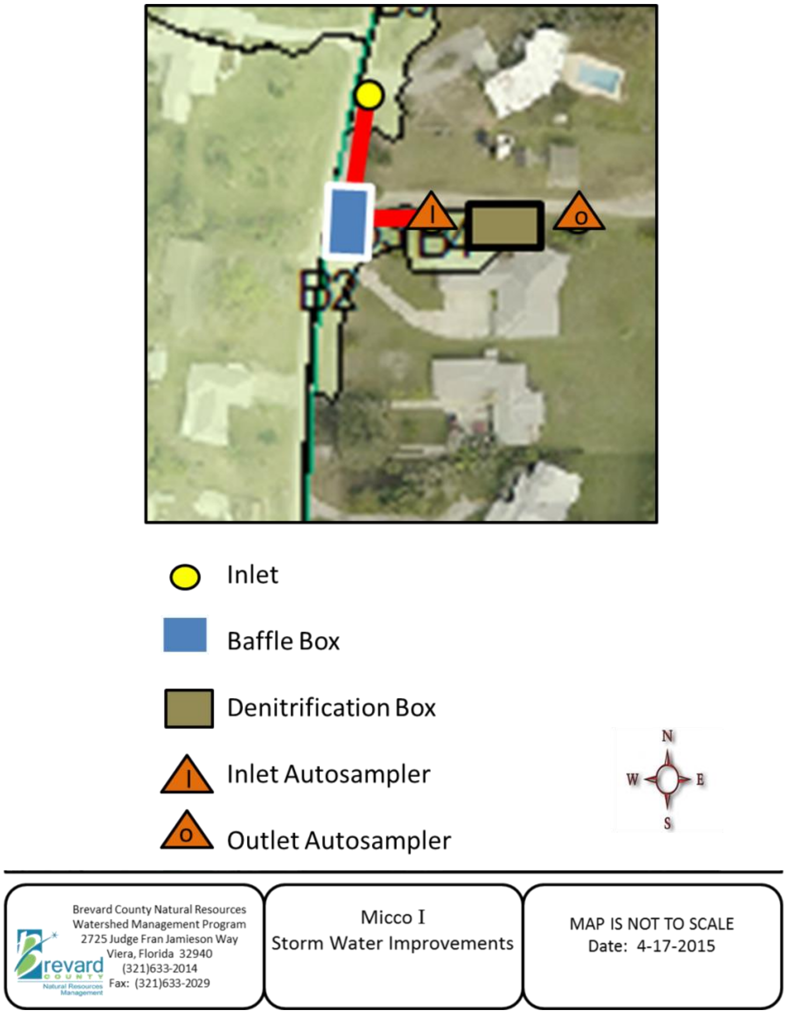


Figure 3- Micco I Stormwater Improvement project**,** South Basin Monitoring Details : Stormwater was directed into the project basin at the inlet pipe (yellow), through a baffle box (blue), and then through a denitrification box (tan). Autosamplers (orange) were be installed at the inlet (I) and outlet (o) of the denitrification box.

The Project region drains to the Sebastian River, which is managed under the Central IRL BMAP. Land use within the project basin is displayed in Table 1.

Table 1- Land Use within the Micco I Project basin

Land Use	Acres	%
Residential	**49.15**	**92**
Industrial/Commercial	**0**	**0**
Agricultural	**0**	**0**
Forested	**3.06**	**8**
Wetlands	**0**	**0**
Land Use Totals (Acreage and %)	**52.21**	**100**

According to the regional BMAP, nutrients and TSS are the pollutants of highest significance for this portion of the Estuary. The PLSM model as well as published literature (Schmidt and Clark, 2013) was used to determine expected pollutant loads and reductions for this project. These values are shown below in Table 2 (reproduced from Amended 319 Grant Application).

Table 2- Expected pollutant load reductions for the Micco I Project (A) North Basin; (B) South Basin (reproduced from Amended 319 Grant Application)

(A)

BMPs Installed Exfiltration		TSS lbs/yr	TP lbs/yr	TN lbs/yr
Pollutant Loads	**Pre-Project**	1,206.53	13.16	92.88
	Post-Project	458.487	3.14	22.19
	Load Reduction	748.05	10.02	70.69
	% Reduction	62%	76%	76%

Denitrification Wall		TSS lbs/yr	TP lbs/yr	TN lbs/yr
Pollutant Loads	Pre-Project	NA	NA	22.19
	Post-Project	NA	NA	0.67
	Load Reduction	NA	NA	21.52
	% Reduction	NA	NA	97%

TOTAL (North Basin)		TSS lbs/yr	TP lbs/yr	TN lbs/yr
Pollutant Loads	Pre-Project	1,206.53	13.16	92.88
	Post-Project	458.487	3.14	0.67
	Load Reduction	748.05	10.02	92.21
	% Reduction	62%	76%	99.3%

(B)

TOTAL South Basin Baffle Box		TSS lbs/yr	TP lbs/yr	TN lbs/yr
Pollutant Loads	Pre-Project	4,133.64	44.54	314.86
	Post-Project	1,355.83	37.64	254.88
	Load Reduction	2,777.81	6.90	59.98
	% Reduction	67.2%	15.5%	19.05%

Section 2: Sampling Methodology

2.1 North Basin

The north and south basins of the Project were monitored separately. The north basin consists of 600 feet of exfiltration pipe surrounded by 8 feet of gravel with a denitrification bioreactor wall that is located below the water table for approximately 450 feet of that length and a control section consisting of exfiltration pipe and gravel alone for 150 feet. Stormwater enters this system through inlets and is then directed through the groundwater exfiltration/denitrification system. The water entering the exfiltration/denitrification treatment system is therefore a mixture of baseflow groundwater and stormwater inputs. There is no immediate outlet to this system therefore the treatment efficacy of the system is evaluated by; comparing baseflow groundwater inputs (Figure 2; 1G-4G) to downgradient well outputs (Figure 2; Cd, 1D-3D) and upgradient well inputs (Figure 2; Cu, 1U-3U) to downgradient wells.

The monitored inlet is one of 10 total inlets to the project. Each of these inlets serves a similar sized basin with similar land-use and is expected to have similar flow/pollutant loads. Therefore, data generated from this point was extrapolated to represent flow throughout the project. A time lag exists as stormwater moves through the exfiltration system; therefore groundwater samples were not collected with each storm event. Rather, groundwater samples were collected on a monthly basis for a period of one year and following three storm events. Weather station data was downloaded from the FAWN weather data network (Indian River, Station 371) for the week prior to each collection event so samples could be further qualified and correlated with weather events.

Transducers were installed at each groundwater transect point, except the center well (3C in Figure 2). Water level differences between wells in a transect and saturated hydraulic conductivities were used to quantify groundwater discharges using the Darcy's Law equation. Saturated hydraulic conductivity was determined using the Hvorslev slug test method on each individual well.

Parameters monitored included TN, TP, TSS, NO_2, NO_3, TKN, NH_3, and Orthophosphate. All field activities were carried out according to applicable FDEP SOPs (2014). Samples were placed on ice and sent to Pace Analytical Laboratory for analysis. See Appendix 1 for applicable

NELAC certifications and Appendix 2 for analytical methods followed for laboratory analyses of each parameter collected.

Differences in nutrient and sediment loads between upgradient and downgradient well sections are initially reported as mass loading rates (kg/d) for a normalized 1 m^2 section of soil/denitrification media with an effective porosity of 0.50. This metric is used in order to have an analogous comparison between control and treatment sections given their different sizes. Total loading rates are then extrapolated to the entire surface area of the bioreactor.

2.2 South Basin

The south basin of the project consists of a baffle box and a denitrification box as shown in Figure 3. Water flows from the baffle box to the denitrification box. An autosampler system with associated flowmeter and rain gauge was set up on both sides of the denitrification box to collect samples from storm events. At the inlet to the box, the auto-sampler was triggered at the start of a storm event and collected flow weighted composite samples during the period of elevated flow. At the outlet station the sampler was triggered by a rise in water level and will collected a 24hr. composite sample with at least 6 evenly-distributed sub-samples. Removal capacity of the denitrification box was determined by comparing water entering the system with water exiting the system.

Parameters monitored in the south basin included TN, TP, TSS, NO_2, NO_3, TKN, NH_3, and Orthophosphate. All field activities were carried out according to applicable FDEP SOPs (2014). Samples were placed on ice and sent to Pace Analytical Laboratory for analysis. See Appendix 1 for applicable NELAC certifications and Appendix 2 for analytical methods followed for laboratory analyses of each parameter collected.

Section 3: Results and Discussion

3.1- North Basin

Nutrient and sediment concentrations and loads were evaluated on a series of groundwater wells within the project area (Figure 2). Differences in concentrations of these parameters were compared between a control section consisting of an exfiltration/gravel system alone, and a treatment section with a denitrification bioreactor enhancement. Storm inputs to the treatment system was evaluated by collecting flow-weighted water samples within an inlet pipe.

3.1a- Water Quality

The denitrification bioreactor is located within the groundwater table and periodically stormwater is directed through the treatment system via perforated pipes. Therefore, the water that is treated by the bioreactor is a mixture of baseflow groundwater nutrient and sediment loads and periodic stormwater pulses. The groundwater doesn't consistently flow from west to east at the project site. There are periods where the groundwater flowed from the downgradient to the upgradient well, particularly in Transect 3 and Transect C (Figure 2). Although, these periods are brief and the total discharge for the 244-day duration of the monitoring is 13,479,047 L/m^2 and 32,030,777 L/m^2 for the control and treatment transects respectively. This positive value indicates that for most of the monitoring duration, wells CU, 1U-3U (Figure 2) were upgradient from wells CD, 1D-3D (Figure 2) and the general flow was through the denitrification bioreactor. The baseflow wells (1G-4G, Figure 2) were consistently lower in elevation than the upgradient wells indicating a hydrologic high near the upgradient wells. The downgradient wells were lower in elevation than the baseflow wells with the exception of the control transect, indicating that the majority of overall baseflow groundwater is from west to east. Due to the stormwater inputs through the perforated pipe, discontinuities in soil porosity between gravel, soil and soil/woodchip mixes in a low relief area, this variability in groundwater flow isn't unexpected.

Average groundwater baseflow nutrient and sediment concentration and loads are shown in Table 3 and average stormflow nutrient and sediment concentrations and loads extrapolated to 10 inlets are shown in Table 4. The storm events monitored encompassed a range of total rainfall from 1.5 – 3.9 cm and volumes extrapolated across the 10 inlets ranging from 73 to 18,269

Liters. Total phosphorus and orthophosphate concentrations are an order of magnitude higher in groundwater than stormflow. Total suspended solids was undetectable in any of the storm samples. All species of nitrogen were comparable in concentration between groundwater and stormwater, although NO_3 was somewhat higher in stormwater. The stormwater loads of each analyte are large as compared to the baseflow groundwater loads.

Table 3 – The concentration and mass loading rate on the denitrification bioreactor from groundwater baseflow. Calculation assumes an effective porosity of 50% and are normalized to one square meter of denitrification bioreactor. The total surface area of the bioreactor is 192 m^2.

Transect		TSS	TN	NH_4	NO_3	Org-N	Ortho-P	TP
1	Load (mg/d per m^2)	7056	428	69	71	287	14	74
	Conc (mg/L)	*14.89*	*0.90*	*0.15*	*0.15*	*0.61*	*0.03*	*0.16*
2	Load (mg/d per m^2)	3566	701	114	141	446	85	185
	Conc (mg/L)	*4.44*	*0.87*	*0.14*	*0.18*	*0.56*	*0.11*	*0.23*
3	Load (mg/d per m^2)	5026	982	103	199	682	423	239
	Conc (mg/L)	*4.44*	*0.87*	*0.09*	*0.18*	*0.60*	*0.37*	*0.21*
Ave.	Load (mg/d per m^2)	5216	423	57	82	236	105	100
	Conc (mg/L)	*7.93*	*0.88*	*0.13*	*0.17*	*0.59*	*0.17*	*0.20*
stdev	Load (mg/d per m^2)	1752.46	277.47	23.33	64.19	198.99	218.64	83.99
	Conc (mg/L)	*6.03*	*0.02*	*0.03*	*0.02*	*0.03*	*0.18*	*0.04*

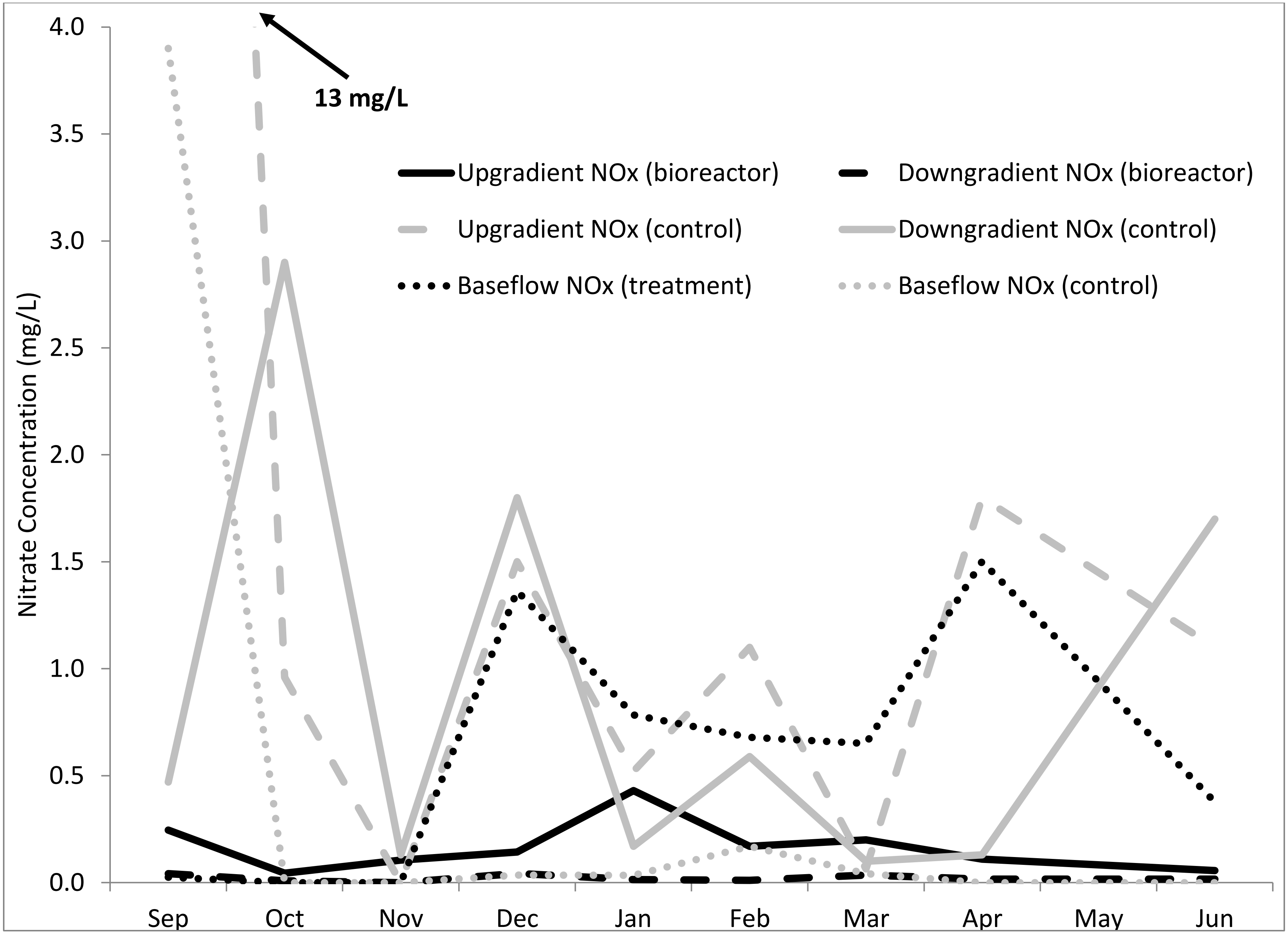
Table 4 - The stormwater concentration and mass loading rate from the monitored inlet as extrapolated to the 10 inlets.

Date		TSS	TN	NH_4	NO_3	Org-N	Ortho-P	TP
3/20/16	Load (mg)	0	57.3	8.0	1.3	35.6	2.5	0.0
	Conc (mg/L)	*0*	*0.79*	*0.11*	*0.18*	*0.49*	*0.035*	*0*
3/24/16	Load (mg)	0	2917.3	0.0	77.4	2143.3	119.1	297.7
	Conc (mg/L)	*0*	*0.49*	*0*	*0.13*	*0.36*	*0.02*	*0.05*
4/15/16	Load (mg)	0	32885.3	5846.3	1352	14250.3	2557.7	3836.6
	Conc (mg/L)	*0*	*1.8*	*0.32*	*0.74*	*0.78*	*0.14*	*0.21*
5/17/16	Load (mg)	0	1317.5	263.5	47.6	618.2	263.5	0.0
	Conc (mg/L)	*0*	*0.13*	*0.026*	*0.047*	*0.061*	*0.026*	*0*
Ave	Load (mg)	0	9294.4	1529.4	369.6	4261.9	735.7	1033.6
	Conc (mg/L)	*0*	*0.80*	*0.11*	*0.27*	*0.42*	*0.06*	*0.07*
stdev	Load (mg)	0	15770.8	2880.5	655.7	6718.0	1219.4	1874.0
	Conc (mg/L)	*0*	*0.72*	*0.15*	*0.32*	*0.30*	*0.06*	*0.10*

The concentrations over time for baseflow, upgradient and downgradient wells are shown in Figure 4. There was no significant difference in baseflow well concentrations of TSS, orthophosphate and TP, so a single average value is shown. There were significant differences in NH_4 and NO_3 between the baseflow well upgradient from the control, and the baseflow wells above the denitrification bioreactor. As such, each concentration is indicated separately on the figure.

During the first sampling event, there were exceptionally high concentrations of NO_3, total nitrogen and TSS in the control transect alone. It is uncertain whether this outlier is due to the recent construction or whether there was an outside pulse of sediments and nutrients. NO_3 concentration was higher in the groundwater baseflow wells upgradient from the denitrification bioreactor as compared to the control groundwater baseflow well indicating a higher load of NO_3 on the bioreactor. NO_3 was consistently reduced below detection within the denitrification bioreactor transects, while no such reduction was consistently observed in the control transects. Interestingly, although NO_3 concentrations in baseflow were higher on the denitrification bioreactor transects, the upgradient wells had much lower NO_3 concentrations than the control upgradient wells. Due to the aforementioned variability in groundwater flow direction, it is possible that NO_3 has been lost in a large pool around the denitrification bioreactor that has influenced the upgradient well.

Ammonium was significantly higher in the groundwater baseflow wells upgradient from the denitrification bioreactor as compared to the control. As such, NH_4 concentrations were higher in upgradient and downgradient wells. With the exception of the last sampling event, the downgradient wells were consistently higher in NH_4 than the upgradient wells within the denitrification bioreactor transects as compared to the upgradient wells indicating a possible source of NH_4 within the bioreactor Organic nitrogen was relatively consistent between upgradient and downgradient wells for both the denitrification bioreactor and control transects. Orthophosphate was generally lower in the downgradient wells within both the control and the bioreactor, although TP changed very little. TSS was not markedly reduced in either the gravel exfiltration system or the denitrification bioreactor, and often both of these treatment systems were a source of TSS.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3.0
2.5
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1.5
1.0
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Nitrate Concentration (mg/L)
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Downgradient NOx (bioreactor)
Upgradient NOx (control)
Downgradient NOx (control)
Baseflow NOx (treatment)
Baseflow NOx (control)
Sep
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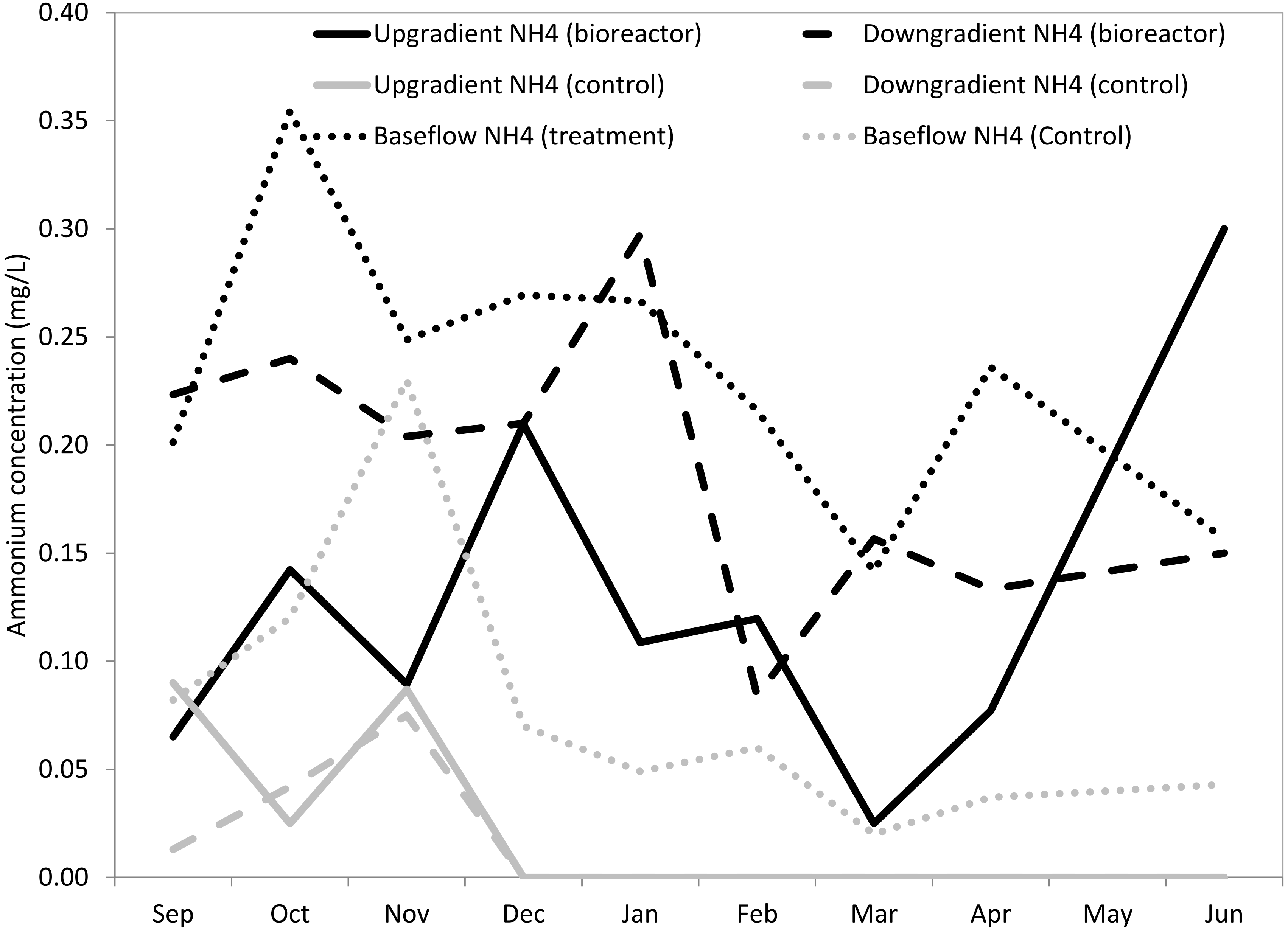
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0.20
0.15
0.10
0.05
0.00
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Downgradient NH4 (bioreactor)
Upgradient NH4 (control)
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Baseflow NH4 (Control)
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Oct
Nov
Dec
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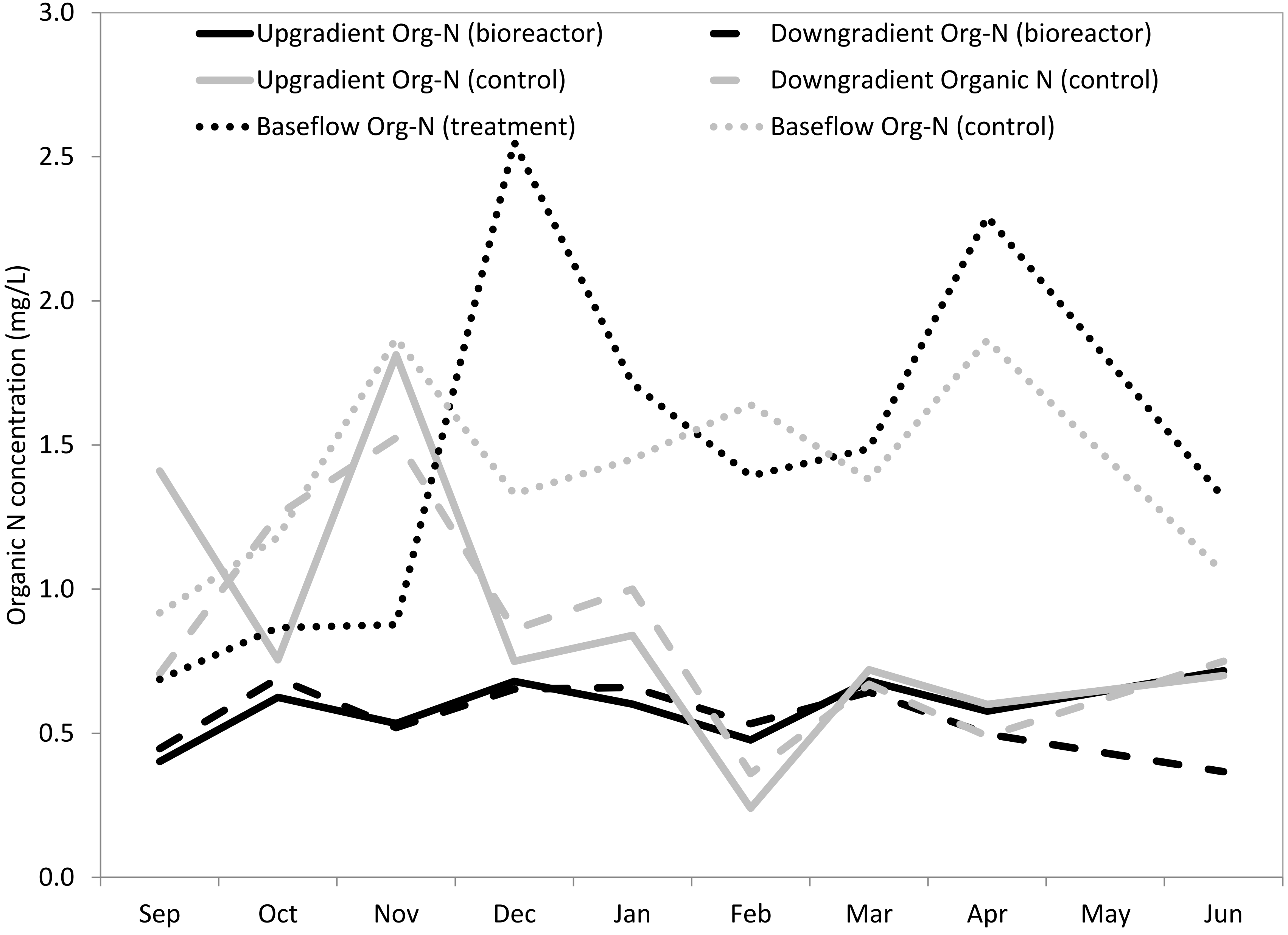
B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1.5
2.0
2.5
3.0
Sep
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Nov
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May
Jun
Upgradient Org-N (bioreactor)
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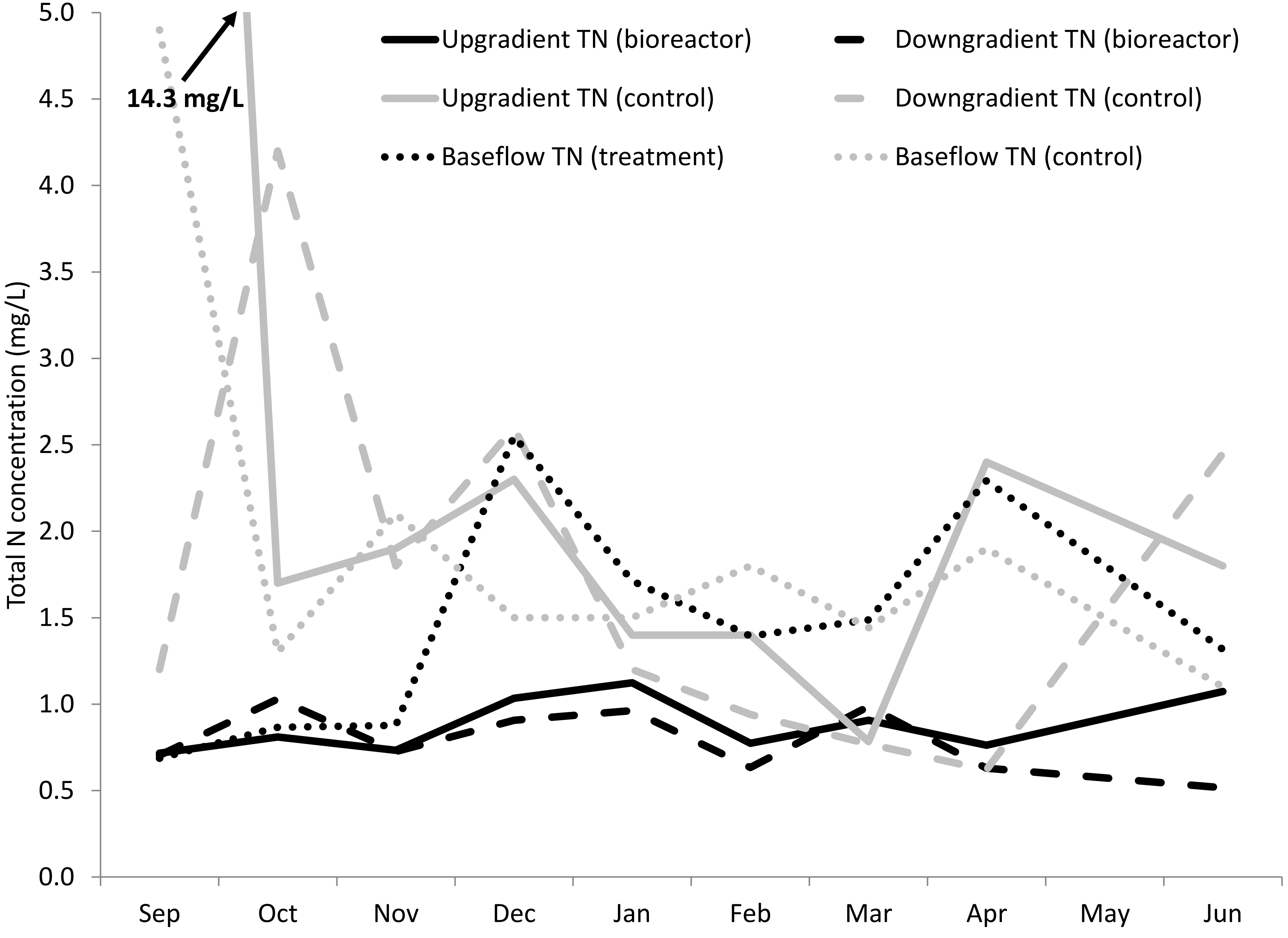
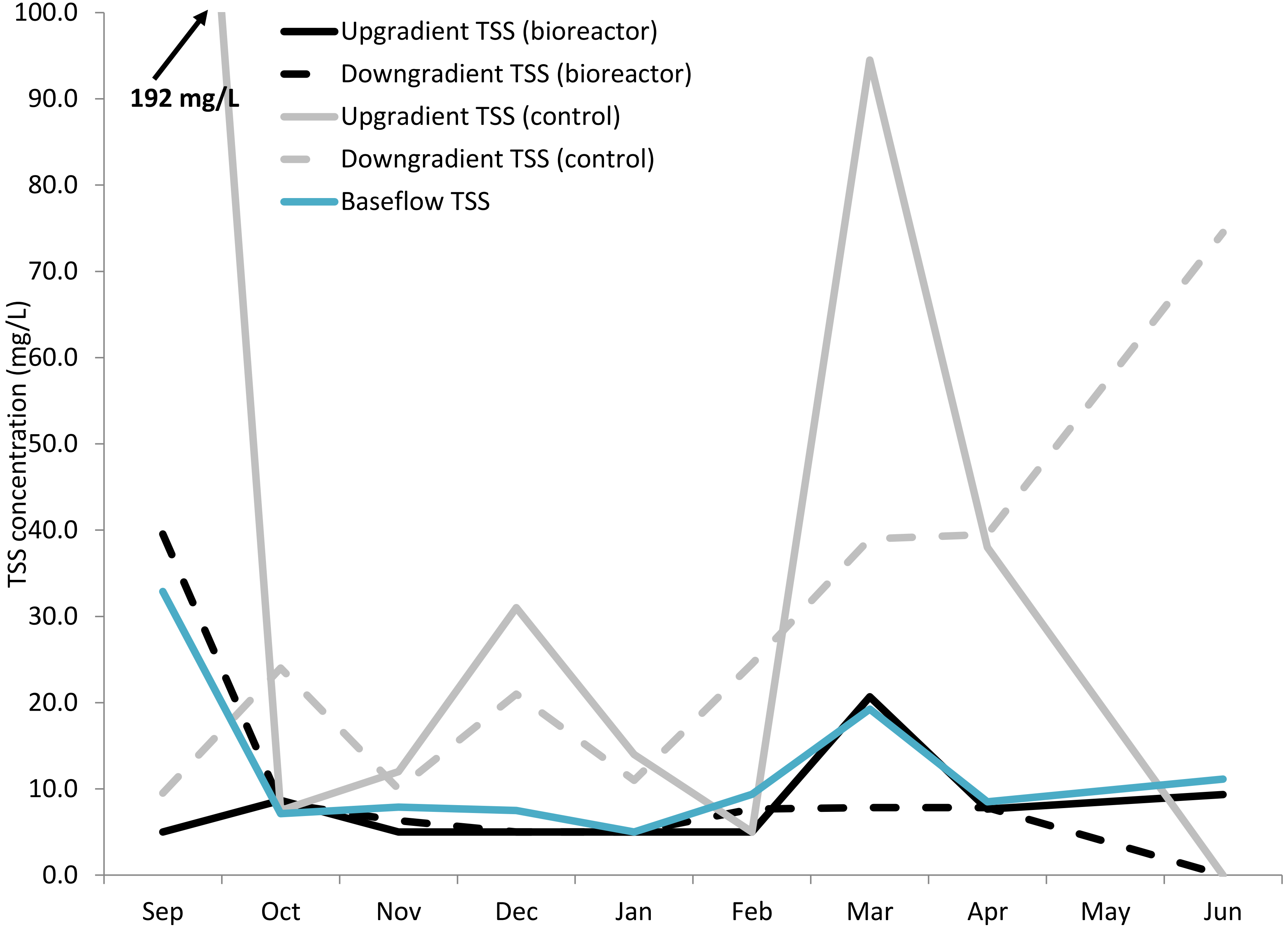
Baseflow Org-N (control)

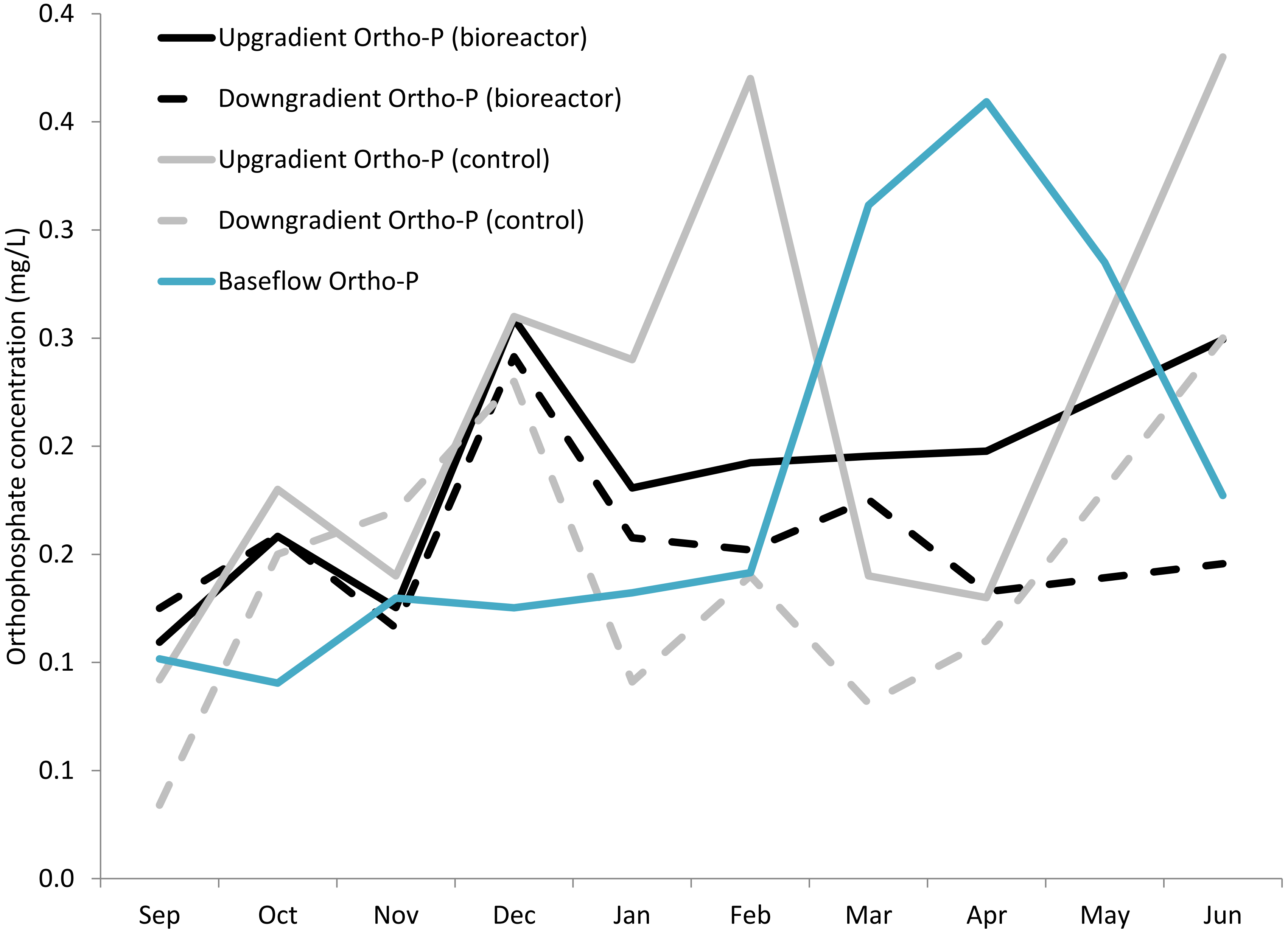
C


5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Total N concentration (mg/L)
14.3 mg/L
Upgradient TN (bioreactor)
Downgradient TN (bioreactor)
Upgradient TN (control)
Downgradient TN (control)
Baseflow TN (treatment)
Baseflow TN (control)
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

D


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
TSS concentration (mg/L)
192 mg/L
Upgradient TSS (bioreactor)
Downgradient TSS (bioreactor)
Upgradient TSS (control)
Downgradient TSS (control)
Baseflow TSS
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

E


0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
Orthophosphate concentration (mg/L)
Upgradient Ortho-P (bioreactor)
Downgradient Ortho-P (bioreactor)
Upgradient Ortho-P (control)
Downgradient Ortho-P (control)
Baseflow Ortho-P
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

F

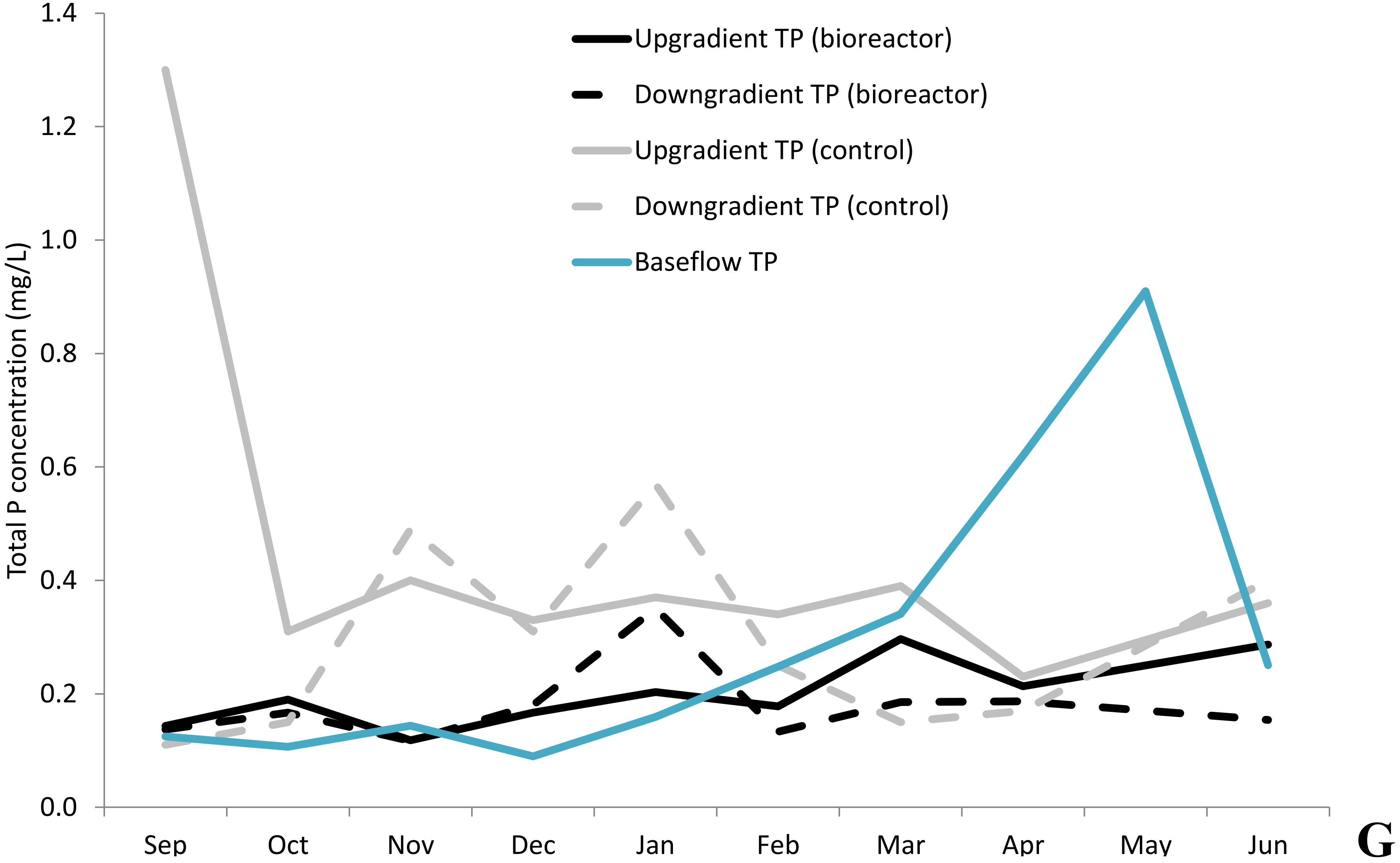


Figure 4 - The concentrations over time of A) NO_3, B) NH_4, C) Organic-N, D) Total N, E) TSS F) orthophosphate, and G) total phosphorus within the well transects.

Percent reductions of each of the measured parameters are summarized in Figure 5. As mentioned previously, NO_3 was reduced within the denitrification bioreactor below detection, with no such reduction within the control transect. The NH_4 concentration was consistently higher in downgradient wells within the denitrification bioreactor until the final sampling event. Other denitrification bioreactors have caused short-term increases in organic nitrogen and NH_4. There was no increase in organic nitrogen in this bioreactor, but there appeared to be a short-term pulse of NH_4. Further monitoring would be necessary to confirm whether this NH_4 increase continues.

Differences in concentration and mass load are compared between the baseflow and downgradient wells (Table 5) as well as the upgradient and downgradient wells (Table 6). Within the section of the exfiltration trench containing a bioreactor, all parameters decreased between the groundwater baseflow wells and the downgradient wells except total phosphorus. Within the control section of the exfiltration trench, TSS and NO_3 increased and all other parameters decreased. Total nitrogen reductions were an order of magnitude higher in the denitrification bioreactor transects as compared to the control transects. Comparing differences in the parameters measured between the upgradient and downgradient wells indicates that within the bioreactor the mass load of total nitrogen, NO_3, organic nitrogen and total phosphorus decreased, while orthophosphate, NH_4 and TSS increased. Within the control transect, orthophosphate and total phosphorus decreased while all other parameters increased. Total nitrogen reductions were several orders of magnitude higher in the denitrification bioreactor transects as compared to the control transects.

Overall, the groundwater baseflow total nitrogen load of 102 kg over the monitoring period (244 days) was reduced by 50%. Comparing between the upgradient and downgradient well the total nitrogen loads were much more modest with a 5% reduction of the total load of 1,530 kg over the monitoring period. The lower reduction percentage of the latter comparison is due to the fact that the upgradient total nitrogen concentrations are much lower, and the groundwater discharges are much higher.

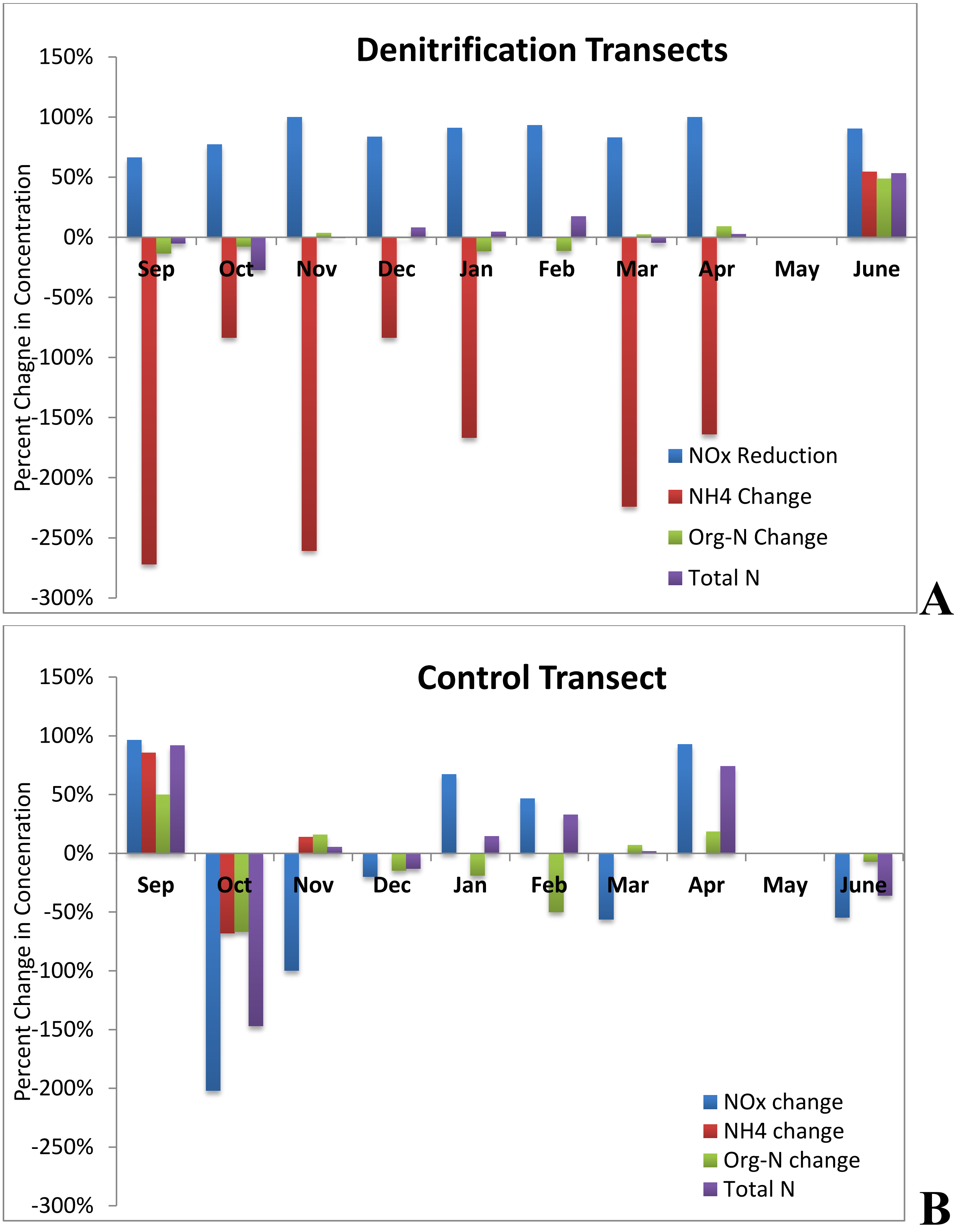


Figure 5 – The % change in analytes over time within A) the denitrification bioreactor transect and B) control transect.

Table 5 – The change in concentration and mass load between the baseflow wells (Figure 2; CG, 1-3G) and the downgradient wells (Figure 2; CD, 1-3D). Mass loads are reported as mass per surface area (m^2) of bioreactor/soil

Analyte	Comparison	Control	Ave. Bioreactor	stdev Bioreactor
TSS	∆ conc (mg/L)	-20.56	2.89	9.93
	∆ Load (kg/m2)	*NA*	0.15	1.67
TN	∆ conc (mg/L)	0.22	3.28	4.38
	∆ Load (kg/m2)	*NA*	0.46	0.55
NH4	∆ conc (mg/L)	0.07	0.04	0.19
	∆ Load (kg/m2)	*NA*	0.01	0.04
Nox	∆ conc (mg/L)	-0.43	0.58	0.42
	∆ Load (kg/m2)	*NA*	0.10	0.07
Org-N	∆ conc (mg/L)	0.59	0.06	0.30
	∆ Load (kg/m2)	*NA*	0.02	0.05
Ortho-P	∆ conc (mg/L)	0.04	0.01	0.10
	∆ Load (kg/m2)	*NA*	0.00	0.01
TP	∆ conc (mg/L)	0.14	-0.01	0.06
	∆ Load (kg/m2)	*NA*	0.00	0.01

Table 6 - The change in concentration and mass load between the upgradient wells (Figure 2; CU, 1-3U) and the downgradient wells (Figure 2; CD, 1-3D). Mass loads are reported as mass per surface area (m^2) of bioreactor/soil.

Analyte	Comparison	Control	Ave. Bioreactor	stdev bioreactor
TSS	Δ conc (mg/L)	-2.86	-1.80	3.5
	Δ Load (kg/m^2)	-91.57	-39.41	74.0
TN	Δ conc (mg/L)	-0.04	0.09	0.2
	Δ Load (kg/m^2)	-1.37	0.63	2.5
NH4	Δ conc (mg/L)	0.00	-0.06	0.1
	Δ Load (kg/m^2)	-0.01	-1.03	1.4
NO_3	Δ conc (mg/L)	-0.01	0.15	0.0
	Δ Load (kg/m^2)	-0.23	1.78	0.7
Org-N	Δ conc (mg/L)	-0.04	0.03	0.0
	Δ Load (kg/m^2)	-1.42	0.36	0.6
Ortho-P	Δ conc (mg/L)	0.09	0.01	0.1
	Δ Load (kg/m^2)	2.89	-0.13	0.8
TP	Δ conc (mg/L)	0.05	0.02	0.1
	Δ Load (kg/m^2)	1.68	0.78	1.2

3.2- South Basin

Grab samples were collected at the inflow and outflow pipes of the denitrification box. Though these grabs did occur during/immediately after rain events, flowmeters had not yet been installed, therefore no flow volume data is available to correlate with the monitored pollutant concentrations. However, these preliminary results indicate that the denitrification box is likely working as expected to lower the loads of nutrients leaving the system. Concentrations of monitored pollutants during this 3 month period are displayed in Table 7.

Table 7- Pollutant concentrations collected as grab samples prior to instillation of autosampler systems. Parameters that indicate a lowered level at the outflow are shown in **bold** type. *

	January 2016		March 2016		April 2016		3 Month Average	
Parameter (mg/L)	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
Nitrogen, Ammonia	0.51	0.31	0.32	0.46	0.32	0.46	0.38	0.41
Nitrogen, Kjeldahl, Total	1	0.77	0.87	0.82	0.87	0.82	**0.91**	**0.80**
Nitrogen, NO2 plus NO3	0.26	0.29	0.19	0.048 I	0.19	0.048 I	**0.21**	**0.13**
Nitrogen, Nitrate	0.19	0.29	0.19	0.048 I	0.19	0.048 I	**0.19**	**0.13**
Nitrogen, Nitrite	0.069	0.032 I	U	U	U	U	**0.02**	**0.01**
Orthophosphate as P	0.11	0.1	0.12	0.098	0.12	0.098	**0.12**	**0.10**
Phosphorus, Total (as P)	0.096 I	0.094 I	0.11	0.079 I	0.11	0.079 I	**0.11**	**0.08**
Total Suspended Solids	U	U	U	U	U	U	U	U
Total Nitrogen	1.3	1.1	1.1	0.87	1.1	0.87	**1.17**	**0.95**

*Data qualifiers are shown to indicate where load and removal calculations have been based on qualified raw data. A data qualifier of U indicates that a parameter was analyzed but not detected, I indicates that a parameter was detected between the Method Minimum Detection Level and Minimum Reporting Level; NA indicates that a value could not be generated for a given parameter, A negative removal or percent indicates an apparent addition to the system.

Five storm events were successfully sampled during the monitoring period. These events all took place during the summer, or typically rainy season. Physical data for these events is displayed below in Table 8.

Table 8- Physical characteristics of the five storm events captured by autosampler during the monitoring period for the Micco I stormwater improvement project.

			Flow Volume (Gal)		Time sampled (hrs)		# Samples Collected	
Event	**Date**	**Rain (in)**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
1	6/6/2016	0.12	90,613.6	67,238.7	43	42	42	27
2	7/1/2016	0.09	44,942	45,661	24	24	45	45
3	8/3/2016	0.26	6,7701.9	40,805.6	47.5	33	45	19
4	8/28/2016	0.12	124,476	39,329.8	25	25	45	17
5	8/29/2016	0.88	191,012	58,394.2	23	26	47	18

Due to time constraints, events four and five are not the requisite 72 hours apart. Pollutant concentration, load, and removal values for each storm event are detailed below in Table 9.

Table 9- Pollutant concentrations, loads, and removal rates for the five storms monitored via autosampler for the Micco I stormwater improvement project, South Basin

Storm Event 1- 6/6/2016

	Concentration (mg/L)		Load (lbs)		Removal (lbs)	
Parameter	IN	OUT	IN	OUT	lbs.	%
Nitrogen, Ammonia	0.22	0.23	0.17	0.13	0.04	22
Nitrogen, Kjeldahl, Total	0.98	0.96	0.74	0.54	0.20	27
Nitrogen, NO2 plus NO3	0.2	0.25	0.15	0.14	0.01	7
Nitrogen, Nitrate	0.2	0.25	0.15	0.14	0.01	7
Nitrogen, Nitrite	0.041 I	0.044 I	0.03	0.02	0.01	20
Orthophosphate as P	0.064	0.073	0.05	0.04	0.01	15
Phosphorus, Total (as P)	0.094 I	0.099 I	0.07	0.06	0.02	22
Total Suspended Solids	U	U	U	U	U	NA
Total Nitrogen	1.2	1.2	0.91	0.67	0.23	26

Storm Event 2- 7/1/2016

	Concentration (mg/L)		Load (lbs)		Removal (lbs)	
Parameter	IN	OUT	IN	OUT	lbs.	%
Nitrogen, Ammonia	0.21	0.26	0.08	0.10	-0.02	-26
Nitrogen, Kjeldahl, Total	1	0.99	0.38	0.38	0.00	-1
Nitrogen, NO2 plus NO3	0.17	0.18	0.06	0.07	0.00	-8
Nitrogen, Nitrate	0.17	0.18	0.06	0.07	0.00	-8
Nitrogen, Nitrite	0.025 I	0.027 I	0.01	0.01	0.00	-10
Orthophosphate as P	0.02	0.054	0.01	0.02	-0.01	-174
Phosphorus, Total (as P)	0.099 I	0.11	0.04	0.04	-0.005	-13
Total Suspended Solids	2.4	3.8	0.90	1.45	-0.55	-61
Total Nitrogen	1.2	1.2	0.45	0.46	-0.01	-2

Storm Event 3- 8/3/2016

	Concentration (mg/L)		Load (lbs)		Removal (lbs)	
Parameter	IN	OUT	IN	OUT	lbs.	%
Nitrogen, Ammonia	0.25	0.3	0.14	0.10	0.04	28
Nitrogen, Kjeldahl, Total	0.93	1	0.53	0.34	0.18	35
Nitrogen, NO2 plus NO3	0.093	0.27	0.05	0.09	-0.04	-75
Nitrogen, Nitrate	0.093	0.27	0.05	0.09	-0.04	-75
Nitrogen, Nitrite	U	U	U	U	U	NA
Orthophosphate as P	0.06	0.13	0.03	0.04	-0.01	-31
Phosphorus, Total (as P)	0.079 I	0.14	0.04	0.05	-0.003	-7
Total Suspended Solids	7.5	6	4.24	2.04	2.20	52
Total Nitrogen	1	1.3	0.57	0.44	0.12	22

Storm Event 4- 8/28/2016

	Concentration (mg/L)		Load (lbs)		Removal (lbs)	
Parameter	IN	OUT	IN	OUT	lbs.	%
Nitrogen, Ammonia	0.26	0.29	0.27	0.10	0.17	65
Nitrogen, Kjeldahl, Total	0.81	0.92	0.84	0.30	0.54	64
Nitrogen, NO2 plus NO3	0.13	0.14	0.14	0.05	0.09	66
Nitrogen, Nitrate	0.13	0.14	0.14	0.05	0.09	66
Nitrogen, Nitrite	U	U	U	U	U	NA
Orthophosphate as P	0.069	0.13	0.07	0.04	0.03	40
Phosphorus, Total (as P)	0.077 I	0.15	0.08	0.05	0.031	38
Total Suspended Solids	U	U	U	U	U	NA
Total Nitrogen	0.94	1.1	0.98	0.36	0.62	63

Storm Event 5- 8/29/2016

Parameter	Concentration (mg/L)		Load (lbs)		Removal (lbs)	
	IN	OUT	IN	OUT	lbs.	%
Nitrogen, Ammonia	0.23	0.22	0.37	0.11	0.26	71
Nitrogen, Kjeldahl, Total	0.81	0.84	1.29	0.41	0.88	68
Nitrogen, NO2 plus NO3	0.088	0.12	0.14	0.06	0.08	58
Nitrogen, Nitrate	0.088	0.12	0.14	0.06	0.08	58
Nitrogen, Nitrite	U	U	U	U	U	NA
Orthophosphate as P	0.062	0.065	0.10	0.03	0.07	68
Phosphorus, Total (as P)	0.091 I	0.084 I	0.15	0.04	0.104	72
Total Suspended Solids	U	U	U	U	U	NA
Total Nitrogen	0.9	0.96	1.44	0.47	0.97	67

*Data qualifiers are shown to indicate where load and removal calculations have been based on qualified raw data. A data qualifier of U indicates that a parameter was analyzed but not detected, I indicates that a parameter was detected between the Method Minimum Detection Level and Minimum Reporting Level; NA indicates that a value could not be generated for a given parameter, A negative removal or percent indicates an apparent addition to the system.

Average pollutant concentrations, loads, and removal rates are displayed below in Table 10.

Table 10- Average pollutant concentrations, loads, and removal rates for the five storms monitored via autosampler for the Micco I stormwater improvement project, South Basin

	Avg. Concentration (mg/L)		**Avg. Load (lbs)**		**Avg. Removal (lbs)**	
Parameter	**IN**	**OUT**	**IN**	**OUT**	**lbs.**	**%**
Nitrogen, Ammonia	0.23	0.26	0.20	0.11	0.10	32
Nitrogen, Kjeldahl, Total	0.91	0.94	0.76	0.39	0.36	39
Nitrogen, NO2 plus NO3	0.14	0.19	0.11	0.08	0.03	10
Nitrogen, Nitrate	0.14	0.19	0.11	0.08	0.03	10
Nitrogen, Nitrite	0.03	0.04	0.02	0.02	0.00	5
Orthophosphate as P	0.06	0.09	0.05	0.04	0.02	-16
Phosphorus, Total (as P)	0.09	0.12	0.08	0.05	0.03	22
Total Suspended Solids	4.95	4.90	2.57	1.75	0.82	-5
Total Nitrogen	1.05	1.15	0.87	0.48	0.39	35

In general, pollutant concentrations and loads flowing into and out of the project were not high. The box worked to remove most pollutants to at least some degree. Total Nitrogen and Total Kjeldhal Nitrogen were removed by 35 and 39% respectively; Ammonia was removed by 32%; and other species of Nitrogen were removed by 5-10%. Total Phosphorous was removed by 22% on average, while Orthophosphate was increased by 16% on average. Orthophosphate was actually removed in three of the five storms sampled- the high rate of addition (175%) detected during storm event 2 renders the average removal a poor representation in this case. It is thought that orthophosphate is being removed to at least some degree by the box. The same effect was observed in the TSS measurements, which were low throughout the monitoring period and attributed to the baffle box upstream. The average value of 5% addition per storm event is a poor representation. Only one of the five storms monitored showed an increase in TSS coming out of the box. TSS was eliminated or not detected during the other events. Thus, it is though that the box is working to reduce TSS to at least some degree. According to storm event monitoring data, the denitrification box seems to be working to further reduce pollutants in the basin.

In addition to storm event samples, a sediment sample was collected prior to the box being cleaned. The box was installed May 19, 2015 and was sampled August 30, 2016, thus the sample represents roughly 15.5 months of accumulation. The loads removed during this period, and an estimated annual removal rate are displayed below in Table 11.

Table 11- Pollutant concentrations, loads, and removal rates for the Micco I South basin baffle box. *

	Concentration (mg/Kg)		Load (lbs.)			Annual Removal Rate (lbs/yr)
Parameter	**First**	**Last**	**First**	**Last**	**Total**	
Nitrogen, Ammonia	1.8	6.9	0.36	0.43	0.79	0.6
Nitrogen, Kjeldahl, Total	68.9 I	542	13.81	33.61	47.42	36.7
Phosphorus, Total (as P)	59.2	53.5 I	11.86	3.32	15.18	11.8
Nitrate as N	U	U	0	0	0	0
Nitrite as N	U	U	0	0	0	0
Nitrogen, NO2 plus NO3	U	U	0	0	0	0
Orthophosphate as P	U	U	0	0	0	0
Total Nitrogen Soil	68.9	542	13.81	33.61	47.42	36.7

*Data qualifiers are shown to indicate where load and removal calculations have been based on qualified raw data. A data qualifier of U indicates that a parameter was analyzed but not detected, I indicates that a parameter was detected between the Method Minimum Detection Level and Minimum Reporting Level; NA indicates that a value could not be generated for a given parameter, A negative removal or percent indicates an apparent addition to the system.

These results are consistent with what was observed with the storm event samples. Total Nitrogen and Total Kjeldhal Nitrogen were the most highly removed, followed by Phosphorous. Other species sampled were removed to lesser degrees or not detected at all in the sediments.

Section 5: Conclusions

The Micco I stormwater improvement provides treatment for 52-acres, divided into two separate basins. The North basin consists of an exfiltration system with a denitrification wall that provides treatment to a 14.78-acre region that previously had no treatment. The South basin consists of a baffle box and a denitrification box provide treatment for a 37.43-acre region that previously had very limited stormwater treatment.

In the North Basin, the total nitrogen load was reduced in the section containing the denitrification bioreactor much more substantially than the control section containing an exfiltration treatment system alone. NO_3 was reduced below detection in the treatment transects and no consistent reductions were observed within the control transects. Concentrations of NH_4 increased within the bioreactor with the exception of the final sampling event. Other denitrification bioreactors have caused short-term increases in NH_4 that initially reduce the total nitrogen load reductions caused by denitrification. Further monitoring would be necessary to determine if the final sampling event is indicative of a reduction in the pulse of NH_4. Both systems were a source of TSS indicating that the gravel pack does little to reduce TSS.

In the South Basin, the denitrification box seems to be working to further reduce pollutant loads from the system. Nitrogen species were all reduced to some degree. Total Phosphorous was also reduced. Orthophosphate and TSS were not reduced, on average, due to an anomalous storm event; however, based on the total storm event data set and sediment sampling, it is thought that these parameters are being reduced to at least some degree by the system. Overall, the County is confident that the Micco I project is working as expected to provide stormwater treatment to the basin.

References Cited:

Schmidt, C.A.; Clark, M.C. 2013. Deciphering and modeling the physicochemical drivers of denitrification rates in bioreactors. Ecological Engineering. 60: 276-288.

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TECHNICAL REPORT FOR BREVARD COUNTY NATURAL RESOURCES MANAGEMENT

PROJECT SITE:	Johnson Junior High
ERD JOB #:	18-006
SAMPLE COLLECTION DATE:	January 28, February 10, March 18, and April 9, 2019
DATE REPORT PREPARED:	April 23, 2019
CLIENT SERVICE CONTACT:	Chip Harper (charper@erd.org)

Report To:

Jennifer Thompson
Brevard County Natural Resources Management
2725 Judge Fran Jamieson Way
Suite A
Melbourne, FL 32940
Jennifer.thompson@brevardfl.gov

Total Number of Pages in Report: 12

Analytical results presented in this report have been reviewed for compliance with the ENVIRONMENTAL RESEARCH & DESIGN, INC. (ERD) Quality Systems Manual and have been determined to meet applicable method guidelines and standards referenced in the 2003/2009 National Environmental laboratory Accreditation Program (NELAP) Quality Manual unless otherwise noted. The Analytical Results within these report pages reflect the values obtained from tests performed on samples as received by the laboratory on the dates listed unless indicated differently.

Cassie Revell

Cassie Revell
Lab Director

NELAC No. E1031026

SAMPLE SUMMARY

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Lab Sample I.D.	Date Collected	Time Collected	Sampler	Date Received	Matrix Code*	Type	Client Sample I.D.
19-0181	1/28/19	10:30	JS	1/29/19	AQ	Surface Water	Pond In
19-0182	1/28/19	9:20	JS	1/29/19	AQ	Surface Water	Thirsty Duck In
19-0183	1/28/19	10:15	JS	1/29/19	AQ	Surface Water	Out 1
19-0184	1/28/19	9:55	JS	1/29/19	AQ	Surface Water	Out 2
19-0185	1/28/19	9:45	JS	1/29/19	AQ	Surface Water	Out 3
19-0299	2/10/19	14:40	JS	2/11/19	AQ	Surface Water	Pond In
19-0300	2/10/19	15:00	JS	2/11/19	AQ	Surface Water	Thirsty Duck In
19-0301	2/10/19	15:35	JS	2/11/19	AQ	Surface Water	Out 1
19-0302	2/10/19	15:25	JS	2/11/19	AQ	Surface Water	Out 2
19-0303	2/10/19	15:15	JS	2/11/19	AQ	Surface Water	Out 3
19-0632	3/18/19	14:40	JS	3/18/19	AQ	Surface Water	Pond In
19-0633	3/18/19	14:00	JS	3/18/19	AQ	Surface Water	Thirsty Duck In
19-0634	3/18/19	13:21	JS	3/18/19	AQ	Surface Water	Out 1
19-0635	3/18/19	13:35	JS	3/18/19	AQ	Surface Water	Out 2
19-0636	3/18/19	13:50	JS	3/18/19	AQ	Surface Water	Out 3
19-0835	4/9/19	12:07	JS	4/10/19	AQ	Surface Water	Pond In
19-0836	4/9/19	11:40	JS	4/10/19	AQ	Surface Water	Thirsty Duck In
19-0837	4/9/19	11:13	JS	4/10/19	AQ	Surface Water	Out 1
19-0838	4/9/19	11:20	JS	4/10/19	AQ	Surface Water	Out 2
19-0839	4/9/19	11:28	JS	4/10/19	AQ	Surface Water	Out 3

*Matrix Code: AQ = Aqueous
SED = Sediment

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Ammonia ($NH_3 + NH_4^+$) **Method**: SM-22, Sec. 4500-NH_3 G **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	37	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0182	Thirsty Duck In	41	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0183	Out 1	571	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0184	Out 2	146	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0185	Out 3	33	I	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0299	Pond In	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0300	Thirsty Duck In	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0301	Out 1	168	---	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0302	Out 2	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0303	Out 3	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0632	Pond In	102	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0633	Thirsty Duck In	92	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0634	Out 1	409	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0635	Out 2	247	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0636	Out 3	176	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0835	Pond In	10	U	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0836	Thirsty Duck In	10	U	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0837	Out 1	99	---	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0838	Out 2	32	I	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0839	Out 3	39	---	37	10	µg/l	4/9/19	4/10/19	4/10/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Ammonium (NH_4^+) **Method**: Calculation based on pH **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	37	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0182	Thirsty Duck In	40	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0183	Out 1	566	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0184	Out 2	146	---	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0185	Out 3	33	I	37	10	µg/l	1/28/19	1/29/19	1/31/19
19-0299	Pond In	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0300	Thirsty Duck In	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0301	Out 1	168	---	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0302	Out 2	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0303	Out 3	10	U	37	10	µg/l	2/10/19	2/11/19	2/14/19
19-0632	Pond In	102	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0633	Thirsty Duck In	91	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0634	Out 1	405	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0635	Out 2	247	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0636	Out 3	176	---	37	10	µg/l	3/18/19	3/18/19	3/20/19
19-0835	Pond In	10	U	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0836	Thirsty Duck In	10	U	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0837	Out 1	98	---	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0838	Out 2	32	I	37	10	µg/l	4/9/19	4/10/19	4/10/19
19-0839	Out 3	39	---	37	10	µg/l	4/9/19	4/10/19	4/10/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrite + Nitrate **Method**: SM-22, Sec. 4500-NO3 F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	260	---	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0182	Thirsty Duck In	16	---	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0183	Out 1	16	---	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0184	Out 2	16	---	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0185	Out 3	24	---	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0299	Pond In	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0300	Thirsty Duck In	4	I	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0301	Out 1	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0302	Out 2	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0303	Out 3	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0632	Pond In	36	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0633	Thirsty Duck In	85	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0634	Out 1	2	U	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0635	Out 2	6	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0636	Out 3	14	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0835	Pond In	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrate **Method**: Calculation **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	242	---	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0182	Thirsty Duck In	3	I	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0183	Out 1	2	U	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0184	Out 2	2	U	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0185	Out 3	4	I	6	2	µg/l	1/28/19	1/29/19	1/30/19
19-0299	Pond In	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0300	Thirsty Duck In	4	I	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0301	Out 1	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0302	Out 2	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0303	Out 3	2	U	6	2	µg/l	2/10/19	2/11/19	2/14/19
19-0632	Pond In	36	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0633	Thirsty Duck In	83	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0634	Out 1	2	U	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0635	Out 2	6	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0636	Out 3	14	---	6	2	µg/l	3/18/19	3/18/19	3/19/19
19-0835	Pond In	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	2	U	6	2	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrite **Method**: SM-22, Sec. 4500-NO3 F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	18	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0182	Thirsty Duck In	15	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0183	Out 1	15	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0184	Out 2	15	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0185	Out 3	20	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0299	Pond In	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0300	Thirsty Duck In	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0301	Out 1	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0302	Out 2	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0303	Out 3	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0632	Pond In	3	U	9	3	µg/l	3/18/19	3/18/19	3/20/19
19-0633	Thirsty Duck In	3	U	9	3	µg/l	3/18/19	3/18/19	3/20/19
19-0634	Out 1	3	U	9	3	µg/l	3/18/19	3/18/19	3/20/19
19-0635	Out 2	3	U	9	3	µg/l	3/18/19	3/18/19	3/20/19
19-0636	Out 3	3	U	9	3	µg/l	3/18/19	3/18/19	3/20/19
19-0835	Pond In	3	U	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	3	U	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	3	U	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	3	U	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	3	U	9	3	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Total Nitrogen **Method**: SM-22, Sec. 4500-N C **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	2,208	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0182	Thirsty Duck In	746	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0183	Out 1	1,307	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0184	Out 2	962	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0185	Out 3	725	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0299	Pond In	2,380	---	135	43	µg/l	2/10/19	2/11/19	2/18/19
19-0300	Thirsty Duck In	807	---	135	43	µg/l	2/10/19	2/11/19	2/18/19
19-0301	Out 1	803	---	135	43	µg/l	2/10/19	2/11/19	2/18/19
19-0302	Out 2	762	---	135	43	µg/l	2/10/19	2/11/19	2/18/19
19-0303	Out 3	699	---	135	43	µg/l	2/10/19	2/11/19	2/18/19
19-0632	Pond In	894	---	135	43	µg/l	3/18/19	3/18/19	3/20/19
19-0633	Thirsty Duck In	919	---	135	43	µg/l	3/18/19	3/18/19	3/20/19
19-0634	Out 1	1,038	---	135	43	µg/l	3/18/19	3/18/19	3/20/19
19-0635	Out 2	1,030	---	135	43	µg/l	3/18/19	3/18/19	3/20/19
19-0636	Out 3	847	---	135	43	µg/l	3/18/19	3/18/19	3/20/19
19-0835	Pond In	1,665	---	135	43	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	702	---	135	43	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	714	---	135	43	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	758	---	135	43	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	673	---	135	43	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: TKN **Method**: Calculation **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	1,948	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0182	Thirsty Duck In	739	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0183	Out 1	1,300	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0184	Out 2	956	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0185	Out 3	718	---	43	14	µg/l	1/28/19	1/29/19	1/31/19
19-0299	Pond In	2,378	---	43	14	µg/l	2/10/19	2/11/19	2/18/19
19-0300	Thirsty Duck In	803	---	43	14	µg/l	2/10/19	2/11/19	2/18/19
19-0301	Out 1	801	---	43	14	µg/l	2/10/19	2/11/19	2/18/19
19-0302	Out 2	760	---	43	14	µg/l	2/10/19	2/11/19	2/18/19
19-0303	Out 3	697	---	43	14	µg/l	2/10/19	2/11/19	2/18/19
19-0632	Pond In	858	---	43	14	µg/l	3/18/19	3/18/19	3/20/19
19-0633	Thirsty Duck In	834	---	43	14	µg/l	3/18/19	3/18/19	3/20/19
19-0634	Out 1	1,036	---	43	14	µg/l	3/18/19	3/18/19	3/20/19
19-0635	Out 2	1,024	---	43	14	µg/l	3/18/19	3/18/19	3/20/19
19-0636	Out 3	833	---	43	14	µg/l	3/18/19	3/18/19	3/20/19
19-0835	Pond In	1,663	---	43	14	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	700	---	43	14	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	712	---	43	14	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	756	---	43	14	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	671	---	43	14	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Soluble Reactive Phosphorus (SRP) **Method**: SM-22, Sec. 4500-P **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	27	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0182	Thirsty Duck In	4	I	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0183	Out 1	14	---	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0184	Out 2	5	I	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0185	Out 3	6	I	9	3	µg/l	1/28/19	1/29/19	1/30/19
19-0299	Pond In	28	---	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0300	Thirsty Duck In	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0301	Out 1	4	I	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0302	Out 2	3	U	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0303	Out 3	3	---	9	3	µg/l	2/10/19	2/11/19	2/14/19
19-0632	Pond In	3	---	9	3	µg/l	3/18/19	3/18/19	3/19/19
19-0633	Thirsty Duck In	6	I	9	3	µg/l	3/18/19	3/18/19	3/19/19
19-0634	Out 1	9	---	9	3	µg/l	3/18/19	3/18/19	3/19/19
19-0635	Out 2	13	---	9	3	µg/l	3/18/19	3/18/19	3/19/19
19-0636	Out 3	36	---	9	3	µg/l	3/18/19	3/18/19	3/19/19
19-0835	Pond In	25	---	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	8	I	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	10	---	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	9	---	9	3	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	13	---	9	3	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Total Phosphorus **Method**: SM-22, Sec. 4500-P F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	80	---	20	6	µg/l	1/28/19	1/29/19	1/31/19
19-0182	Thirsty Duck In	32	---	20	6	µg/l	1/28/19	1/29/19	1/31/19
19-0183	Out 1	37	---	20	6	µg/l	1/28/19	1/29/19	1/31/19
19-0184	Out 2	29	---	20	6	µg/l	1/28/19	1/29/19	1/31/19
19-0185	Out 3	27	---	20	6	µg/l	1/28/19	1/29/19	1/31/19
19-0299	Pond In	117	---	20	6	µg/l	2/10/19	2/11/19	2/18/19
19-0300	Thirsty Duck In	33	---	20	6	µg/l	2/10/19	2/11/19	2/18/19
19-0301	Out 1	23	---	20	6	µg/l	2/10/19	2/11/19	2/18/19
19-0302	Out 2	25	---	20	6	µg/l	2/10/19	2/11/19	2/18/19
19-0303	Out 3	24	---	20	6	µg/l	2/10/19	2/11/19	2/18/19
19-0632	Pond In	28	---	20	6	µg/l	3/18/19	3/18/19	3/20/19
19-0633	Thirsty Duck In	21	---	20	6	µg/l	3/18/19	3/18/19	3/20/19
19-0634	Out 1	19	I	20	6	µg/l	3/18/19	3/18/19	3/20/19
19-0635	Out 2	21	---	20	6	µg/l	3/18/19	3/18/19	3/20/19
19-0636	Out 3	46	---	20	6	µg/l	3/18/19	3/18/19	3/20/19
19-0835	Pond In	64	---	20	6	µg/l	4/9/19	4/10/19	4/11/19
19-0836	Thirsty Duck In	21	---	20	6	µg/l	4/9/19	4/10/19	4/11/19
19-0837	Out 1	22	---	20	6	µg/l	4/9/19	4/10/19	4/11/19
19-0838	Out 2	17	I	20	6	µg/l	4/9/19	4/10/19	4/11/19
19-0839	Out 3	46	---	20	6	µg/l	4/9/19	4/10/19	4/11/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Dissolved Organic Carbon (DOC) **Method**: SM-22, Sec. 5310B-11 **Analyst**: FN

Lab Sample I.D.	Client Sample I.D.	Result*	Qualifier**	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	58	---	1.7	0.4	mg/l	1/28/19	1/29/19	2/11/19
19-0182	Thirsty Duck In	17	---	1.7	0.4	mg/l	1/28/19	1/29/19	2/11/19
19-0183	Out 1	19	---	1.7	0.4	mg/l	1/28/19	1/29/19	2/11/19
19-0184	Out 2	19	---	1.7	0.4	mg/l	1/28/19	1/29/19	2/11/19
19-0185	Out 3	18	---	1.7	0.4	mg/l	1/28/19	1/29/19	2/11/19
19-0632	Pond In	19	---	1.7	0.4	mg/l	3/18/19	3/18/19	3/25/19
19-0633	Thirsty Duck In	18	---	1.7	0.4	mg/l	3/18/19	3/18/19	3/25/19
19-0634	Out 1	21	---	1.7	0.4	mg/l	3/18/19	3/18/19	3/25/19
19-0635	Out 2	22	---	1.7	0.4	mg/l	3/18/19	3/18/19	3/25/19
19-0636	Out 3	24	---	1.7	0.4	mg/l	3/18/19	3/18/19	3/25/19

Analyte: Total Suspended Solids (TSS) **Method**: SM-22, Sec. 2540 D **Analyst**: AM

Lab Sample I.D.	Client Sample I.D.	Result*	Qualifier**	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-0181	Pond In	2.9	I	4.5	1.4	mg/l	1/28/19	1/29/19	2/11/19
19-0182	Thirsty Duck In	8.2	---	4.5	1.4	mg/l	1/28/19	1/29/19	2/11/19
19-0183	Out 1	1.3	U	4.5	1.4	mg/l	1/28/19	1/29/19	2/11/19
19-0184	Out 2	2.9	I	4.5	1.4	mg/l	1/28/19	1/29/19	2/11/19
19-0185	Out 3	1.3	U	4.5	1.4	mg/l	1/28/19	1/29/19	2/11/19
19-0632	Pond In	7.5	---	4.5	1.4	mg/l	3/18/19	3/18/19	3/23/19
19-0633	Thirsty Duck In	4.3	I	4.5	1.4	mg/l	3/18/19	3/18/19	3/23/19
19-0634	Out 1	3.1	I	4.5	1.4	mg/l	3/18/19	3/18/19	3/23/19
19-0635	Out 2	1.3	U	4.5	1.4	mg/l	3/18/19	3/18/19	3/23/19
19-0636	Out 3	2.6	I	4.5	1.4	mg/l	3/18/19	3/18/19	3/23/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

END OF REPORT

ERD
Water Quality Engineering

ENVIRONMENTAL RESEARCH & DESIGN, INC.
Engineering • Science • Chemistry • Research
3419 Trentwood Blvd. • Suite 102 • Belle Isle (Orlando), FL 32812-4864
Telephone: 407-855-9465 • Fax: 407-826-0419

April 24, 2019

Ms. Jennifer Thompson
Brevard County Natural Resources Management
2725 Judge Fran Jamieson Way, Suite A
Melbourne, FL 32940
(Jennifer.thompson@brevardfl.gov)

RE: Invoice #4 - Johnson Jr. High Project (PO# 4500098399) for Water Samples Collected on January 28, February 10, March 18, and April 9, 2019

Dear Jennifer:

Attached is an invoice for laboratory analyses performed on the water samples collected on the dates listed above. The invoice is based on our Fee Proposal dated March 2, 2018. The data were sent to you in a Technical Report dated April 24, 2019.

Thank you for the opportunity of providing laboratory services to Brevard County. If you have any questions concerning the attached invoice, please feel free to contact me directly.

Sincerely,

Harvey H. Harper, III

Harvey H. Harper, Ph.D., P.E.
President

HHH:shd
Enclosure: Invoice

cc: Jackie Thompson (Jackie.Thompson@brevardfl.gov)
Terry Williamson (terry.williamson@brevardfl.gov)

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Telephone: 407-855-9465 • Fax: 407-826-0419 • FEIN: 59-2721335

INVOICE

BILL TO:
Brevard County Natural Resources Management 2725 Judge Fran Jamieson Way, Suite A Melbourne, FL 32940

INVOICE DATE:	April 24, 2019
ERD INVOICE #:	7231
ERD PROJECT #:	18-006
PURCHASE ORDER #:	4500098399
TERMS:	Due Upon Receipt

REFERENCED PROJECT:	Invoice #4 – Johnson Jr. High Water Samples
PERIOD OF SERVICE:	Samples Collected on January 28, February 10, March 18, and April 9, 2019

PARAMETER	SAMPLE FEE ($)	NO. OF SAMPLES ANALYZED	TOTAL FEE ($)
Ammonia	10.00	20	200.00
Ammonium	12.00	20	240.00
Nitrite + Nitrate	12.00	20	240.00
Nitrite	12.00	20	240.00
Nitrate	5.00	20	100.00
Total Nitrogen	25.00	20	500.00
TKN	5.00	20	100.00
SRP	10.00	20	200.00
Total Phosphorus	15.00	20	300.00
DOC	65.00	10	650.00
TSS	12.00	10	120.00
		TOTAL:	**$ 2,890.00**

TOTAL AMOUNT DUE THIS INVOICE: $ 2,890.00

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Telephone: 407-855-9465 • Fax: 407-826-0419

TECHNICAL REPORT FOR
BREVARD COUNTY NATURAL RESOURCES MANAGEMENT

PROJECT SITE:	Johnson Junior High
ERD JOB #:	18-006
SAMPLE COLLECTION DATE:	May 14, 2019
DATE REPORT PREPARED:	June 13, 2019
CLIENT SERVICE CONTACT:	Chip Harper (charper@erd.org)

Report To:

Jennifer Thompson
Brevard County Natural Resources Management
2725 Judge Fran Jamieson Way
Suite A
Melbourne, FL 32940
Jennifer.thompson@brevardfl.gov

Total Number of Pages in Report: 5

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Cassie Revell

Cassie Revell
Lab Director

NELAC No. E1031026

SAMPLE SUMMARY

Client:	Brevard County Natural Resources Management
Project Name:	Johnson Junior High
ERD Job #:	18-006

Lab Sample I.D.	Date Collected	Time Collected	Sampler	Date Received	Matrix Code*	Type	Client Sample I.D.
19-01159	5/14/19	9:38	JT	5/15/19	AQ	Surface Water	Pond In
19-01160	5/14/19	9:24	JT	5/15/19	AQ	Surface Water	Thirsty Duck In
19-01161	5/14/19	9:00	JT	5/15/19	AQ	Surface Water	Out 1
19-01162	5/14/19	9:10	JT	5/15/19	AQ	Surface Water	Out 2
19-01163	5/14/19	9:15	JT	5/15/19	AQ	Surface Water	Out 3

*Matrix Code: AQ = Aqueous
SED = Sediment

SUMMARY OF ANALYSES

Client:	Brevard County Natural Resources Management
Project Name:	Johnson Junior High
ERD Job #:	18-006

Analyte: Ammonia ($NH_3 + NH_4^+$) **Method**: SM-22, Sec. 4500-NH_3 G **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	13	I	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01160	Thirsty Duck In	22	I	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01161	Out 1	272	---	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01162	Out 2	85	---	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01163	Out 3	10	U	37	10	µg/l	5/14/19	5/15/19	5/16/19

Analyte: Ammonium (NH_4^+) **Method**: Calculation based on pH **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	13	I	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01160	Thirsty Duck In	22	I	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01161	Out 1	272	---	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01162	Out 2	85	---	37	10	µg/l	5/14/19	5/15/19	5/16/19
19-01163	Out 3	10	U	37	10	µg/l	5/14/19	5/15/19	5/16/19

Analyte: Nitrate **Method**: Calculation **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	2	U	6	2	µg/l	5/14/19	5/15/19	5/15/19
19-01160	Thirsty Duck In	6	---	6	2	µg/l	5/14/19	5/15/19	5/15/19
19-01161	Out 1	5	I	6	2	µg/l	5/14/19	5/15/19	5/15/19
19-01162	Out 2	39	---	6	2	µg/l	5/14/19	5/15/19	5/15/19
19-01163	Out 3	7	---	6	2	µg/l	5/14/19	5/15/19	5/15/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrite **Method**: SM-22, Sec. 4500-NO3 F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	12	---	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01160	Thirsty Duck In	7	I	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01161	Out 1	3	U	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01162	Out 2	3	U	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01163	Out 3	5	I	9	3	µg/l	5/14/19	5/15/19	5/15/19

Analyte: TKN **Method**: Calculation (TN-NO_x) **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	1067	---	43	14	µg/l	5/14/19	5/15/19	5/16/19
19-01160	Thirsty Duck In	699	---	43	14	µg/l	5/14/19	5/15/19	5/16/19
19-01161	Out 1	916	---	43	14	µg/l	5/14/19	5/15/19	5/16/19
19-01162	Out 2	832	---	43	14	µg/l	5/14/19	5/15/19	5/16/19
19-01163	Out 3	641	---	43	14	µg/l	5/14/19	5/15/19	5/16/19

Analyte: Soluble Reactive Phosphorus (SRP) **Method**: SM-22, Sec. 4500-P **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	6	I	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01160	Thirsty Duck In	7	I	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01161	Out 1	12	---	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01162	Out 2	10	---	9	3	µg/l	5/14/19	5/15/19	5/15/19
19-01163	Out 3	19	---	9	3	µg/l	5/14/19	5/15/19	5/15/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Total Phosphorus **Method**: SM-22, Sec. 4500-P F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01159	Pond In	16	I	20	6	µg/l	5/14/19	5/15/19	5/16/19
19-01160	Thirsty Duck In	15	I	20	6	µg/l	5/14/19	5/15/19	5/16/19
19-01161	Out 1	17	I	20	6	µg/l	5/14/19	5/15/19	5/16/19
19-01162	Out 2	18	I	20	6	µg/l	5/14/19	5/15/19	5/16/19
19-01163	Out 3	26	---	20	6	µg/l	5/14/19	5/15/19	5/16/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

END OF REPORT

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Telephone: 407-855-9465 • Fax: 407-826-0419

TECHNICAL REPORT FOR
BREVARD COUNTY NATURAL RESOURCES MANAGEMENT

PROJECT SITE:	Johnson Junior High
ERD JOB #:	18-006
SAMPLE COLLECTION DATE:	June 17, 2019
DATE REPORT PREPARED:	July 15, 2019
CLIENT SERVICE CONTACT:	Chip Harper (charper@erd.org)

Report To:

Jennifer Thompson
Brevard County Natural Resources Management
2725 Judge Fran Jamieson Way
Suite A
Melbourne, FL 32940
Jennifer.thompson@brevardfl.gov

Total Number of Pages in Report: 5

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Cassie Revell

Cassie Revell
Lab Director

NELAC No. E1031026

SAMPLE SUMMARY

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Lab Sample I.D.	Date Collected	Time Collected	Sampler	Date Received	Matrix Code*	Type	Client Sample I.D.
19-01500	6/17/19	10:39	JT	6/18/19	AQ	Surface Water	Pond In
19-01501	6/17/19	10:13	JT	6/18/19	AQ	Surface Water	Thirsty Duck In
19-01502	6/17/19	9:46	JT	6/18/19	AQ	Surface Water	Out 1
19-01503	6/17/19	9:57	JT	6/18/19	AQ	Surface Water	Out 2
19-01504	6/17/19	10:06	JT	6/18/19	AQ	Surface Water	Out 3

*Matrix Code: AQ = Aqueous
SED = Sediment

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Ammonia ($NH_3 + NH_4^+$) **Method**: SM-22, Sec. 4500-NH_3 G **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	44	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01501	Thirsty Duck In	48	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01502	Out 1	301	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01503	Out 2	142	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01504	Out 3	21	I	37	10	µg/l	6/17/19	6/18/19	6/21/19

Analyte: Ammonium (NH_4^+) **Method**: Calculation based on pH **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	44	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01501	Thirsty Duck In	48	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01502	Out 1	301	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01503	Out 2	142	---	37	10	µg/l	6/17/19	6/18/19	6/21/19
19-01504	Out 3	21	I	37	10	µg/l	6/17/19	6/18/19	6/21/19

Analyte: Nitrate **Method**: Calculation **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	2	U	6	2	µg/l	6/17/19	6/18/19	6/20/19
19-01501	Thirsty Duck In	10	---	6	2	µg/l	6/17/19	6/18/19	6/20/19
19-01502	Out 1	6	---	6	2	µg/l	6/17/19	6/18/19	6/20/19
19-01503	Out 2	2	U	6	2	µg/l	6/17/19	6/18/19	6/20/19
19-01504	Out 3	2	U	6	2	µg/l	6/17/19	6/18/19	6/20/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrite **Method**: SM-22, Sec. 4500-NO3 F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01501	Thirsty Duck In	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01502	Out 1	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01503	Out 2	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01504	Out 3	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19

Analyte: TKN **Method**: Calculation (TN-NO$_x$) **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	1663	---	43	14	µg/l	6/17/19	6/18/19	6/19/19
19-01501	Thirsty Duck In	830	---	43	14	µg/l	6/17/19	6/18/19	6/19/19
19-01502	Out 1	1006	---	43	14	µg/l	6/17/19	6/18/19	6/19/19
19-01503	Out 2	877	---	43	14	µg/l	6/17/19	6/18/19	6/19/19
19-01504	Out 3	654	---	43	14	µg/l	6/17/19	6/18/19	6/19/19

Analyte: Soluble Reactive Phosphorus (SRP) **Method**: SM-22, Sec. 4500-P **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	16	---	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01501	Thirsty Duck In	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01502	Out 1	4	I	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01503	Out 2	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19
19-01504	Out 3	3	U	9	3	µg/l	6/17/19	6/18/19	6/20/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Total Phosphorus **Method**: SM-22, Sec. 4500-P F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01500	Pond In	73	---	20	6	μg/l	6/17/19	6/18/19	6/19/19
19-01501	Thirsty Duck In	12	I	20	6	μg/l	6/17/19	6/18/19	6/19/19
19-01502	Out 1	22	---	20	6	μg/l	6/17/19	6/18/19	6/19/19
19-01503	Out 2	13	I	20	6	μg/l	6/17/19	6/18/19	6/19/19
19-01504	Out 3	6	U	20	6	μg/l	6/17/19	6/18/19	6/19/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

END OF REPORT

ERD
Water Quality Engineering

ENVIRONMENTAL RESEARCH & DESIGN, INC.

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Telephone: 407-855-9465 • Fax: 407-826-0419

TECHNICAL REPORT FOR BREVARD COUNTY NATURAL RESOURCES MANAGEMENT

PROJECT SITE:	Johnson Junior High
ERD JOB #:	18-006
SAMPLE COLLECTION DATE:	July 25, 2019
DATE REPORT PREPARED:	July 31, 2019
CLIENT SERVICE CONTACT:	Chip Harper (charper@erd.org)

Report To:

Jennifer Thompson
Brevard County Natural Resources Management
2725 Judge Fran Jamieson Way
Suite A
Melbourne, FL 32940
Jennifer.thompson@brevardfl.gov

Total Number of Pages in Report: 5

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Cassie Revell

Cassie Revell
Lab Director

NELAC No. E1031026

SAMPLE SUMMARY

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Lab Sample I.D.	Date Collected	Time Collected	Sampler	Date Received	Matrix Code*	Type	Client Sample I.D.
19-01807	7/25/19	10:46	JT	7/26/19	AQ	Surface Water	Pond In
19-01808	7/25/19	10:18	JT	7/26/19	AQ	Surface Water	Thirsty Duck In
19-01809	7/25/19	9:49	JT	7/26/19	AQ	Surface Water	Out 1
19-01810	7/25/19	9:58	JT	7/26/19	AQ	Surface Water	Out 2
19-01811	7/25/19	10:08	JT	7/26/19	AQ	Surface Water	Out 3

*Matrix Code: AQ = Aqueous
SED = Sediment

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Ammonia ($NH_3 + NH_4^+$) **Method**: SM-22, Sec. 4500-NH_3 G **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	12	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01808	Thirsty Duck In	28	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01809	Out 1	533	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01810	Out 2	339	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01811	Out 3	6	I	10	3	µg/l	7/25/19	7/26/19	7/26/19

Analyte: Ammonium (NH_4^+) **Method**: Calculation based on pH **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	12	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01808	Thirsty Duck In	28	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01809	Out 1	526	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01810	Out 2	339	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01811	Out 3	6	I	10	3	µg/l	7/25/19	7/26/19	7/26/19

Analyte: Nitrate **Method**: Calculation **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	53	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01808	Thirsty Duck In	50	---	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01809	Out 1	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01810	Out 2	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01811	Out 3	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrite **Method**: SM-22, Sec. 4500-NO3 F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01808	Thirsty Duck In	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01809	Out 1	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01810	Out 2	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19
19-01811	Out 3	3	U	10	3	µg/l	7/25/19	7/26/19	7/26/19

Analyte: TKN **Method**: Calculation (TN-NO$_x$) **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	723	---	10	3	µg/l	7/25/19	7/26/19	7/29/19
19-01808	Thirsty Duck In	703	---	10	3	µg/l	7/25/19	7/26/19	7/29/19
19-01809	Out 1	1365	---	10	3	µg/l	7/25/19	7/26/19	7/29/19
19-01810	Out 2	1270	---	10	3	µg/l	7/25/19	7/26/19	7/29/19
19-01811	Out 3	692	---	10	3	µg/l	7/25/19	7/26/19	7/29/19

Analyte: Soluble Reactive Phosphorus (SRP) **Method**: SM-22, Sec. 4500-P **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	17	---	5	1	µg/l	7/25/19	7/26/19	7/26/19
19-01808	Thirsty Duck In	3	I	5	1	µg/l	7/25/19	7/26/19	7/26/19
19-01809	Out 1	22	---	5	1	µg/l	7/25/19	7/26/19	7/26/19
19-01810	Out 2	23	---	5	1	µg/l	7/25/19	7/26/19	7/26/19
19-01811	Out 3	26	---	5	1	µg/l	7/25/19	7/26/19	7/26/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Total Phosphorus **Method**: SM-22, Sec. 4500-P F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-01807	Pond In	31	---	7	2	µg/l	7/25/19	7/26/19	7/29/19
19-01808	Thirsty Duck In	22	---	7	2	µg/l	7/25/19	7/26/19	7/29/19
19-01809	Out 1	42	---	7	2	µg/l	7/25/19	7/26/19	7/29/19
19-01810	Out 2	50	---	7	2	µg/l	7/25/19	7/26/19	7/29/19
19-01811	Out 3	27	---	7	2	µg/l	7/25/19	7/26/19	7/29/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

END OF REPORT

ENVIRONMENTAL RESEARCH & DESIGN, INC.
Engineering • Science • Chemistry • Research
3419 Trentwood Blvd. • Suite 102 • Belle Isle (Orlando), FL 32812-4864
Telephone: 407-855-9465 • Fax: 407-826-0419

TECHNICAL REPORT FOR BREVARD COUNTY NATURAL RESOURCES MANAGEMENT

PROJECT SITE: Johnson Junior High

ERD JOB #: 18-006

SAMPLE COLLECTION DATE: August 8, 2019

DATE REPORT PREPARED: September 9, 2019

CLIENT SERVICE CONTACT: Chip Harper
(charper@erd.org)

Report To:

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Brevard County Natural Resources Management
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Total Number of Pages in Report: 5

Analytical results presented in this report have been reviewed for compliance with the ENVIRONMENTAL RESEARCH & DESIGN, INC. (ERD) Quality Systems Manual and have been determined to meet applicable method guidelines and standards referenced in the 2003/2009 National Environmental laboratory Accreditation Program (NELAP) Quality Manual unless otherwise noted. The Analytical Results within these report pages reflect the values obtained from tests performed on samples as received by the laboratory on the dates listed unless indicated differently.

Cassie Revell

Cassie Revell
Lab Director

NELAC No. E1031026

SAMPLE SUMMARY

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Lab Sample I.D.	Date Collected	Time Collected	Sampler	Date Received	Matrix Code*	Type	Client Sample I.D.
19-1913	8/8/19	11:02	JT	8/9/19	AQ	Surface Water	Pond In
19-1914	8/8/19	10:40	JT	8/9/19	AQ	Surface Water	Thirsty Duck In
19-1915	8/8/19	10:14	JT	8/9/19	AQ	Surface Water	Out 1
19-1916	8/8/19	10:21	JT	8/9/19	AQ	Surface Water	Out 2
19-1917	8/8/19	10:30	JT	8/9/19	AQ	Surface Water	Out 3

*Matrix Code: AQ = Aqueous
SED = Sediment

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Ammonia ($NH_3 + NH_4^+$) **Method**: SM-22, Sec. 4500-NH_3 G **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	3	U	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1914	Thirsty Duck In	54	---	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1915	Out 1	375	---	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1916	Out 2	72	---	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1917	Out 3	32	---	8	3	µg/l	8/8/19	8/9/19	8/13/19

Analyte: Ammonium (NH_4^+) **Method**: Calculation based on pH **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	3	U	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1914	Thirsty Duck In	53	---	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1915	Out 1	375	---	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1916	Out 2	72	---	8	3	µg/l	8/8/19	8/9/19	8/13/19
19-1917	Out 3	31	---	8	3	µg/l	8/8/19	8/9/19	8/13/19

Analyte: Nitrate **Method**: Calculation **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	3	U	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1914	Thirsty Duck In	49	---	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1915	Out 1	12	---	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1916	Out 2	34	---	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1917	Out 3	6	I	10	3	µg/l	8/8/19	8/9/19	8/12/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client: Brevard County Natural Resources Management
Project Name: Johnson Junior High
ERD Job #: 18-006

Analyte: Nitrite **Method**: SM-22, Sec. 4500-NO3 F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	3	U	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1914	Thirsty Duck In	3	U	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1915	Out 1	3	U	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1916	Out 2	3	U	10	3	µg/l	8/8/19	8/9/19	8/12/19
19-1917	Out 3	3	U	10	3	µg/l	8/8/19	8/9/19	8/12/19

Analyte: TKN **Method**: Calculation (TN-NO_x) **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	679	---	10	3	µg/l	8/8/19	8/9/19	8/13/19
19-1914	Thirsty Duck In	742	---	10	3	µg/l	8/8/19	8/9/19	8/13/19
19-1915	Out 1	1043	---	10	3	µg/l	8/8/19	8/9/19	8/13/19
19-1916	Out 2	686	---	10	3	µg/l	8/8/19	8/9/19	8/13/19
19-1917	Out 3	611	---	10	3	µg/l	8/8/19	8/9/19	8/13/19

Analyte: Soluble Reactive Phosphorus (SRP) **Method**: SM-22, Sec. 4500-P **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	3	I	5	1	µg/l	8/8/19	8/9/19	8/12/19
19-1914	Thirsty Duck In	1	U	5	1	µg/l	8/8/19	8/9/19	8/12/19
19-1915	Out 1	5	---	5	1	µg/l	8/8/19	8/9/19	8/12/19
19-1916	Out 2	1	U	5	1	µg/l	8/8/19	8/9/19	8/12/19
19-1917	Out 3	6	---	5	1	µg/l	8/8/19	8/9/19	8/12/19

*U = Result is < MDL I = Result is $\geq$ MDL but < PQL

SUMMARY OF ANALYSES

Client:	Brevard County Natural Resources Management
Project Name:	Johnson Junior High
ERD Job #:	18-006

Analyte: Total Phosphorus **Method**: SM-22, Sec. 4500-P F **Analyst**: CR

Lab Sample I.D.	Client Sample I.D.	Result	Qualifier*	PQL	MDL	Units	Date Collected	Date Received	Date Analyzed
19-1913	Pond In	20	---	7	2	µg/l	8/8/19	8/9/19	8/13/19
19-1914	Thirsty Duck In	19	---	7	2	µg/l	8/8/19	8/9/19	8/13/19
19-1915	Out 1	22	---	7	2	µg/l	8/8/19	8/9/19	8/13/19
19-1916	Out 2	13	---	7	2	µg/l	8/8/19	8/9/19	8/13/19
19-1917	Out 3	12	---	7	2	µg/l	8/8/19	8/9/19	8/13/19

*U = Result is < MDL I = Result is ≥ MDL but < PQL

END OF REPORT

Lamont and Hubbell QAPP

Date	23-Sep	6-Oct	18-Oct	22-Nov	3-Jan	11-Apr	21-May	13-Jun	24-Jul
Location	Upstream	Upstream	Upstream	Upstream	Upstream	Upstream	Upstream	Upstream	Upstream
Specific Conductance (umhos/cm)	86.1	101	123	37.6	70.2	197	85.1	25.4	19.7
Total Suspended Solids (mg/L)	37	11	13	14.5	11.5	28.5	15	5.0 U	15.5
pH at 25 Degrees C	6.9	7.7	7.8	8.5	7.2	7.8	8.1	7.5	7.0
Total Nitrogen (mg/L)	0.93	0.27 I	0.45 I	0.82	0.38	2.1	0.33 I	0.34 I	0.29 I
Total Kjeldahl Nitrogen (mg/L)	0.70	0.24 I	0.37 I	0.72	0.35	1.3	0.21 I	0.16 I	0.22 I
NO2/NO3 (mg/L)	0.23	0.036 I	0.081	0.1	0.29	0.73	0.12	0.18	0.077
Total Phosphorus (mg/L)	0.42	0.050 U	0.058 I	0.19	0.58	0.099	0.050 U	0.050 U	0.050 U

	23-Sep	6-Oct	18-Oct	22-Nov	3-Jan	11-Apr	21-May	13-Jun	24-Jul
	Downstream	Downstream	Downstream	Downstream	Downstream	Downstream	Downstream	Downstream	ownstream
	80	93.3	116	39.2	78.4	135	62.4	22.5	20.2
	21	6	15	13	6.5	5 U	8	5.0 U	5.5
	6.7	7.2	7.7	7.8	6.6	7.8	8.4	7.3	6.9
	1.1	0.22 I	0.39 I	0.66	0.21	0.78	0.22 I	0.32 I	0.22 I
	0.85	0.19 I	0.31 I	0.56	0.18	0.4 I	0.16 I	0.15 I	0.15 I
	0.22	0.027 I	0.089	0.11	0.29	0.39	0.063	0.17	0.075
	0.51	0.050 U	0.050 U	0.19	0.54	0.05 U	0.050 U	0.050 U	0.050 U

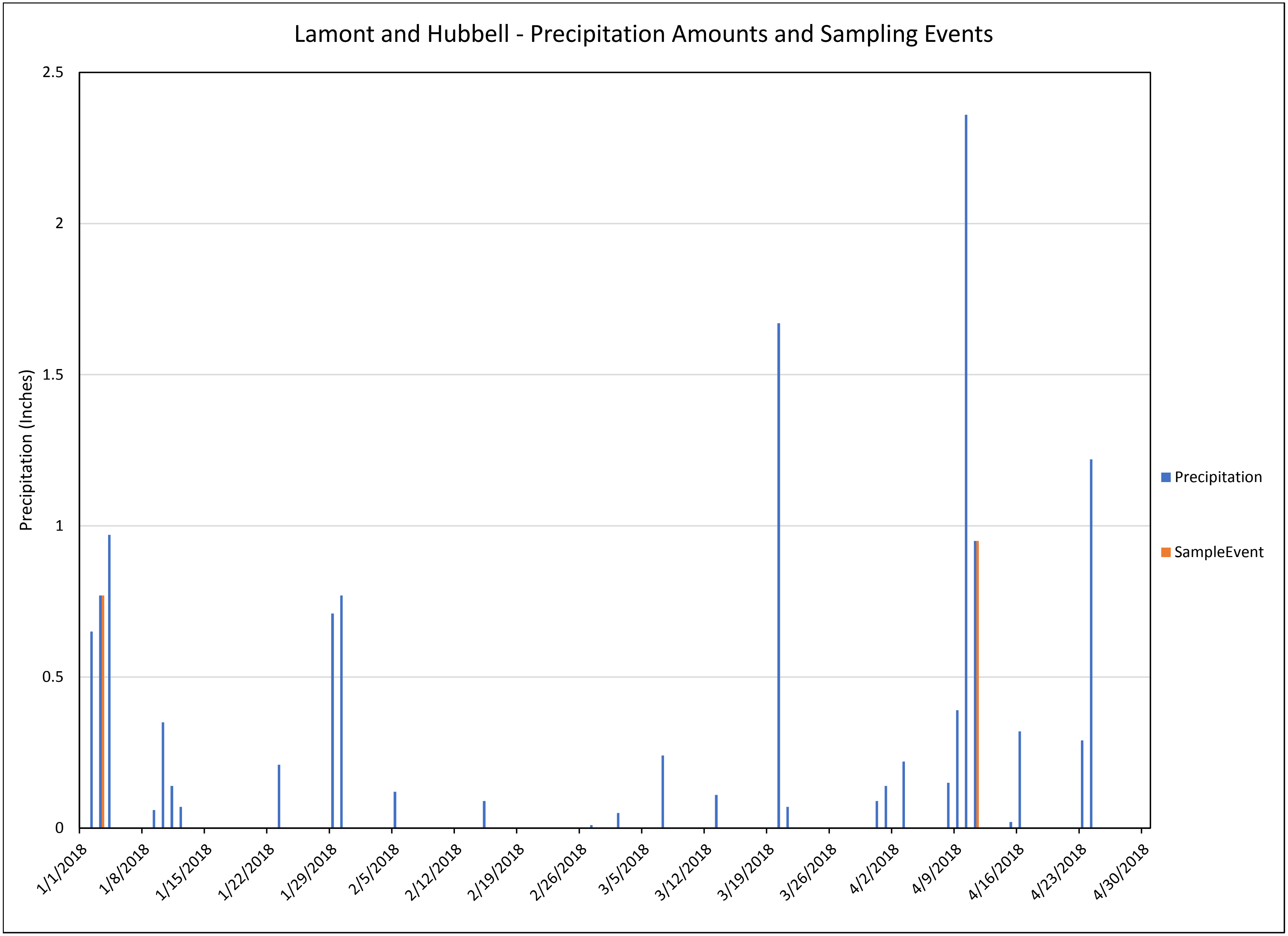
Averages	Upstream	Downstream	% Improvement
Specific Conductance (umhos/cm)	82.79	71.89	13.2
Total Suspended Solids (mg/L)	18.25	10.71	41.3
pH at 25 Degrees C	7.61	7.38	
Total Nitrogen (mg/L)	1.06	0.69	35.0
Total Kjeldahl Nitrogen (mg/L)	0.77	0.53	30.9
NO2/NO3 (mg/L)	0.23	0.18	22.2
Total Phosphorus (mg/L)	0.32	0.41	-28.3

Precipitation via NOAA Station: Edgewater 2.4 N, FL US US1FLVL0006

Date	Precipitation (Inches)	Dates Sampled
1/1/2018	0	
1/2/2018	0.65	
1/3/2018	0.77	0.77
1/4/2018	0.97	
1/5/2018	0	
1/6/2018	0	
1/7/2018	0	
1/8/2018	0	
1/9/2018	0.06	
1/10/2018	0.35	
1/11/2018	0.14	
1/12/2018	0.07	
1/13/2018	0	
1/14/2018	0	
1/15/2018	0	
1/16/2018	0	
1/17/2018	0	
1/18/2018	0	
1/19/2018	0	
1/20/2018	0	
1/21/2018	0	
1/22/2018	0	
1/23/2018	0.21	
1/24/2018	0	
1/25/2018	0	
1/26/2018	0	
1/27/2018	0	
1/28/2018	0	
1/29/2018	0.71	
1/30/2018	0.77	
1/31/2018	0	
2/1/2018	0	
2/2/2018	0	
2/3/2018	0	
2/4/2018	0	
2/5/2018	0.12	
2/6/2018	0	
2/7/2018	0	
2/8/2018	0	
2/9/2018	0	
2/10/2018	0	
2/11/2018	0	
2/12/2018	0	

2/13/2018	0
2/14/2018	0
2/15/2018	0.09
2/16/2018	0
2/17/2018	0
2/18/2018	0
2/19/2018	0
2/20/2018	0
2/21/2018	0
2/22/2018	0
2/23/2018	0
2/24/2018	0
2/25/2018	0
2/26/2018	0
2/27/2018	0.01
2/28/2018	0
3/1/2018	0
3/2/2018	0.05
3/3/2018	0
3/4/2018	0
3/5/2018	0
3/6/2018	0
3/7/2018	0.24
3/8/2018	0
3/9/2018	0
3/10/2018	0
3/11/2018	0
3/12/2018	0
3/13/2018	0.11
3/14/2018	0
3/15/2018	0
3/16/2018	0
3/17/2018	0
3/18/2018	0
3/19/2018	0
3/20/2018	1.67
3/21/2018	0.07
3/22/2018	0
3/23/2018	0
3/24/2018	0
3/25/2018	0
3/26/2018	0
3/27/2018	0
3/28/2018	0
3/29/2018	0
3/30/2018	0
3/31/2018	0.09

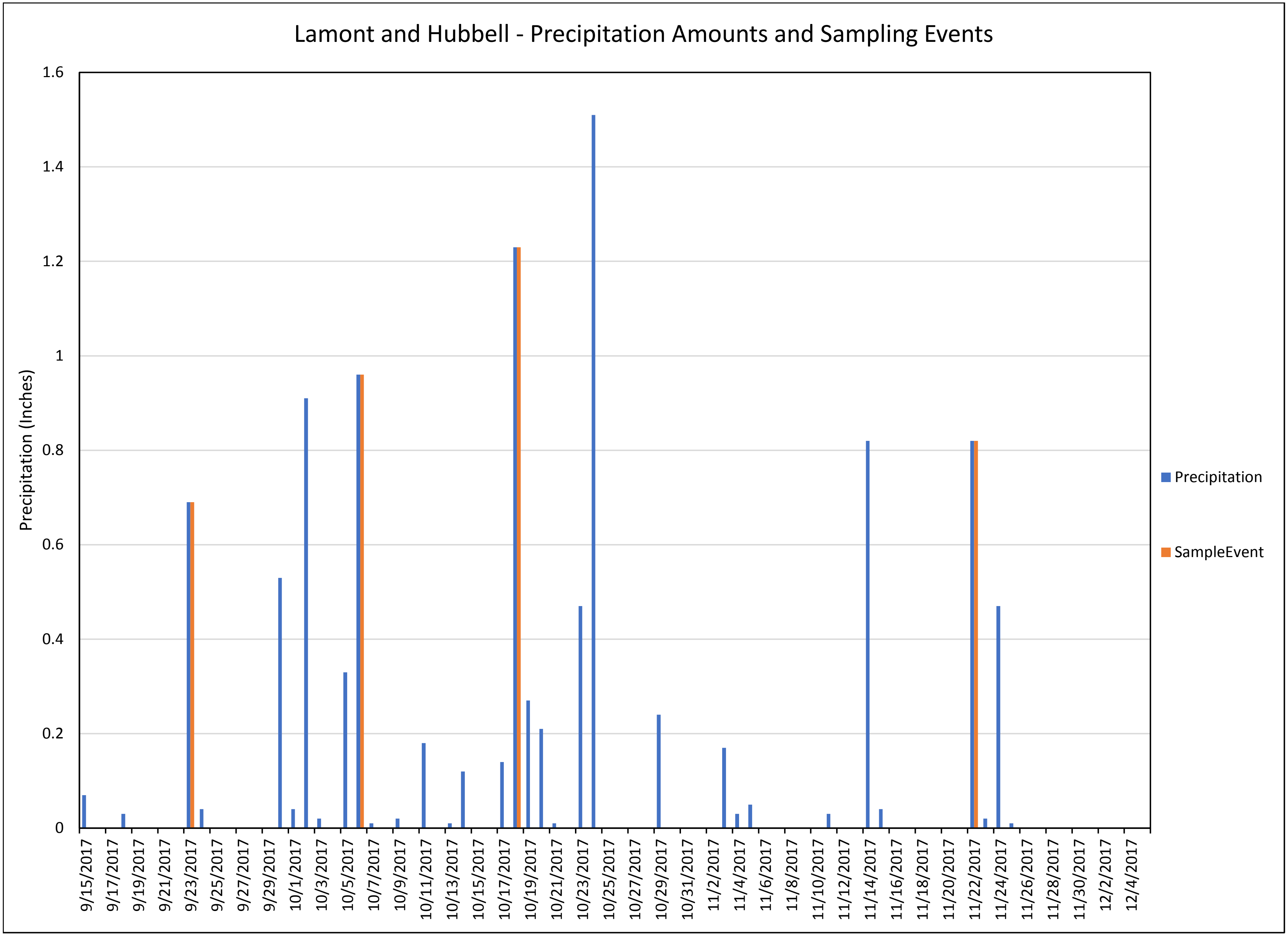
4/1/2018	0.14	
4/2/2018	0	
4/3/2018	0.22	
4/4/2018	0	
4/5/2018	0	
4/6/2018	0	
4/7/2018	0	
4/8/2018	0.15	
4/9/2018	0.39	
4/10/2018	2.36	
4/11/2018	0.95	0.95
4/12/2018	0	
4/13/2018	0	
4/14/2018	0	
4/15/2018	0.02	
4/16/2018	0.32	
4/17/2018	0	
4/18/2018	0	
4/19/2018	0	
4/20/2018	0	
4/21/2018	0	
4/22/2018	0	
4/23/2018	0.29	
4/24/2018	1.22	
4/25/2018	0	
4/26/2018	0	
4/27/2018	0	
4/28/2018	0	
4/29/2018	0	
4/30/2018	0	


Lamont and Hubbell - Precipitation Amounts and Sampling Events
Precipitation (Inches)
2.5
2
1.5
1
0.5
0
1/1/2018
1/8/2018
1/15/2018
1/22/2018
1/29/2018
2/5/2018
2/12/2018
2/19/2018
2/26/2018
3/5/2018
3/12/2018
3/19/2018
3/26/2018
4/2/2018
4/9/2018
4/16/2018
4/23/2018
4/30/2018
Precipitation
SampleEvent

Precipitation via NOAA Station: Edgewater 2.4 N, FL US US1FLVL0006

Date	Precipitation (Inches)	Dates Sampled
9/15/2017	0.07	
9/16/2017	0	
9/17/2017	0	
9/18/2017	0.03	
9/19/2017	0	
9/20/2017	0	
9/21/2017	0	
9/22/2017	T	
9/23/2017	0.69	0.69
9/24/2017	0.04	
9/25/2017	0	
9/26/2017	0	
9/27/2017	0	
9/28/2017	T	
9/29/2017	0	
9/30/2017	0.53	
10/1/2017	0.04	
10/2/2017	0.91	
10/3/2017	0.02	
10/4/2017	T	
10/5/2017	0.33	
10/6/2017	0.96	0.96
10/7/2017	0.01	
10/8/2017	0	
10/9/2017	0.02	
10/10/2017	0	
10/11/2017	0.18	
10/12/2017	0	
10/13/2017	0.01	
10/14/2017	0.12	
10/15/2017	0	
10/16/2017	0	
10/17/2017	0.14	
10/18/2017	1.23	1.23
10/19/2017	0.27	
10/20/2017	0.21	
10/21/2017	0.01	
10/22/2017	T	
10/23/2017	0.47	
10/24/2017	1.51	
10/25/2017	0	
10/26/2017	0	
10/27/2017	0	

10/28/2017	0	
10/29/2017	0.24	
10/30/2017	0	
10/31/2017	0	
11/1/2017	0	
11/2/2017	0	
11/3/2017	0.17	
11/4/2017	0.03	
11/5/2017	0.05	
11/6/2017	0	
11/7/2017	0	
11/8/2017	0	
11/9/2017	0	
11/10/2017	0	
11/11/2017	0.03	
11/12/2017	T	
11/13/2017	0	
11/14/2017	0.82	
11/15/2017	0.04	
11/16/2017	0	
11/17/2017	0	
11/18/2017	0	
11/19/2017	0	
11/20/2017	T	
11/21/2017	0	
11/22/2017	0.82	0.82
11/23/2017	0.02	
11/24/2017	0.47	
11/25/2017	0.01	
11/26/2017	0	
11/27/2017	0	
11/28/2017	0	
11/29/2017	0	
11/30/2017	0	
12/1/2017	0	
12/2/2017	0	
12/3/2017	0	
12/4/2017	0	
12/5/2017	0	


Lamont and Hubbell - Precipitation Amounts and Sampling Events
Precipitation (Inches)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
9/15/2017
9/17/2017
9/19/2017
9/21/2017
9/23/2017
9/25/2017
9/27/2017
9/29/2017
10/1/2017
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Appendix C

EarthRenew

Presentation to Harris Ranch Beef Company

Growing for a better tomorrow.

CSE: ERTH

Forward-looking statements

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All statements, other than statements of historical fact, contained in this presentation constitute “forward-looking statements” and are based on the reasonable expectations, estimates and projections of the Company as of the date of this presentation. Forward-looking statements include, without limitation, possible events, trends and opportunities and statements with respect to possible events, trends and opportunities, including with respect to, among other things, the growth of the biosolid market, global market trends, expected industry demands, the Company’s business strategy and investment criteria, the nature of potential business acquisitions, costs and timing of business acquisitions, capital expenditures, successful development of potential acquisitions, currency fluctuations, government regulation and environmental regulation. The words “plans,” “expects,” or “does not expect,” “is expected,” “budget,” “scheduled,” “estimates,” “forecasts,” “intends,” “anticipates,” or “does not anticipate,” or “believes,” or variations of such words and phrases or statements that certain actions, events or results “may,” “could,” “would,” “might,” or “will be taken,” “occur” or “be achieved” and similar expressions identify forward-looking statements. Forward-looking statements are necessarily based upon a number of estimates and assumptions that, while considered reasonable by the Company as of the date of such statements, are inherently subject to significant business, economic and competitive uncertainties and contingencies. The estimates and assumptions contained in this presentation, which may prove to be incorrect, include, but are not limited to, the various assumptions of the Company set forth herein. Known and unknown factors could cause actual results to differ materially from those projected in the forward-looking statements. Such factors include, but are not limited to, fluctuations in the supply and demand for soil amendments, changes in competitive pressures, including pricing pressures, timing and amount of capital expenditures, changes in capital markets and corresponding effects on the Company’s investments, changes in currency and exchange rates, unexpected geological or environmental conditions, changes in and the effects of, government legislation, taxation, controls and regulations and political or economic developments in jurisdictions in which the Company carries on its business or expects to do business, success in retaining or recruiting officers and directors for the future success of the Company’s business, officers and directors allocating their time to other ventures; success in obtaining any required additional financing to make target acquisitions or develop an acquired business; employee relations, and risks associated with obtaining any necessary licenses or permits. Many of these uncertainties and contingencies can affect the Company’s actual results and could cause actual results to differ materially from those expressed or implied in any forward-looking statements made by, or on behalf of, the Company. There can be no assurance that forward-looking statements will prove to be accurate, as actual results and future events could differ materially from those anticipated in such statements. All of the forward-looking statements made in this presentation are qualified by these cautionary statements. These factors are not intended to represent a complete list of the factors that could affect the Company. The Company disclaims any intention or obligation to update or revise any forward-looking statements whether as a result of new information, future events or otherwise, or to explain any material difference between subsequent actual events and such forward-looking statements, except to the extent required by applicable law. The forward-looking statements set forth herein are for the purposes of providing potential investors with information concerning the Company’s future business plans in order to assist potential investors in determining whether or not to invest in subscription receipts of the Company and may not be appropriate for other purposes. The reader is cautioned not to place undue reliance on forward-looking statements. The purpose of the financial information is to provide investors with an economic outlook for the company. The forward-looking information regarding financial information is dated as of March 26, 2020 and should not be used for, and cannot be relied upon, for any other purpose. These materials may contain inaccuracies or typographical errors. The Company shall not be responsible for any errors or omissions contained in these materials and does not guarantee the accuracy, completeness or timeliness of the information contained herein.

EarthRenew Turns Waste into Wonder

Livestock waste is often a significant liability for farmers and negatively impacts their bottom line. **EarthRenew turns livestock waste into a saleable organic fertilizer**, transforming a liability into an asset.

Proprietary production process

Our proprietary technology allows us to convert livestock waste into affordable, effective organic fertilizer in a pelleted form factor.

Modular, scalable facilities

The modular design of our production facilities provides livestock operators with scalable waste management solutions, and an **on-site source of electricity generation.**

Multiple revenue streams

We receive revenue from organic fertilizer sales, electricity sales, and can share in savings for manure management.

Value-add synergies

Partnered with numerous companies to enhance the value of our organic fertilizer and expand product offerings. Our initiatives have received support from government and other agencies, including the Industrial Research Assistance Program (IRAP).

Our Production Process

Raw livestock waste is transported to a pre-conditioning building where the material is treated to remove foreign objects (i.e. rocks and unwanted organics).

Livestock waste is moved to a dryer, where waste heat from an active natural gas turbine (which is used to generate electricity) thermally treats the waste. **Our patented thermal processing technology eliminates all potential pathogens in the manure without charring or burning.**

Processed livestock waste is combined with environmentally friendly additives to create our proprietary fertilizer blend. We are currently working with multiple companies to diversify our product line and offer organic fertilizer blends with different nitrogen, phosphate, potassium (NPK) ratios.

Finished product is then pelleted and bagged before being sold. **Additonally, the electricity produced earlier in the process by the natural gas turbine is contributed to the host farm, or sold to third parties or back to the grid.**

Strathmore Facility

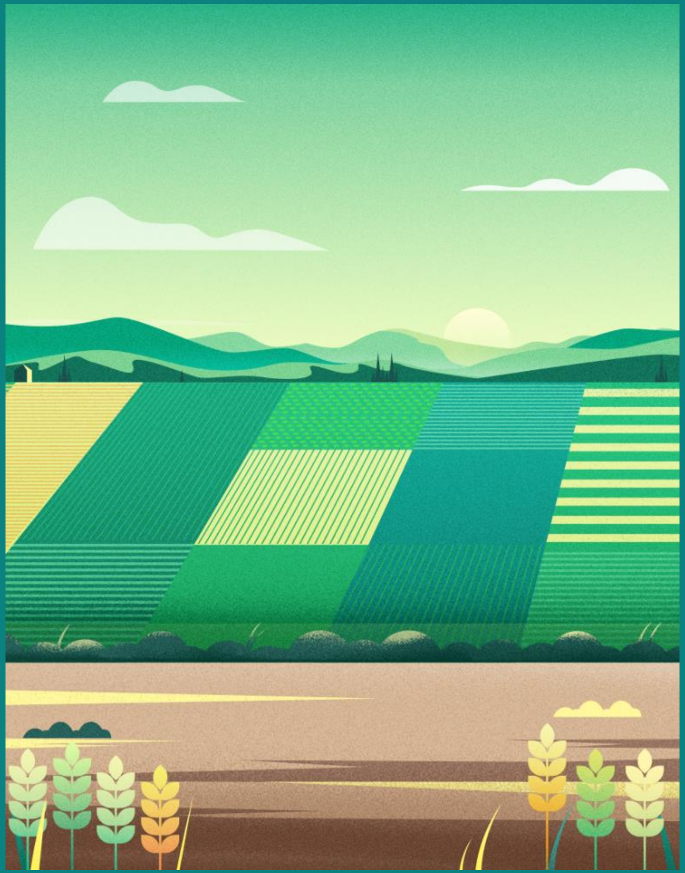
January 2020 was a record month for electricity sales as it generated approximately $117,000 in revenue for EarthRenew

Our flagship Strathmore Facility, which is located on a ~25,000 head Cattleland Feedyards feedlot near Calgary, Alberta, has received facility permitting and operations approval from the Ministry of Alberta Environment and Parks. We are currently in the process of incorporating a new facility design by Stantec **(capital budget ~$5 million)** that features several durability and performance improvements.

Upon completion of this facility’s redesign, we will have the ability to create multiple organic fertilizer formulations for different crops and soil types, opening multiple new potential revenue streams. Our facility will be capable of producing 10 tonnes per hour of dry finished pellets once fully operational.

* Equipment has been sized so that EarthRenew has the ability to run a viable business on only Cattleland feedstock, while also retaining the ability to increase production by acquiring feedstock from other sites or to do contract pelleting, should opportunities arise.

Why EarthRenew Organic Fertilizer?



- EarthRenew's base organic fertilizer formula offers **120% to 145%** of the yield achieved using an equivalent application of chemical fertilizer due to plant nutrient uptake (PNU) of roughly **90%**
- EarthRenew's base organic fertilizer formula has a weighting of **50% of organic matter (OM)**, ensuring plants maximize the benefits of all available nutrients
- Organic fertilizer pellets are slow releasing, which means nutrients are held close to the plant over a longer period of time. This **prevents fertilizer runoff** while extending the utility of fertilizer application long beyond the growing season (3-6 years)
- EarthRenew is working with multiple companies to diversify its product line and offer organic fertilizer blends with different nitrogen, phosphorous, potassium (NPK) ratios
- EarthRenew's organic fertilizer is **easy to transport and apply** due to its pelleted form factor

Product Certifications

CFIA·ACIA

cdfa

WSDA

OMRI LISTED For Organic Use

- Approved for use in both Canada and the US under current formulations
- Significant portfolio of field testing with multiple high value crops
- Suitable for agriculture, horticulture, reclamation, golf courses, parks
- Proven safe and more cost-effective relative to numerous competing organic fertilizers
- Ideal for areas that have chemical fertilizer bans and/or restrictions

Refreshing Field Trials

Conduct in-depth organic fertilizer studies (Q2 2020)

To add further depth to a strong history of field trial studies and to quantify the agronomic benefits of our new organic fertilizer formulations, we plan to conduct field and greenhouse trials on **broadacre** (i.e. wheat, oats, barley) and **specialty crops** (i.e. potatoes) during Q2 to Q4 2020. These studies can provide us with critical market validation by determining the effects of EarthRenew's organic fertilizer on:

A crop yields in a variety of different real-world farming scenarios (i.e. various soil conditions and treatment methodologies).

B germination rates of crops in a potted greenhouse setting. Germination rates are an indicator of plant vigor, or how well a plant responds to its environment.

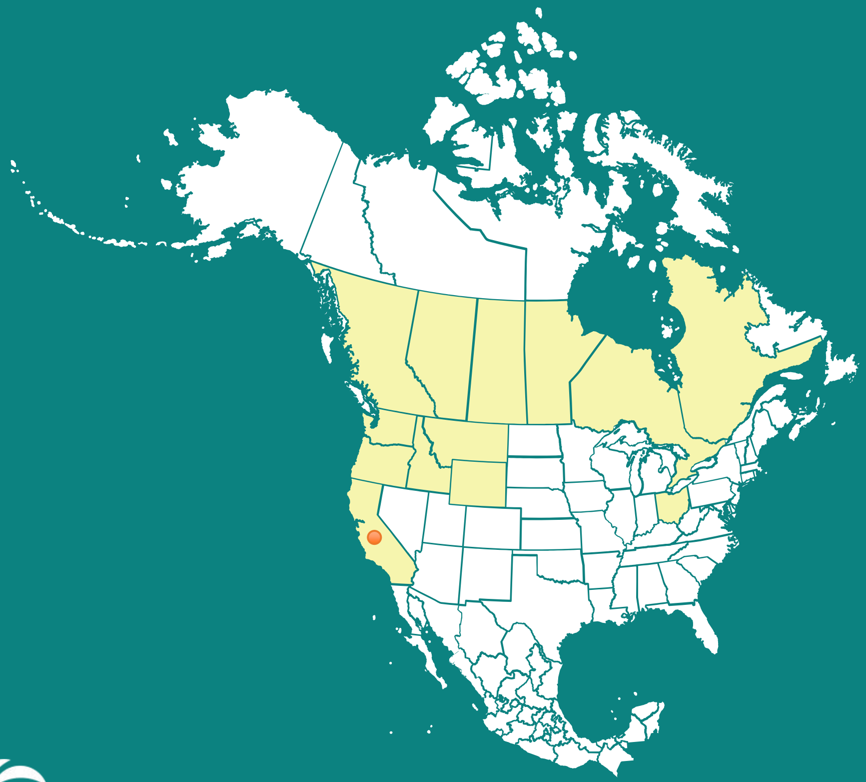
Increasing Agronomic Value

Expand product offering with nitrogen fertilizer enhancement (Q1 2021)

EarthRenew has identified CCm Technologies Limited (“**CCm**”), an award-winning cleantech company based in the UK, as a key partner. By integrating CCm’s carbon capture and conversion technology, we can increase the nitrogen content in our organic fertilizer from **2% to over 10%** while reducing CO_2 emissions during the production process. CCm has already successfully deployed its technology in the UK.

The addition of CCm’s technology provides a new value-added step between mixing and pelleting

Partnership Opportunity
Harris Ranch and BiocharNow



While we establish a stronghold in Canada, we are keen to expand into the multi-billion dollar US market, beginning with California.

A Partnership with Harris Ranch would allow EarthRenew and BiocharNow to provide Harris Ranch with a high-value unique manure waste solution.

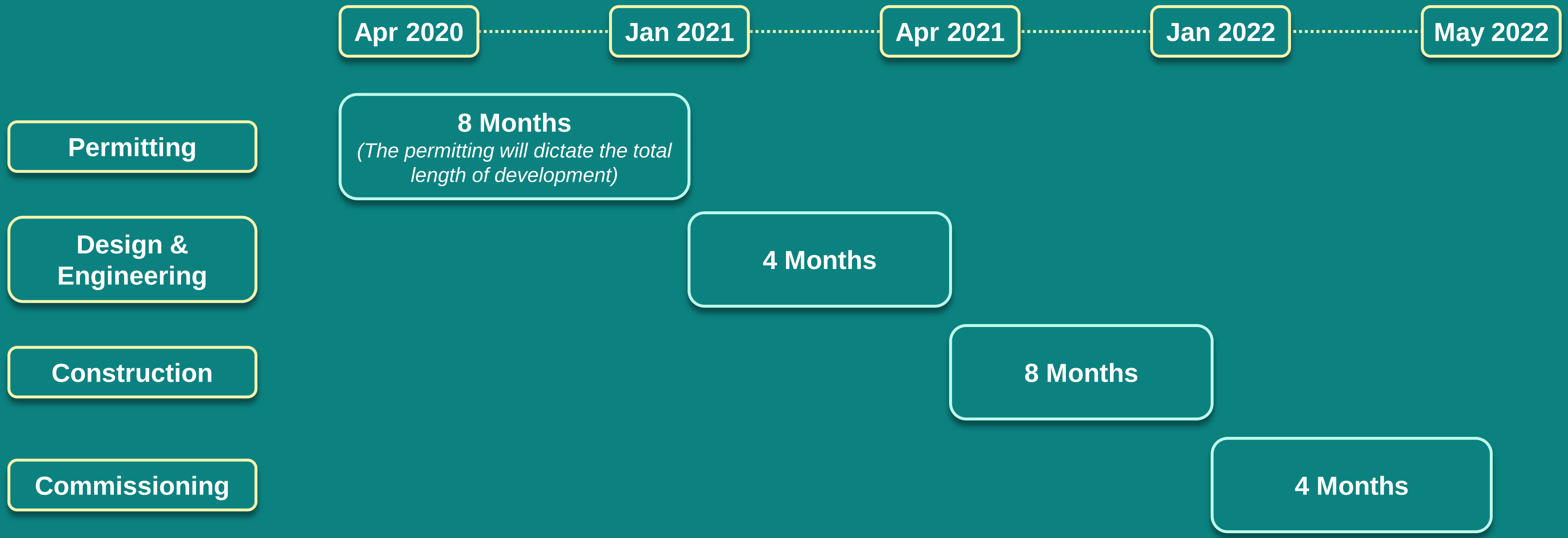
Partnership Structure

Biochar Now EarthRenew EST. 1937 HARRIS RANCH

Needs	Biochar Now and EarthRenew are actively looking for new sites to co-locate their next facilities. Biochar Now and EarthRenew benefit from co-locating their facilities because they can make better fertilizer products together	Harris Ranch needs biochar for its ration and a solution for its manure waste
Receives	EarthRenew secures a feedstock for its next facility Biochar Now gets the binding agent and fertilizer partner it needs to distribute its product in larger volumes	Harris Ranch receives increased herd performance and finds value for its manure

Development Timeline

Our development timeline would have the facility in California ready to produce organic fertilizer for the 2022 growing season.



EarthRenew

Illustrative Financials

*25,000 Head Feedlot

		Base Case	Outperform
Fertilizer Output	tonne / year	~18,000	~35,000
Electricity Production	kWh	~22,000	~22,000
Total Revenue	$	$4,800,000	$10,000,000
COGS	$	$1,400,000	$3,700,000
Gross Margin	$	$3,400,000	$6,300,000
Gross Margin %	%	70%	63%
EBITDA	**$**	**$2,000,000**	**$5,000,000**

EarthRenew

The base case assumes operations 275 days a year and a fertilizer price of $200/tonne, whereas the outperform case assumes operations 355 days a year and a fertilizer price of $250/tonne.

We Look Forward to Exploring This Opportunity with You

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TECHNICAL MEMORANDUM

Johnson Jr. High School Stormwater Improvements Project

TO:	Jeff Rapolti (Brevard County)
FROM:	Justin Gregory, PE; Rich Koller, PE, LEED AP; Brett Cunningham, PE (Jones Edmunds)
DATE:	October 31, 2016
SUBJECT:	Media Formulation Recommendations Jones Edmunds Project No. 08705-043-01

1 INTRODUCTION AND BACKGROUND

Brevard County is implementing a series of projects to reduce nutrient discharges to the Indian River Lagoon (IRL). As part of this Countywide program, the County has identified the Johnson Jr. High School stormwater pond as a site where a stormwater system retrofit could provide additional nutrient load reductions. Johnson Jr. High School is in the Eau Gallie River basin, which ultimately outfalls to Zone B of the North IRL Basin Management Action Plan (BMAP). The goal of the retrofit will be to improve the nutrient-removal efficiency of the existing wet detention pond that treats stormwater runoff from Johnson Jr. High School and the neighborhood immediately north of the school. As part of this retrofit, Brevard County has contracted with Jones Edmunds to provide recommendations for biosorption activated media (BAM) that can be used to enhance the nutrient removal efficiency of the system.

2 EXISTING WATER QUALITY DATA AND NUTRIENT REMOVAL GOALS

Brevard County used the Environmental Protection Agency (EPA) Spreadsheet Tool for Estimating Pollutant Loads (STEPL) model to calculate nutrient loads to the pond. Based on these calculations, the County determined that 33.8 kg/year of total phosphorus (TP) and 467.9 kg/year of total nitrogen (TN) would be discharged on average from the pond. The County identified the goal of the project as reducing these TP and TN loads from the pond by 80% (27 kg/year) and 40% (187 kg/year), respectively.

The County recently sampled water quality at sites in the vicinity of the Johnson Middle School. Table 1 provides the results. These results show TN concentrations increasing downstream of the pond, which may indicate that the pond is a source of nitrogen. This could be further justification for enhancing the nutrient removal efficiency of the system. We recommend additional testing to confirm this trend. Samples should be collected at the inflow to the pond and at the outfall structure. Total suspended solids (TSS) concentration are also higher than expected for a wet detention pond and we would recommend that sampling within the pond be conducted to ensure that a pre-filter would not be necessary.

Table 1 Water Quality Sampling Results from Upstream and Downstream of the Johnson Jr. High School Stormwater Pond

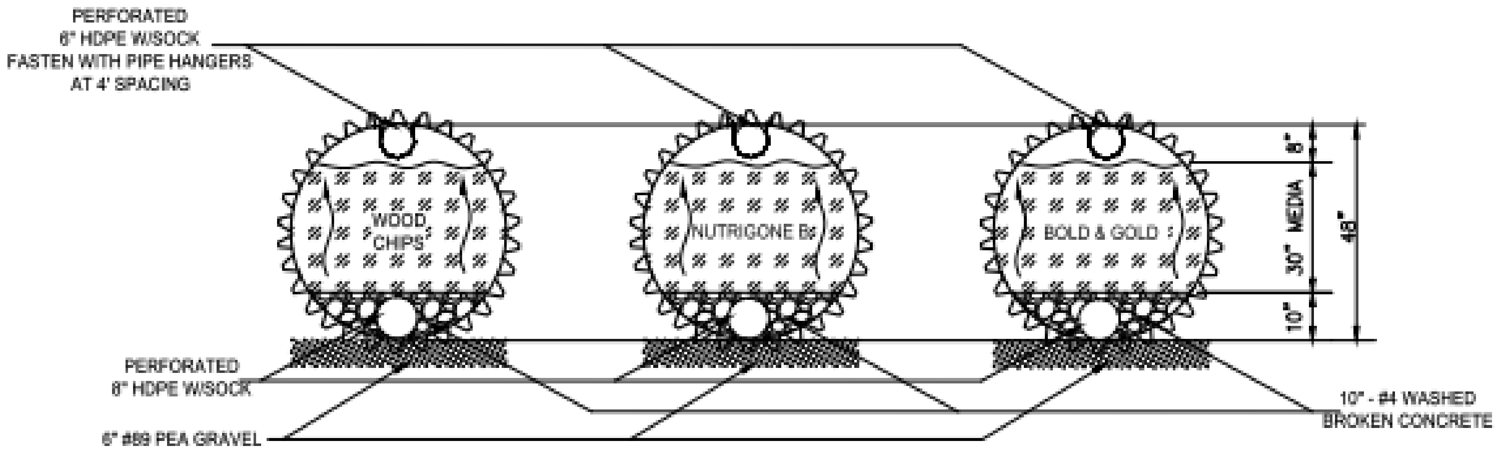
Constituent	Sampled Concentrations B-1392 (mg/l)	Sampled Concentrations B-1349 V. Espana (mg/l)
Nitrogen, Ammonia	0.27	0.053
Nitrogen, Kjeldahl, Total	1.3	0.79
Nitrogen, NO2 plus NO3	0.063	0.18
Nitrogen, Nitrate	0.063	0.18
Nitrogen, Nitrite	0.025	0.025
Orthophosphate as P	0.087	0.052
Phosphorus, Total (as P)	0.16	0.10
Total Suspended Solids	2.1	2.7
Total Nitrogen	1.4	0.97

3 SYSTEM DESCRIPTION

The Johnson Jr. High School wet detention pond is a 2.8-acre pond. The control structure consists of a bleed-down orifice at 20.9 feet (NAVD88) and an emergency overflow weir at 24.3 feet (NAVD88). The County calculated the permanent pool volume to be 14.2 acre-feet with a 10.5-day wet-season residence time. The County has proposed the following enhancements to the pond:

- Modify the control structure on the south bank of the pond by installing a removable weir block over the bleed down weir, while maintaining the emergency over flow.
- Install a Thirsty Duck flow regulator on the west bank of the pond. The Thirsty Duck will regulate the drawdown from the pond to a constant flow rate of 0.89 cfs.
- Install an 8-inch PVC manifold to divert flows from the Thirsty Duck to three denitrification chambers, which can also be described as denitrifying bioreactors. These denitrification chambers would be configured as upflow filters. Each denitrification chamber is expected to use a different BAM mix. The County could then evaluate and compare the effectiveness of the three media mixes under real-world conditions. The chambers will be constructed from a 48-inch high-density polyethylene (HDPE) pipe with perforated 8-inch and 6-inch HDPE used to provide inflow and outflow to the upflow filter. Figure 1 shows a cross-section of the system. The length of each chamber will be 250 feet. This will provide approximately 2,900 cubic feet of denitrification media in each chamber. The contact time would be approximately 66 minutes for each chamber when the system is flowing at its regulated flow rate of 0.89 cfs.
- Water quality sampling locations will be included at both the inflow and outflow points to each chamber. Independent flow control valves will also be installed for each chamber that will allow the flow rate through each chamber to be adjusted.
- Flow from the outfall of the chamber will be collected and routed to the existing pond outfall structure.

Figure 1 Cross-Section of Proposed Denitrification Chambers



4 BAM FORMULATION REVIEW

Jones Edmunds reviewed research reports and journal articles on a number of studies to evaluate BAM mixes that could be included in the three chambers. These media can provide a number of benefits such as the sorption and precipitation of pollutants and filtering of particles. However, the primary benefit that was evaluated for this review is the capacity of the media to promote nitrification and denitrification, which is one of the primary mechanisms for nitrogen removal from stormwater. A list of the studies we used is provided in the References Section of this memo. The three media mixes that we evaluated are Bold & Gold®, NutriGone™, and a custom blend of wood chips and fine gravel.

The documented denitrification rates and overall nutrient removal capacity of all the BAM mixes we evaluated show considerable variation under different scenarios, with a few of the key factors being:

- Contact time.
- Influent concentrations.
- Water temperature.
- Antecedent moisture condition of media mix.

The prediction of the performance of these systems can be difficult. However, the media listed below have been demonstrated to provide denitrification. More details on each of the three BAM formulations is provided below.

4.1 BOLD & GOLD®

Bold & Gold® is a BAM developed by the Stormwater Academy at the University of Central Florida. This media mix has been widely used to provide nitrogen and phosphorus reduction in stormwater, wastewater, and agriculture settings in Florida. Multiple studies document the performance of various Bold & Gold mixes under different conditions. The FDOT report *Demonstration Bio Media for Ultra-urban Stormwater Treatment* published in May 2014 documents the performance of two Bold & Gold mixes under different conditions. Based on the results of this report, Media Mix 1 would seem to provide an approximate reduction in TN of 40% and in TP reduction of approximately 45%. Plastic Tubing Industries, Inc. will be able to provide recommendations on the most appropriate Bold and Gold blend for this installation.

4.2 NUTRIGONE™

NutriGone™ is a propriety media formulated by EcoSense International to provide denitrification and adsorption, which can provide removal of nitrates, phosphorus, and ammonia. The media consists of a zeolite material and red lava rocks in addition to two sources of carbon. The carbon sources consist of a blend of charcoal, corn cobs, straw, coconut fibers, and biochar. The formulation of the media can be varied based on site conditions. EcoSense has conducted independent toxicity testing of the NutriGone media, and no toxicity was found.

The effectiveness of NutriGone has been tested using bench-scale tests and at a stormwater treatment site near the Sebastian River in south Brevard County. Monitoring of this site is described in Schmidt and Housley (2016) and shows TN mass removal rates that vary from 22% to 67%, with one of the sampled events showing a slight increase in nutrients and total suspended solids (TSS). The contact times for this system were less than the proposed contact time, and the denitrification potential of this media mix is should increase with the increased contact time.

4.3 WOOD CHIP AND GRAVEL BLEND

Wood chips have been shown to be an effective source of carbon for promoting denitrification under anaerobic conditions (Schmidt and Cark, 2013; Lynn et al., 2015a). Brevard County has access to wood chips through their yard waste collection program, which significantly decreases the costs of this media mix for the County. We reviewed literature that tested media mix that includes woodchips be could be used in one of the denitrification chambers.

When selecting wood chips for the project, the chips must be a uniform size and an appropriate wood type. Schmidt and Cark (2013) evaluated various wood media types and found that the denitrification rates were lower for some of the oak wood chip mixes compared to pine. They also noted that other research had found that oak wood leachate had higher tannin, lignin, phenols, and chemical oxygen demand than pine leachate and that these properties have been found to increase the toxicity of wood leachate to aquatic organisms. In addition, concerns have been raised about the toxicity of wood chips collected from an urban environment. Based on these concerns, care should also be taken to select wood chips that do not pose an environmental risk.

Lynn et al. (2015a) evaluated the nitrate removal performance of various wood chip media mixes and found that gravel-woodchip mixes performed better than sand-woodchip mixes. The studies were based on Eucalyptus woodchips. Based on these findings, Jones Edmunds recommends that the County consider using a 0.25-inch to 0.5-inch pea gravel mixed with 0.5-inch to 1-inch woodchips. For the Lynn et al. study the gravel and woodchips were mixed in 2:1 (volume/volume) ratio. Care should be taken to ensure that the wood chips are evenly distributed in the mix.

5 FURTHER CONSIDERATIONS

Jones Edmunds makes the following recommendations for the County to consider during implementation of the Johnson Jr. High School stormwater system enhancement and for consideration for future projects:

- Bench-scale testing can be used to evaluate the performance of the media under conditions similar to the proposed system. The costs for these tests are significantly less than the cost of implementing the full-scale stormwater system. We recommend that the County consider bench-scale testing of the listed media to ensure that it performs as expected under conditions that are similar to the proposed installation.

- When testing the performance of the system it will be important to ensure that there is the same flow rate through each chamber and to monitor water quality at both the inflow to the system and at the sampling points immediately downstream of each chamber. At a minimum the following characteristics should be recorded at the inflow to the system and at the downstream clean out / sampling point for each chamber:
  - Ammonia
  - Kjeldahl Nitrogen
  - NO2 plus NO3
  - Nitrate
  - Nitrite
  - Orthophosphate as P
  - Total Nitrogen
  - Phosphorus, Total (as P)
  - Total Suspended Solids
  - Dissolved Oxygen
  - Temperature
  - Flow Rate
  - Alkalinity
  - pH
- Consider using the control valves to evaluate the performance of the media under different contact times. Contact time is a critical parameter that affects the cost and performance of denitrification systems. Understanding the relationship between these variables is important when optimizing the system. This may point to an optimal design contact time that provides more cost-effective nutrient removal.
- Consider using continuous, inter-event treatment as this can be a more cost-effective solution for providing enhanced treatment of stormwater in wet detention systems or other surface storage systems such as large canals. These treatment systems can be significantly smaller than event-based treatment systems since they can treat a small flow continuously. They do have additional pumping costs, but the pumps for these types of systems are small and can potentially be solar powered.

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Phosphorus and Nitrogen Removal in Modified Biochar Filters

Ylva Stenström

ABSTRACT

Phosphorus and Nitrogen Removal in Modified Biochar Filters

Ylva Stenström

Onsite wastewater treatment systems in Sweden are getting old and many of them lack sufficient phosphorus, nitrogen and organic carbon reduction. Biochar is a material that has been suggested as an alternative to the common sand or soil used in onsite wastewater treatment systems. The objective of this study was to compare the phosphorus removal capacity between three different modified biochars and one untreated biochar in a batch adsorption and column filter experiment. The modifications included impregnation of ferric chloride ($FeCl_3$), calcium oxide (CaO) and untreated biochar mixed with the commercial phosphorus removal product Polonite. To further study nitrogen removal a filter with one vertical unsaturated section followed by one saturated horizontal flow section was installed.

The batch adsorption experiment showed that CaO impregnated biochar had the highest phosphorus adsorption, i.e. of 0.30 ± 0.03 mg/g in a 3.3 mg/L phosphorus solution. However, the maximum adsorption capacity was calculated to be higher for the $FeCl_3$ impregnated biochar (3.21 ± 0.01 mg/g) than the other biochar types. The pseudo 2nd order kinetic model proved better fit than the pseudo 1st order model for all biochars which suggest that chemical adsorption was important. Phosphorus adsorption to the untreated and $FeCl_3$ impregnated biochar fitted the Langmuir adsorption isotherm model best. This indicates that the adsorption can be modeled as a homogenous monolayer process. The CaO impregnated and Polonite mixed biochars fitted the Freundlich adsorption model best which is an indicative of heterogenic adsorption.

CaO and $FeCl_3$ impregnated biochars had the highest total phosphorus (Tot-P) reduction of 90 ± 8 % and 92 ± 4 % respectively. The Polonite mixed biochar had a Tot-P reduction of 65 ± 14 % and the untreated biochar had a reduction of 43 ± 24 %. However, the effluent of the CaO impregnated biochar filter acquired a red-brown tint and a precipitation that might be an indication of incomplete impregnation of the biochar. The $FeCl_3$ effluent had a very low pH. This can be a problem if the material is to be used in full-scale treatment system together with biological treatment for nitrogen that require a higher pH.

The nitrogen removal filter showed a total nitrogen removal of 62 ± 16 % which is high compared to conventional onsite wastewater treatment systems. Batch adsorption and filter experiment confirms impregnated biochar as a promising replacement or addition to onsite wastewater treatment systems for phosphorus removal. However the removal of organic carbon (as chemical oxygen demand COD) in the filters was lower than expected and further investigation of organic carbon removal needs to be studied to see if these four biochars are suitable in real onsite wastewater treatment systems.

Keywords: biochar, modified biochar, phosphorus filter, wastewater, batch adsorption experiment, nitrogen filter, COD, Tot-P, Tot-N

Department of Molecular Sciences, Swedish University of Agricultural Science (SLU)
Almas allé SE 750 07 UPPSALA

REFERAT

Fosfor och kväverening i modifierade biokolsfilter

Ylva Stenström

Många av Sveriges små avloppssystem är gamla och saknar tillräcklig rening av fosfor, kväve och organiskt material. Följden är förorenat grundvatten samt övergödning i hav, sjöar och vattendrag. Lösningar för att förbättra fosfor- och kvävereningen finns på marknaden men många har visat brister i rening och robusthet. Biokol är ett material som har föreslagits som ersättare till jord eller sand i mark och infiltrationsbäddar. Denna studie syftade till att i skak- och kolonnfilterexperiment jämföra fosforreduktion mellan tre modifierade biokol och ett obehandlat biokol. Modifieringen av biokolet innebar impregnering med järnklorid ($FeCl_3$), kalciumoxid (CaO) samt blandning med Polonite som är en kommersiell produkt för fosforrening. För att undersöka förbättring av kväverening installerades även ett filter med obehandlat biokol där en vertikal aerob modul kombinerades med en efterföljande horisontell anaerob modul.

Skakstudien där biokolen skakades i 3.3 mg/L fosforlösning visade att adsorptionen var högst i det CaO-impregnerade biokolet, 0.3 ± 0.03 mg/g. Den maximala potentiella fosforadsorptionen beräknades dock vara högst för biokolet som impregnerats med $FeCl_3$, 3.21 ± 0.01 mg/g. Skakförsöket visade också att fosforadsorptionen var främst kemisk då adsorptionen passade bättre med pseudo andra ordningens modell än pseudo första. Adsorption av fosfor på obehandlat biokol och $FeCl_3$ impregnerat biokol modellerades bäst med Langmuir modellen, vilket tyder på en homogen adsorption. Det Polonite-blandade biokolet och CaO-impregnerade biokolet modellerades bäst med Freundlich modellen vilket är en indikation på en heterogen adsorptionsprocess.

Biokol impregnerat med CaO och $FeCl_3$ gav de högsta totalfosforreduktionerna på 90 ± 8 % respektive 92 ± 4 %. Biokolet som var blandat med Polonite hade en reduktion på 65 ± 14 % och det obehandlade biokolet 43 ± 24 %. Ett problem med filtratet från CaO-filtret var att det fick en rödbrun färg samt en fällning vilket kan ha berott på ofullständig pyrolysering och impregnering. Filtratet från det $FeCl_3$ impregnerade biokolet hade mycket lågt pH vilket kan vara problematiskt om mikrobiologisk tillväxt i filtret för rening av kväve och organiskt material vill uppnås.

Filtret för kväverening gav en total kvävereduktion på 62 ± 16 % vilket är högre än kommersiella system. Resultaten från skak och filterstudien visade på att impregnerade biokol kan ge en förbättrad fosforrening om de skulle användas i små avloppssystem. Rening av organiskt material, kemisk syreförbrukning (COD), var dock låg i alla filter och behöver studeras ytterligare för att avgöra om dessa biokol är lämpliga för småskalig avloppsvattenrening.

Nyckelord: biokol, impregnerat biokol, fosforfilter, avloppsvatten, skakexperiment, kvävefilter, COD, Tot-P, Tot-N

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PREFACE

This project is the final thesis for the Master's Program in Environmental and Water Engineering at Uppsala University (UU) and the Swedish University of Agricultural Science (SLU). It corresponds to 30 ETCS. The project was financed by the Swedish Agency for Marine and Water Management. I would like to give thanks to my supervisor and biochar expert Sahar Dalahmeh, researcher at the Department of Energy and Technology at SLU, for helping me with everything throughout the project. I would also like to thank the subject reviewer Mikael Pell, professor at the Department of Molecular Sciences at SLU for help with the experiments and with thorough reviewing of the report.

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POPULÄRVETENSKAPLIG SAMANFATTNING

Kväve och fosforrening i modifierade biokolsfilter

Ylva Stenström

Till små avloppsanläggningar räknas de anläggningar som renar avloppsvatten för upp till ca 200 personer. De flesta anläggningarna som används idag byggdes på 1970 och 80-talet. Många av dem har börjat tappa funktionen och renar avloppsvattnet allt sämre. De flesta små avlopp är markbaserade där avloppsvatten renas genom att filtreras genom en bädd med sand eller direkt ner i jorden. I marken eller sanden börjar det växa bakterier som konsumerar kväve och organiskt material (COD). Fosfor i avloppsvattnet fastnar också i marken genom bindning till markpartiklarna. Då avloppsanläggningar inte fungerar som avsett släpps kväve, fosfor och COD ut i grundvatten eller ytvatten. Orenat avloppsvatten i grundvatten är inte önskvärt eftersom många hämtar sitt dricksvatten därifrån. Näringsämnen som hamnar i ytvatten skapar övergödning och algblomningar vilket förstör vattenmiljöer, badplatser och förutsättningar för fisk. I Östersjön märks det att de små avloppen har stor påverkan. Även fast bara 10 % av Sveriges befolkning renar sitt avloppsvatten i små avlopp står de för 15 % av det totala fosfortillskottet. Resten av Sveriges befolkning (ca 90 %) som renar sitt vatten i större reningsverk står för endast 18 % av fosforbelastningen. För att förbättra reningen i små avlopp har nya prefabricerade lösningar introducerats på marknaden. Ett problem med dessa är dock att de behöver omfattande tillsyn och underhåll och inte är särskilt robusta.

Ett material som har visat sig vara intressant för avloppsvattensrening är biokol. Biokol är egentligen samma material som grillkol men som tillverkats med miljömässigt eller agronomiskt syfte. Biokol är mest känt för sina jordförbättrande egenskaper inom odling, men materialets stora yta och bindningsförmåga gör det lämpligt för kväve och fosforrening. Om man jämför ett gram biokol med ett gram sand finns det i biokolen 100 gånger så stor yta där fosfor kan fastna. Den större ytan gör även biokol till ett bra material för tillväxt av mikroorganismer. I tidigare studier har det kommit fram att biokol är väldigt bra på att ta bort organiskt material (> 90 % COD borttagning). Dock finns fortfarande brister i fosfor- och kvävereduktion. I denna studie undersöktes därför modifierade biokol för att se om en modifiering kunde öka reningsgraden.

För att undersöka fosforreduktion impregnerades biokol gjort av pilbark med järnklorid och kalciumoxid som är två kemikalier som används för fosforbindning. Ett tredje biokol blandades med det fosforbindande materialet Polonite som innehåller mycket kalk. De impregnerade biokolen och polonitkolet jämfördes med obehandlat pilbarkskol i ett skakförsök. I skakförsöket skakades de i olika koncentrationer av fosforlösningar för att se hur mycket som kunde bindas. Biokolen testades också i ett kolonnförsök där de packades i kolonner för att filtrera riktigt avloppsvatten.

För att undersöka kvävereningsförmågan byggdes ett avloppsvattenfilter med två delar, en del med vertikalt flöde följt av en vattenfylld del med horisontellt flöde. Detta skapade ett filter med en syresatt del följt av en syrefattig vilket är gynnsamt för de bakterier som renar kväve.

Resultatet från skakstudien visade att det kalciumoxidimpregnerade biokolet hade störst kapacitet att avlägsna fosfor. Det framgick också att järnkloridimpregnerat biokol har stor potential att binda fosfor men att bindningen tar längre tid. Från kolonnexperimentet var det klart att de kalciumoxid-och järnkloridimprgnerade biokolen hade högst fosforreduktion på mer än 90 %. Inget av de två kolen visade tecken på minskad fosforreningsförmåga under studien. Ett problem med de impregnerade biokolsfiltrena var att utflödet från det kalciumoxidbehandlade materialet fick en gul-brunaktig färg samt en fällning vilket kan betyda att kolet inte hade blivit helt förkolnat vid tillverkningen. En bättre impregnering av kalciumoxid hade möjligen resulterat i en bättre karaktär på vattnet. Vatten filtrerat i järnkloridfiltret hade väldigt lågt pH vilket kan vara ett problem om man vill använda materialet som fosfor och kvävefilter, då de kvävereducerande bakterierna trivs i ett högre pH. Det polonitblandade biokolet hade en fosforreduktion på ca 65 % medan det obehandlade biokolet bara tog bort ca 43 %. Både Polonite-biokolsfiltret och det obehandlade biokolsfiltret tappade i effektivitet under försökets gång. Kvävefiltret visade hög kvävereningsförmåga på ca 60 %.

Denna studie visar att biokol tillverkat av pilbark inte var bättre att rena avloppsvatten från kväve och fosfor än konventionella små avloppsanläggningar. Men om biokolet modifieras med impregnering kan materialet ses som lovande för fosforrening. Om en syrefri del läggs till i ett biokolsfilter kan kvävereningen också förbättras väsentligt. Dock krävs vidare studier för att undersöka hur biokolfilter bäst kan användas. Intressant var även att alla biokolfilter visade en låg COD borttagningsförmåga jämfört med tidigare studier vilket även det skulle behöva undersökas vidare.

1. INTRODUCTION

It is estimated that there are about 750 000 onsite wastewater treatment systems (OWTSs) in Sweden. Out of these, only 400 000 have a treatment process that goes beyond primary sedimentation. Most existing sites were built in the 1970s and 1980s (Ridderstolpe, 2009), and today many systems are getting old and lack sufficient pollution reduction. This leads to discharge of nitrogen (N) and phosphorus (P) into the environment causing eutrophication in downstream water bodies (Hjelmqvist, 2012; Ejhed et al., 2004; Naturvårdsverket, 2014). Another problem is that drilled drinking water wells risk contamination from nearby malfunctioning OWTSs (Miljömålsrådet, 2010).

P has been suggested as a major concern regarding small wastewater treatment systems (Ridderstolpe, 2009). Only a small fraction (about 10 %) of Sweden's population uses OWTS, yet they represent 15 % of the total net anthropogenic load of P on the Baltic Sea. This can be compared with the load from larger wastewater treatment plants (WWTPs) treating the water of 90 % of the population, but is responsible for only 18 % of the P load (HaV, 2016a). For eutrophication to decrease in Swedish waters the level of P emissions have to decline (Boesch et al., 2006). The N load to the Baltic sea from OWTS is small relative other anthropogenic sources (HaV, 2016a). Nevertheless it is still important that the systems have a sufficient N treatment to prevent eutrophication close to them and inadvertent pollution of ground water reservoirs that are used as drinking water resources.

1.1 ONSITE WASTWATER TREATMENT SYSTEMS

OWTSs are defined as systems treating wastewater for up to 200 population equivalents and most OWTSs in Sweden are built as vertical soil filters. The filters are installed with a septic tank in which heavy particles in the wastewater undergo sedimentation. The water is then either led by gravity or pumped into an infiltration unit. The effluent from infiltration units with closed bottoms is collected and conveyed to a ditch or river. Effluent from infiltration systems with open bottom is discharged directly to the ground water. In the latter the water percolates the underlying natural soil. The vertical distance from the filter bottom to the ground water table is crucial and needs to be at least 1 m (Ridderstolpe, 2009). The recommended hydraulic load for a Swedish OWTS is 30 – 60 L/m^2 and day (Olshammar et al., 2015).

The main mechanism behind P removal in vertical soil filters is adsorption or precipitation to the soil or bed material. The phosphate ions (PO_4^{3+}) adsorbed to the surface of the material can also react with iron (Fe), aluminum (Al) or calcium (Ca) minerals to form strong precipitates or surface complexes. The pH in the soil affects the reaction. At low pH, the phosphate reacts with Fe and Al more easily forming e.g. $FePO_4 \cdot H_2O$. At higher pH the PO_4^{3+} forms complexes with Ca ions more easily, such as $CaHPO_4 \cdot 2H_2O$ and $Ca_4H(PO_4) \cdot 3H_2O$ (US EPA, 2002). Some of the P bound in organic particles can be removed physically by the filtration through the soil. Initially the P reduction can be very high. But the capacity to remove P will successively decrease and at some point the bed material will reach saturation. At this time the efficiency of the P removal will be essentially lowered or even cease (Olshammar et al., 2015). It has also been shown that P may be released (desorbed) from the material in the event of heavy rains (Eveborn et al., 2012). This has made it difficult to estimate the lifetime of P removal in soil infiltration beds.

N in vertical soil filters is removed partly by adsorption by ammonium (NH_4^+). However, the main removal mechanism is through bacterial mediated processes. Bacterial growth is favored in soils and materials with large pore volume and specific surface area (US EPA, 2002). By consuming organic material (measured as chemical oxygen demand, COD, or biochemical oxygen demand, BOD) in the wastewater, the bacteria will grow and create an active biofilm. Some parts of the biofilm will be exposed to air and other parts will not. Nitrifying bacteria in the biofilm derive their energy from oxidation of NH_4^+ to nitrite (NO_2^-) in a first step and then further to nitrate (NO_3^-). This process called nitrification is aerobic and the bacteria derive their carbon from carbon dioxide fixation. Under anaerobic conditions, another group of bacteria called denitrifying bacteria reduces NO_3^- or other nitrogen oxides to form nitrous oxide (N_2O) and nitrogen gas (N_2) in a process called denitrification. When denitrifying the NO_3^- is used instead of oxygen for respiration. In addition, denitrifying bacteria must be supplied with a readily available energy and carbon source to denitrify. The combined nitrification-denitrification will lower the total content of N (Tot-N) in the water (US EPA, 2002).

The rate of rebuilding and improving older OWTSs is low. Even some newly built systems have shown poor pollutant reduction and do not pass the regulations on nutrient reduction. The Swedish Agency for Marine and Water Management (Havs och Vattenmyndigheten) issued a proposition in 2016 during the time that this thesis was being written. The proposition was to decrease the required total P (Tot-P) removal from 70 % to be 40 % for general sites. However, for areas classified as sensitive to wastewater the required Tot-P reduction was to be increased to 90 % (HaV, 2016b). Furthermore, the reduction of organic material was suggested to be at least 90 % for all sites. It was also suggested that requirements for N reduction should be removed completely for general OWTS. However requirements for N removal was suggested to be put to 50 % if the area is classified as sensitive. A soil based wastewater system built according to present recommendations has the capability to remove 30 ± 10 %, 70 ± 20 % and 80 ± 10 % of influent N, P and COD, respectively (Olshammar et al., 2015). One problem is that many systems today have not been built according to the recommended guidelines. A common mistake is to locate the soil filter too close to the ground water, less than one meter. If the distance is too short the water does not get treated. N and P removal also show large variations depending on soil, placement and load.

To improve the P and N removal in vertical soil filters, alternative solutions and upgrades have become available on the market. An example is precipitation in the septic tank using iron or aluminum salts that significantly improves the P removal rate. Other popular but not as common upgrades are prefabricated treatment systems such as separate phosphor filters. Phosphor filters are commonly made from material with high calcite content and are placed after a closed sand bed to polish the effluent water. They are said to be able to remove up to 90 % of the P (Avloppsguiden, 2009). Polonite is an example of a material used in P filters. It is produced by heating the sedimentary rock opoka that has a high silica and CaO content. Opoka also contains MgO, Al_2O_3 and Fe_2O_3 that helps improve P removal (Brogowski & Renman, 2004). Solutions for improving N removal also exist. They can for instance be compact mini-treatment plants, mimicking large-scale WWTPs. There are many different versions of mini treatment plants but most are built with sedimentation, biological and chemical treatment. All mini-treatment plants use nitrification-denitrification for the reduction of N and can remove around 30 – 60 % of total N. Artificial bed material with large specific surface area is also a method to ensure good microbial development yielding N and BOD removal rates of about 20 – 40 and 90 %, respectively (Avloppsguiden, 2009).

Alternative treatment methods, like the ones mentioned, have shown higher P, N and BOD removal rates than vertical soil filters, but as of today require much supervision and service (HaV, 2016b). A treatment system based on infiltration requires minimal attention and is robust to changes in both load and temperature (Ridderstolpe, 2009). A robust system with high removal capacity is desirable. However, the lack of quality in vertical soil filters makes it necessary to look for new solutions for a secure reduction on P and N.

1.2 BIOCHAR

Char is the product of pyrolysis, where biomass is heated at high temperatures with no access to oxygen. Char is known for its ability to improve soil quality and plant growth. It has also proven itself useful for energy production, climate change mitigation and water treatment. Biochar is defined as char specifically produced for agronomic and environmental management applications (Joseph & Lehman, 2009). The char created after pyrolysis does not degrade over time, but is still a reactive material. The material is similar to activated carbon but does not undergo any activation process, making it a less expensive alternative. Yet biochar has twice the porosity of sand and has a specific surface area more than a 100 times higher than sand or soil with corresponding particle size (Dalahmeh, 2016). This gives biochar an excellent adsorption potential and can create a good environment for microbiological growth which could be beneficial for P, N and COD removal.

P adsorption to biochar is physical and/or chemical. The physical adsorption constitutes weak van der Waals forces between the phosphate ions and the surface. The large pore volume and specific surface area of biochar increases the potential for physical adsorption (Lehmann & Joseph, 2009). What chemical reaction that binds the P depends on the biochar surface and its chemical composition.

A review of several different biochar experiments showed that P removal was not affected much by hydraulic loading rate or particle size (Dalahmeh, 2016). However, to reach an optimal removal of COD and pathogens, a particle size of 1.4 mm and hydraulic load of less than 50 L/m^2 and day was recommended. In the results of the review it was clear that biochar had the capacity to remove 62 – 88 % of the total nitrogen (Tot-N). Biochar also had the capacity to remove 32 – 89 % of the total P (Tot-P), highly depending on its mother material. COD and BOD removal in biochar filters was proven to be high (> 90%) and consistent while it was suggested that the P and N removal processes in biochar filters needed further investigation to reach sufficient and reliable reduction (Dalahmeh, 2016).

1.3 IMPREGNATED BIOCHAR

Recent studies of modified biochar have focused on removal of several different substances; from reduction of heavy metals to carbon dioxide emissions. To impregnate or modify biochar with different elements as a method to improve the removal of specific substances is a growing research field (Rajapaksha et al., 2016). Modifications may occur before or after the biomass undergoes pyrolysis and can include heat treatment, impregnation of different substances and acid or base treatment to change and improve structure and removal properties. Modification of biochar with the objective to remove P has been investigated in a few studies by preforming sorption experiments with P solutions. In a study by Chen et al. (2011), biochar powder for P removal was produced at different temperatures and impregnated with magnetite (Fe_2O_3) with a biochar to Fe ratio of 0.9. The modified biochar showed higher P adsorption (up to 99 % removal) compared to unmodified replicates. Adding iron oxides to the biochar can also have structural benefits producing larger pore volume and specific surface area (Ren et al., 2015). Ferric chloride biochar has been studied by Li et al. (2016) where a Fe to biochar ratio of 0.7 in the biochar resulted in a P adoption as high as 16.58 mg P/g biochar which could be compared to natural sand that can have an adsorption less than 1 mg/g P (Del Bubba et al., 2003). When Liu et al. (2015) tested column filters with Fe modified biochar, 99 % of the Tot-P concentration was removed. Ca modified biochar filters have been studied for the removal of arsenic and chromium (Agrafioti et al., 2014) but is not as common for P removal. However Seo et al. (2005) impregnated and compared construction aggregate quarry with CaO, Al and Fe and found that the CaO impregnated material had superior P removal. Jung et al. (2016) analyzed fine biochar material produced by algae, drained and dried in calcium-alginate beads to investigate P removal and found that the biochar had the capacity to remove 100 mg P/g biochar.

1.4 OBJECTIVES

The overall goal of the project was to investigate the potential of biochar as filter media for removal of wastewater pollutants. Biochar filter materials were tested in a batch adsorption experiment with various phosphate concentrations and in filters for removal of P, N and COD from municipal wastewater. Specific objectives were to:

(i) Evaluate P removal capacity using biochar modified by impregnation with ferric chloride, calcium oxide and biochar mixed with Polonite in a batch adsorption experiment using increasing concentrations of phosphate solutions.

(ii) Evaluate P removal capacity using the same biochar types as in (i) but in a column filters fed with wastewater.

(iii) Investigate N transformation and removal in a biochar filter unit consisting of a vertical flow non-saturated section followed by a horizontal flow saturated section.

2. MATERIALS AND METHOD

2.1 BIOCHAR PREPERATION

Pine bark of particle size of 1 – 7 mm was saturated with solutions of ferric chloride ($FeCl_3$), calcium oxide (CaO) before pyrolysis. $FeCl_3$ and CaO are two common precipitation chemicals used for P removal (US EPA, 2002). After being mixed in the solutions for 24 hours in room temperature, the bark was dried in 100 ºC for another 24 hours. Finally the biochars were pyrolysed in 350 ºC for 3.5 hours. The ratio between ion and biochar was 0.3 for both impregnated biochars. The third biochar type was produced without any impregnation before pyrolysis but also had the pine bark as mother material. After pyrolysis, it was mixed with granular Polonite at a ratio of 0.3. The four different types of modified biochar used in the batch experiment and column filter experiment were named as follows:

UBC – untreated biochar
FBC – biochar impregnated with ferric chloride ($FeCl_3$)
CBC –biochar impregnated with calcium oxide (CaO)
PBC–biochar mixed with Polonite

The biochar used in the N removal filter originated from mixture of hard wood biomass and was obtained from Vildelkol AB (Vindelkol, 2017).

2.2 BATCH ADSORPTION EXPERIMENT

A batch experiment was carried out to assess and compare the adsorption capacity of P for the different types of biochar. One gram of each biochar type was added to 500 mL E-flasks containing 100 mL of phosphate solution of the concentrations 0.5, 3.3, 6.5, 13 and 26 mg PO_4-P/L (labeled C1-C5). The concentration were prepared by diluting 1000 mg PO_4/L stock solution based on monopotassium phosphate (KH_2PO_4) with distilled water (Table 1). The PO_4-P concentrations were selected based on what can be expected in an OWTS and diluted according to Table 1 (Palm et al., 2002). Three replicates (n=3) were prepared for each concentration except for C1 having only one replicate (n=1). The beakers were shaken on a rotary table for 24 hours at 130 rpm and constant room temperature 20 ± 2 ºC. Samples of the adsorbate solution (6 mL) from each of the beakers were extracted after 0 min, 15 min, 75 min, 4 h and 24 h using a pipette. The sorbate samples were filtered through a 0.45 µm filter and their PO_4-P concentration was determined according to method given in Table 2. The pH of the P solutions with biochar was measured during the experiment using pH strips (Table 2). After 24 hours the residual solids were washed with deionized water and then oven dried 80 ºC for 4 hours. The solids were finally stored in plastic bags for later analysis using Scanning Electron Microscopy (SEM) and Fourier Transform- Infrared Spectroscopy (FTIR), but this analysis was not performed during this thesis and was thus not included in the report.

Table 1 Dilution scheme for preparation of different concentrations of P solutions used in biochar adsorption batch experiment. Stock KH_2PO_4 solution of 1000 mg PO_4/L was mixed with distilled water into 100 mL beakers.

Label	PO_4 stock solution (mL)	Volume of beaker (mL)	Final concentration (mg P/L)
C1	0.15	100	0.5
C2	1	100	3.3
C3	2	100	6.5
C4	4	100	13.0
C5	8	100	26.08

2.2.1 Adsorption isotherm

An adsorption isotherm is the relationship between the equilibrium concentration in a solution (Ce) and the amount of adsorbate adsorbed on the surface of the material (Q) at constant temperature. The adsorption of phosphate (Q) from the batch adsorption experiment was calculated using Equation 1:

$$Q = (C_0 - C_e)\frac{V}{m} \qquad (1)$$

where Q is the mass P adsorbed per mass biochar (mg/g), C_0 the initial concentration of the solution (mg/L), C_e the concentration (mg/L) after 24 hours of the batch equilibrium experiment, V the volume of the solution (mL) and m the mass of the adsorbent (g).

The adsorption isotherm is often modelled with a Langmuir or Freundlich equation model (Messing, 2013). Langmuir and Freundlich adsorption isotherms were calculated for each biochar type with data used from the batch adsorption experiment. The Langmuir isotherm (Equation 2) models a monolayer adsorption on a uniform surface, while the Freundlich isotherm (Equation 3) models non-uniform adsorption on a non-uniform surface.

$$Q_e = \frac{k_L Q_m C_e}{1+k_L C_e} \qquad (2)$$

Q_e (mg/g) Equilibrium adsorption capacity
C_e (mg/L) Concentration at equilibrium
k_L (L/mg) Langmuir adsorption constant
Q_m (mg/g) Maximum adsorption capacity

$$Q_e = k_F C_e^{1/n} \qquad (3)$$

k_F (L/g) Freundlich constant
n Dimensionless Freundlich heterogeneity exponent

In order to explore what model best described the batch experimental data, the parameters k_L, Q_m, k_F and n were determined for the models. This was done by linearizing the model Equations (2) and (3). The linear equation of the Langmuir (Equation 4) and Freundlich (Equation 5) was expressed on the form y = kx + m.

$$\frac{C_e}{Q_e} = \frac{Ce}{Q_m} + \frac{1}{k_L Q_m} \qquad (4) \qquad\qquad \ln(Q_e) = \frac{1}{n} lnC_e + \ln(k_F) \qquad (5)$$

Linear plots of the Langmuir Equation (4) were created with Ce as x-axis vs C_e/Q_e as y-axis. This provided the Langmuir parameters Q_m and k_L were $1/k_LQ_m$ is the intercept and $1/Q_m$ as the slope. Graphing Equation (5) with ln(Ce) on the x-axis and $\ln(Q_e)$ on the y-axis provided the Freundlich parameters k_F and n where $\ln(k_F)$ was the intercept and 1/n the slope. This was done for all biochar types.

After obtaining all the parameters, Q_e was calculated for each C_e with the Langmuir and Freundlich Equations (2) and (3). The model that calculated Q_e correlated best with the experimental Q_e was considered the best model to describe the P adsorption on each biochar type.

2.2.2 Kinetic isotherm

A kinetic isotherm describes the adsorption (Q) over time (t). The concentrations analyzed after 0 min, 15 min, 75 min, 4 h and 24 h in the batch adsorption experiment were used to calculate Q_t with Equation (1). The pseudo first (Equation 6) and second (Equation 7) order kinetic models are commonly used to describe the adsorption over time:

$$\frac{dQ_t}{dt} = k_1(Q_e - Q_t) \qquad (6) \qquad\qquad \frac{dQ_t}{dt} = k_2(Q_e - Q_t)^2 \qquad (7)$$

Q_t (mg/L) Amount adsorbed at time t
k_1 (min^{-1}) Pseudo 1st rate constant
k_2 (g/mg/min) Pseudo 2nd rate constant

In order to see which of pseudo 1st and pseudo 2nd order kinetic models best described the adsorption experiment their linear forms Equation (8) and (9) were used:

$$\ln(Q_e - Q_t) = lnQ_e - k_1 t \qquad (8) \qquad\qquad \frac{t}{Q_t} = \frac{1}{k_2 Q_e} + \frac{t}{Q_e} \qquad (9)$$

The pseudo 1st order equation was graphed on linear form with $\ln(Q_e – Q_t)$ on the y-axis and t on the x-axis. From the linear plot the rate constant k_1 (slope of the graph) and correlation coefficient R^2 was determined. Pseudo 2nd order equation was linearly graphed with t/Q_t on the y-axis and t on the x-axis with the intercept of the graph being $1/k_2Q_e$ and the slope $1/Q_e$. By plotting data this way the k_2 and R^2 for the pseudo 2nd order equation was determined. The linear plot of the two models with the highest correlation coefficient (R^2) was considered the best model to describe the P adsorption of the biochar types over time.

2.3 COLUMN FILTERS

To investigate the removal of P from real wastewater the four biochar types were tested in a 14 week long column filter experiment. Four 60 cm tall acrylic glass columns with diameter 4.25 cm were filled separately with untreated biochar (UBC), biochar impregnated with calcium oxide (CBC), biochar impregnated with ferric chloride (FBC), and biochar mixed with Polonite (PBC). Underneath and on top of the main biochar layer, 5 cm coarser untreated biochar (8 mm in diameter) was filled to prevent clogging on the very top of the filter and facilitate drainage on the bottom (Figure 1). The filters received 71 mL wastewater per day divided equally between the times 24:00, 08:30 and 16:00 to mimic the load of a real vertical soil infiltration system with 50 L/m^2 and day (Olshammar et al., 2015). Peristaltic pumps regulated with timers were used to feed the filters with wastewater stored in a fridge (2 – 4 ^{o}C). Before feeding, the wastewater was left outside the fridge for 20 minutes to reach room temperature. The wastewater was collected twice a week on Mondays and Thursdays mornings from the municipal wastewater treatment plant in Uppsala (Kungsängsverket). The water was collected directly from the primary sedimentation step of the plant and had to be filtered through a 0.8 mm mesh to remove particles to prevent clogging of the pipe of the pumps.

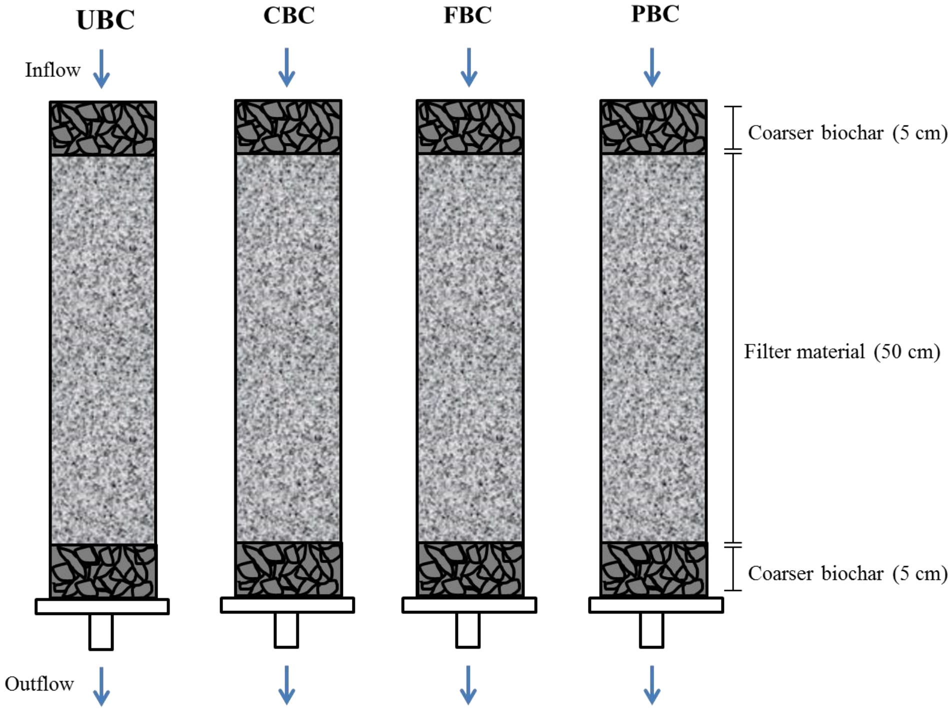


Figure 1 Experimental set-up for column filters filled with untreated biochar (UBC), biochar impregnated with calcium oxide (CBC), biochar impregnated with ferric chloride (FBC) and biochar mixed with Polonite (PBC).

Sampling of the inflow and outflow was done once a week, on Wednesdays, starting on the third week of the experiment. The following parameters were determined weekly: Tot-P, PO_4-P, Tot-N, NO_3-N, NH_4-N and pH and every second week COD was analyzed. The main objective was to investigate P but N measurements took place too. All analysis was conducted using chemical kits (Table 2).

Table 2 Analytical kits, analytical concentration ranges and instruments used for analyzing pollutants in wastewater used in the column filter and lab-scale filter unit experiments.

Substance	Kit name/Method	Range mg/L	Instruments
Tot-N	Spectroquant Crack Set 20 1.14963.0001	0.1-25.0	Spectroquant NOVA 60, VWR International Sverige Thermal reactor TR420, Merck
NH4-N	Spectroquant Ammonium Test 1.00683.0001	2.0-150	Spectroquant NOVA 60 and Aquamate, VWR International Sverige
NO3-N	Spectroquant Nitrate Test 1.09713.0002	0.1-25.0	Spectroquant NOVA 60 and Aquamate, VWR International Sverige
Tot-P	Spectroquant Crack set 10 1.14687.0001	0.0025-5	Spectroquant NOVA 60 and Aquamate, VWR International Sverige Thermal reactor TR420, Merck
PO4-P	Spectroquant Phosphate test 1.14848.0002	0.0025-5	Spectroquant NOVA 60 and Aquamate, VWR International Sverige
COD	Spectroquant COD Cell test 1.09772.0001 and 1.09773.0001	10-100 and 100 - 1500	Spectroquant NOVA 60
pH	pH strips	7-14, 1-7 and 1-14	Papier dosatest, VWR MColorptest, Merck

Removal efficiency was calculated from the difference in concentrations of inflow and outflow of the filters (Equation 10):

$$E = 100\,\frac{C_{in}-C_{out}}{C_{in}} \qquad (10)$$

where E is the removal efficiency (%); C_{in} the concentration of the influent (mg/L); and C_{out} the concentration of the effluent (mg/L).

2.4 NITROGEN REMOVAL FILTER

A biochar filter with an aerobic vertical flow section combined with an anaerobic horizontal flow section was installed at Kungsängsverket and operated for 14 weeks. The biochar used originated from mixture of hard wood biomass and was obtained from Vildelkol AB (Vindelkol, 2017). The horizontal and vertical flow sections were installed using two boxes each with the size of 74×40×29 cm placed on top of each other (Figure 2). In the vertical flow section, a 3 cm drainage layer was prepared with coarse biochar (8 - 16 mm in diameter) at the bottom which had a slope of (1.5: 60; i.e. 2.5%). The section was then filled up to 30 cm with biochar of a particle size that varied between 2.5 and 5 mm. A second 3 cm layer of coarse biochar was placed on the top of the main filter to prevent clogging on the surface.

The horizontal flow biochar section was prepared by filling the box with coarse biochar (25 - 40 mm in diameter) in two 10 cm layers at the inlet and outlet sides. The main 54 cm part of the section was then filled with biochar (1.6 - 2.5 mm in diameter). The depth of the biochar in the horizontal flow section was 30 cm. The outlet of the horizontal flow section was located at a level 4 cm below the inlet level. Before the start of the experiment the filter was gently washed with distilled water. During the experiment, pumps fed the filter with 3 L three times a day, at 9:00, 16:00 and 01:00. This gave a flow of around 42 L/m^2 and day. The wastewater was initially pumped from after primary sedimentation in the plant. However, $FeCl_3$ added directly after the primary sedimentation in the plant interfered with N analysis so the filter with sampling point was relocated in week 7 to a location before the actual $FeCl_3$ dosing in the middle of the primary sedimentation. The water pumped from the primary sedimentation was filtered through a 0.8 mm sieve and the flow was lowered to 1.5 L/day giving a load of 21 L/m^2 to prevent clogging.

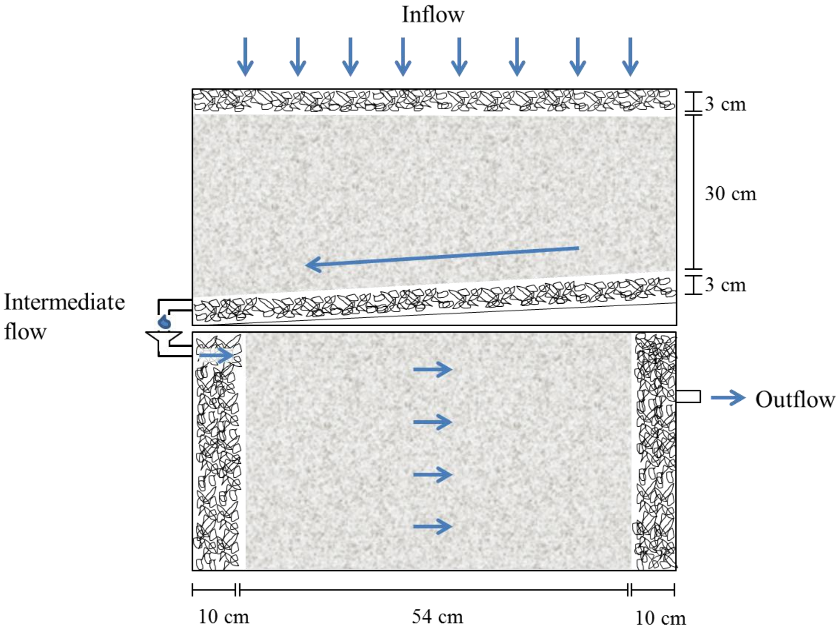


Figure 2 Combined aerobic vertical flow and anaerobic horizontal flow biochar filter unit for wastewater nitrogen removal. The material in the filter was biochar made from hardwood biomass.

Samples were taken from the inflow, intermediate flow and outflow of the filter once a week and N transformation and concentration was measured as Tot-N, NH_4-N and NO_3-N. Even though N was the main investigation objective for this filter P concentrations were also analyzed as Tot-P and PO_4-P. COD concentrations were also analyzed and all analysis was made according to methods given in Table 2. Removal efficiency was calculated according to Equation 10.

3. RESULTS

3.1 BATCH ADSORPTION EXPERIMENT

The mean concentration of P in all solutions (C1 – C5) of the batch adsorption experiment decreased with time for all biochars, except for PBC in C1, where the mean PO_4-P concentrations fluctuated with time and was higher than at start after 24 hours of shaking (Table 3 & Table 10-AI).

The untreated biochar showed low adsorption in the concentration range 0.5 - 13 mg/L (C1-C4) and it was never tested for the highest concentration (26 mg P/L, i.e. C5). The achieved PO_4-P reductions were 16 ± 3 (mean ± standard deviation; n=3) % for UBC, 80 ± 24 % for CBC, 63 ± 22 % for FBC and 50 ± 52 % for PBC after 24 hours of shaking.

Table 3 The average PO_4-P concentrations from shaking experiment where 1 g of untreated biochar (UBC), CaO biochar (CBC), $FeCl_3$ biochar (FBC) and Polonite biochar (PBC) were shaken in five P concentrations C1 – C5 (mg/L) for 24 h.

Biochar	**Time**	**C1**	**C2**	**C3**	**C4**	**C5**
UBC	t_0 (0min)	0.57	3.26	5.87	12.77	X
	t_1 (15min)	0.49	3.25	6.53	12.77	X
	t_2 (1h 15min)	0.53	2.65	5.30	11.59	X
	t_3 (4 h)	0.51	2.90	4.90	10.77	X
	t_4 (24 h)	0.48	2.57	5.00	10.82	X
CBC	t_0 (0min)	0.57	3.48	6.43	13.00	26.30
	t_1 (15min)	0.45	1.27	1.93	8.17	21.80
	t_2 (1h 15min)	0.32	0.48	0.44	1.18	8.66
	t_3 (4 h)	0.33	0.40	0.40	0.81	1.95
	t_4 (24 h)	0.32	0.42	0.50	0.63	0.66
FBC	t_0 (0min)	0.51	3.38	6.72	12.67	25.85
	t_1 (15min)	0.70	2.77	3.78	10.93	23.30
	t_2 (1h 15min)	0.67	2.18	3.07	8.68	20.68
	t_3 (4 h)	0.55	1.75	3.20	6.49	16.79
	t_4 (24 h)	0.36	0.81	1.78	3.52	9.91
PBC	t_0 (0min)	0.46	3.51	6.27	13.07	25.95
	t_1 (15min)	0.67	1.44	2.68	10.37	24.85
	t_2 (1h 15min)	0.49	0.52	0.98	4.82	21.87
	t_3 (4 h)	0.47	0.58	1.10	3.84	16.65
	t_4 (24 h)	0.59	0.74	1.58	3.59	11.06

At the end of the 24 h shaking period the UBC, FBC and PBC biochars were still intact but CBC had disintegrated into fine particles more noticeable than the other biochar types. Beakers with CBC got a red-brown and FBC yellow color while UBC and PBC stayed uncolored.

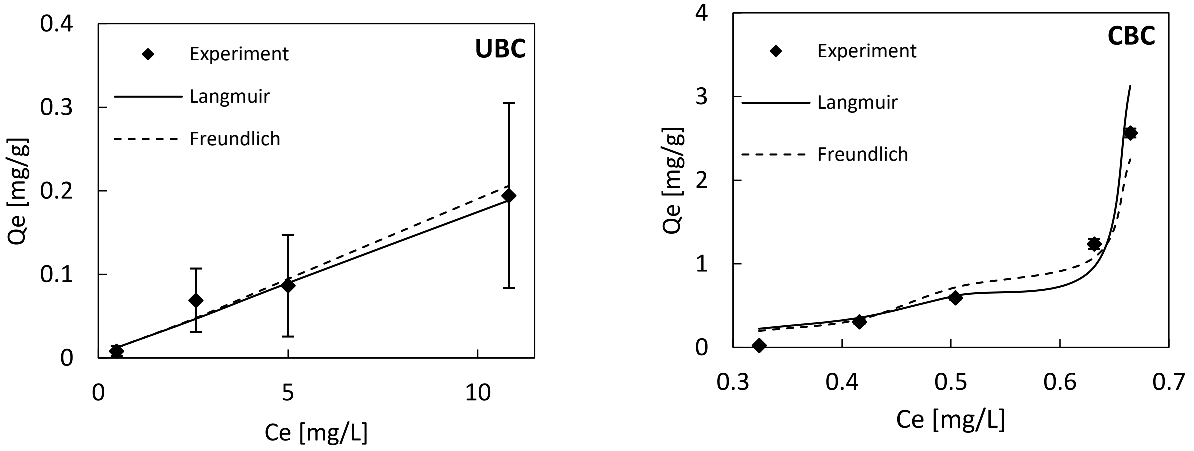
The pH in the PO_4 solution at the start of the shaking (t_0) was 7.0, but it changed with time (Table 4). In the flasks with UBC, CBC and PBC, pH increased to 7.5, 8.5 and 8.8 while the solution with FBC's pH was lowered to 3.0.

Table 4 Mean pH in the different solution concentrations during the batch adsorption experiment for untreated biochar (UBC), calcium oxide impregnated biochar (CBC), ferric chloride impregnated biochar (FBC) and untreated biochar mixed with Polonite (PBC).

Time	UBC	CBC	FBC	PBC
t_0 (0min)	7.0	7.0	7.0	7.0
t_1 (15min)	x	8.7	4.7	9.2
t_2 (1h 15min)	7.0	9.0	4.5	9.5
t_3 (4 h)	7.3	8.8	4.3	9.3
t_4 (24 h)	7.5	8.5	3.0	8.8

3.1.1 Adsorption isotherm

All adsorption isotherm curves show that increasing equilibrium concentrations (C_e) gave an increase in P adsorbed on the surface (Q_e) (Figure 3). The UBC isotherm showed linear behavior, where an increase in concentration (C_e) gave a constant increase in the P concentration on the biochar surface (Q_e). However, the standard deviations of the replicates were high and hence observed trends can only be considered indicative as error bars overlapped to a large extent. Adsorption isotherm curves for FBC and PBC were linear in lower concentrations but at higher equilibrium concentrations, Q_e increased less. CBC showed the opposite with a small increase of Q_e in lower concentrations but higher Q_e when the concentration became higher.



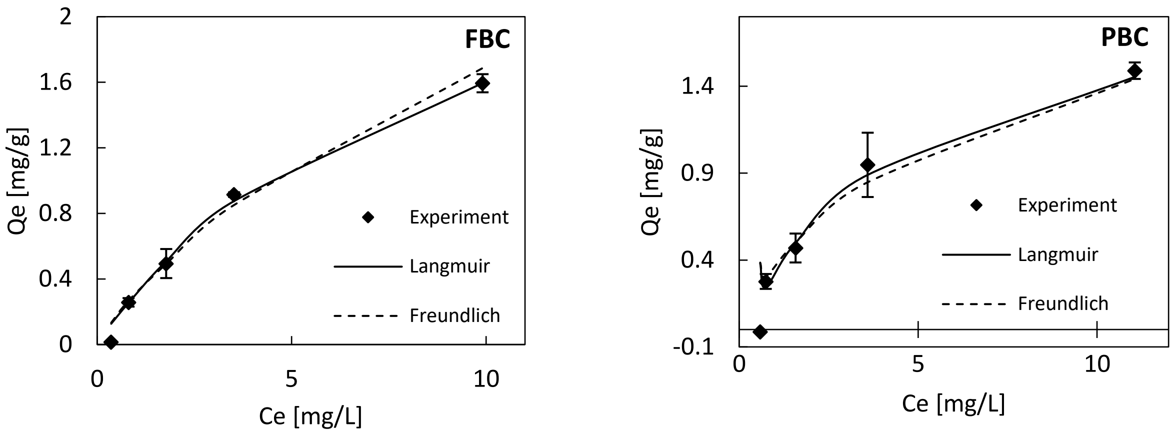


Figure 3 Relation between the concentration of P in the solutions from the batch adsorption experiment at the end of the shaking experiment (C_e) and the concentration of P adsorbed on to the biochar (Qe). Diamond symbols represent measured mean ± standard deviation, n=3.The Langmuir and Freundlish adsorption isotherm models calculated from the data are expressed as solid or dashed lines, respectively. This was done for untreated biochar (UBC), CaO impregnated biochar (CBC), $FeCl_3$ impregnated biochar and untreated biochar mixed with Polonite (PBC) was shaken in initial P solutions of 0.5-26 mg/L.

The correlation coefficients (R^2) were in the range of 0.957 - 0.997 for Langmuir isotherm and 0.960 - 0.993 for Freundlich isotherm for the adsorption of PO_4-P to the biochar types (Table 5). The Langmuir had a higher correlation for UBC and FBC and Freundlich for CBC and PBC. The parameters were calculated from liner plots of the two equations as presented in Figure 11-A2 & Figure 12-A2. FBC had the highest maximum adsorption capacity (Q_m) according the Langmuir (3.21 ± 0.01 mg/g) while Q_m for CBC was negative. CBC also had a negative mean Langmuir adsorption constant k_F. PBC had the highest k_F but also a high standard deviation of 0.21 ± 0.17 L/mg.

Table 5 Model parameters (mean ± standard deviation, n=3) for the Langmuir equation and Freundlich equation calculated from linear plots presented in Figure 11 & Figure 12-A2 for untreated biochar (UBC), CaO impregnated biochar (CBC), $FeCl_3$ impregnated biochar and untreated biochar mixed with Polonite (PBC). A higher R^2 value means a better fit.

Material	**Langmuir model parameters**			**Freundlich model parameters**		
	Q_m (mg/g)	**k_L** (L/mg)	**R^2**	**n**	**k_F** (L/g)	**R^2**
UBC	1.53±2.4	0.004±0.04	0.973±0.48	0.98±0.12	0.02±0.01	0.964±0.17
CBC	-0.41±0.19	-1.18±0.33	0.975±0.48	0.34±0.14	9.04±8.50	0.997±0.49
FBC	3.21±0.01	0.11±0.01	0.997±0.09	1.29±0.13	0.32±0.02	0.993±0.49
PBC	2.42±0.47	0.21±0.17	0.957±0.27	1.68±0.36	0.40±0.13	0.959±0.47

3.1.2 Kinetic isotherms

The UBC reached equilibrium adsorption (Q_e) after 3 hours in all PO_4-P concentrations tested for (Figure 4) with Q_e varying between 0.05 and 0.2 mg/g. This was lower than for the other biochar types. The Q is said to have reached equilibrium when the curve stops increasing and is then named Q_e. The adsorption rate for FBC was faster during the first three hours (240 min) and then slowed down. FBC did however not reach adsorption equilibrium Q in any of the concentrations C2 - C5. PBC reached a stable Q in C2, C3 and C4 but in C5 the biochar never reached equilibrium displaying a final adsorption of around 1.5 mg/g. The CBC reached stable adsorption capacities of 0.3, 0.6 and 1.2 mg/g after 1 hour in C2, C3 and C4 and these were higher than the other biochar types at corresponding concentrations. In C5 the equilibrium occurred first after 3 hours and was around 2.5 mg/g.

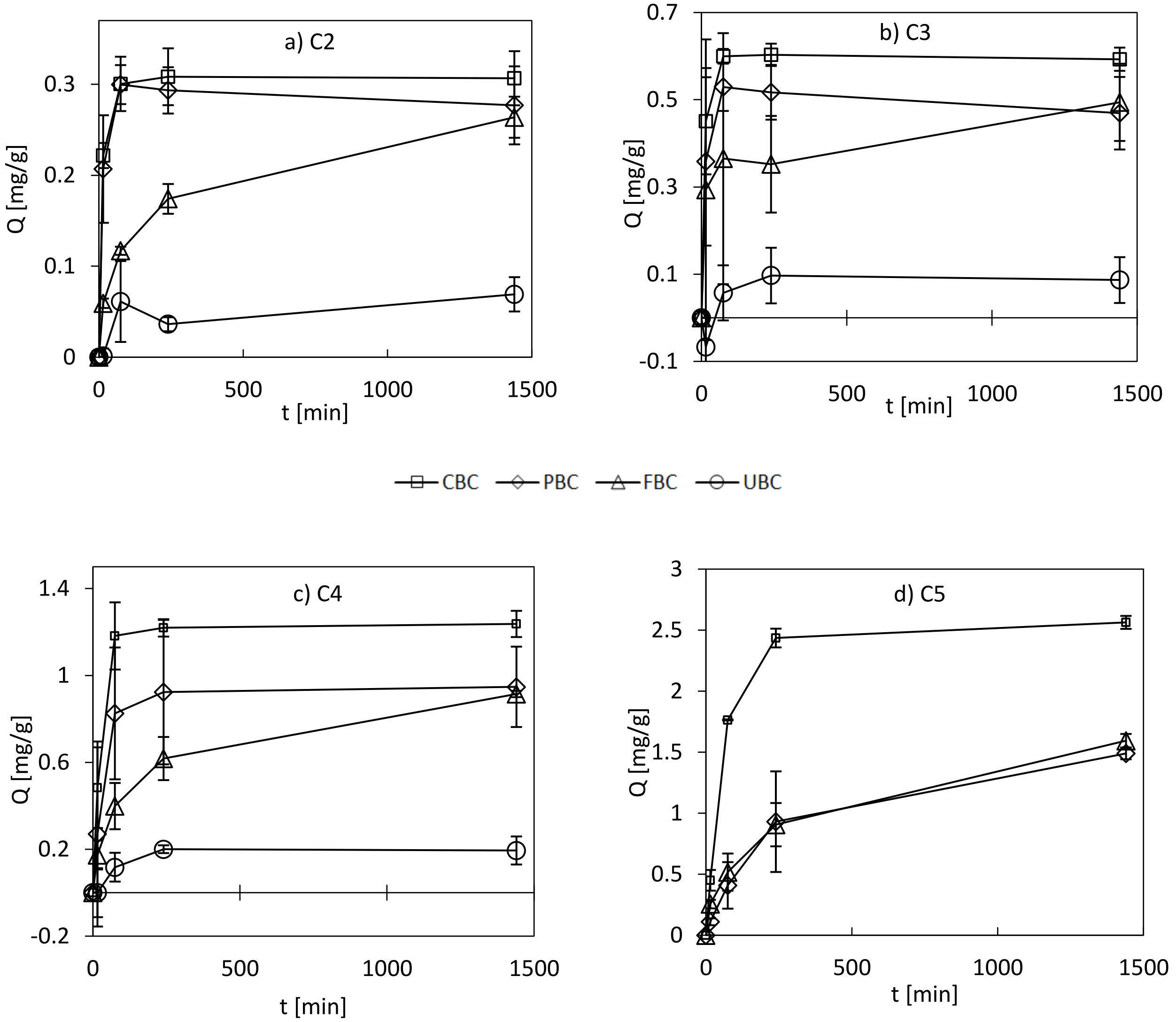


Figure 4 Adsorption of P (Q) onto four biochar types at four P solution concentrations, **a)** 3.3 mg P/L (C2) **b)** 6.5 mg P/L (C3) **c)** 13 mgP/L (C4) and **d)** 26 mg P/L (C5) over 24 hours. Symbols are mean values and error bars the standard deviation.

Higher adsorption capacities were achieved at higher P concentrations for CBC, FBC and PBC (Figure 5). Even if some biochars did not reach equilibrium, their final Q is presented as their equilibrium adsorption Q_e in Figure 5. UBC had the least amount adsorbed P per gram biochar, with around 0.07 - 0.2 mg/g for all concentrations. FBC and PBC displayed similar equilibrium adsorptions of 0.2 and 0.26 mg/g for C2, 0.49 and 0.46 mg/g for C3, 0.91 and 0.95 for C4 and 1.6 and 1.5 mg/g in C5. CBC had the highest equilibrium adsorption in all concentrations with around 0.3 mg/g in C2, 0.6 mg/g in C3, 1.2 mg/g in C4 and 2.6 mg/g in C5. At higher concentrations the gap to the other biochars became wider.

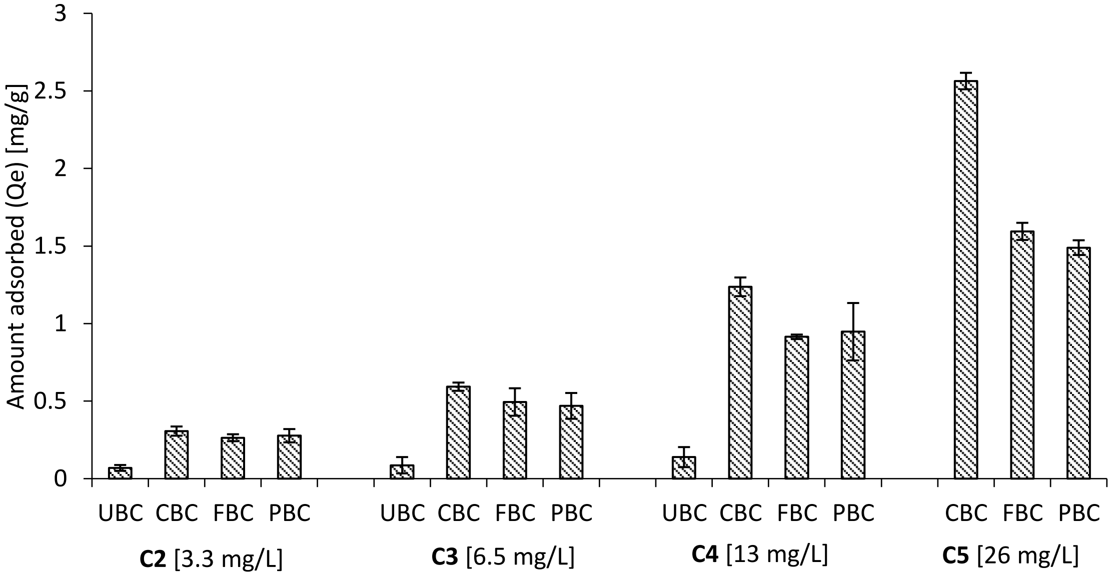


Figure 5 Amount P adsorbed in mg per g biochar after 24 hours of shaking four different biochar types in solutions of 3.3 (C2), 6.5 (C3), 13 (C4) and 26 (C5) mg PO_4^{3-}-P/L. Error bars are mean values ± standard deviations, n =3.

The pseudo 2nd order model had higher R^2 values (0.9102 - 0.9999) than the 1st order model (0.7785 - 0.997) for all biochar types shaken in the PO_4-P concentration 3.3 mg/L (Table 6). This difference was also the case for all other concentrations except for PBC shaken in C5 (26 mg/L) Table 11-A3. Kinetic model parameters for all concentrations and biochars and the linear plots providing the parameters can be found in Table 11-A3 and Figure 13-A3. The Q_e calculated for the 2nd order models were all close to the experimental Q_e. The k_1 value was highest for PBC, 0.097 ± 0.01 min^{-1} and lowest for UBC and PBC, 0.004 min^{-1}. CBC had the highest k_2 at 1.717 ± 1.13 L/mg.

Table 6 Pseudo 1st and pseudo 2nd order model parameters and the experimental value of equilibrium adsorption (Qe) from batch adsorption experiment where four different types of biochar were shaken in 3.3 mg P/L (C2). All parameters are presented as mean ± standard deviation, n=3 and they were calculated by linearization of pseudo 1st and pseudo 2nd order kinetic models (Figure 13-A3).

Material	**Pseudo first order model**			**Pseudo second order model**			**Experimental**
	$\mathbf{Q_e}$ [mg/g]	$\mathbf{R^2}$	$\mathbf{k_1}$ [min^{-1}]	$\mathbf{Q_e}$ [mg/g]	$\mathbf{R^2}$	$\mathbf{k_2}$ [L/mg]	$\mathbf{Q_e}$ [mg/g]
UBC	0.064±0.03	0.779±0.26	0.004±0.02	0.068±0.02	0.911±0.081	-0.021±0.37	0.069±0.01
CBC	0.156±0.09	0.836±0.14	0.028±0.02	0.307±0.03	0.999±0.0001	1.717±1.13	0.307±0.03
FBC	0.229±0.03	0.919±0.07	0.004±0.00	0.281±0.03	0.997±0.002	0.036±0.01	0.264±0.02
PBC	0.266±0.04	0.997±0.01	0.097±0.05	0.264±0.04	0.999±0.001	-0.499±1.35	0.277±0.04

3.2 COLUMN FILTERS

The concentration of the Tot-P in the influent to the column filters fluctuated between 2.3 and 6.2 mg/L during the experimental period (Figure 6a), with a mean of 3.84 ± 1.14 mg/L (Table 7). The Tot-P concentrations in all effluents were around or below 1 mg/L during the 5 first weeks of the experiment. After week 5 the concentrations in UBC and PBC gradually increased and reached stable effluent concentrations after week 10 of about 2.6 ± 0.1 and 1.5 ± 0.1 mg/L, respectively. Effluent concentrations of CBC and FBC started above 0.5 mg/L but after week 4 they decreased and remained below < 0.5 mg/L until the end of the experiment. The removal efficiencies of UBC and PBC fluctuated and decreased from about 60 and 80 % initially to around 20 and 55 % after week 10. The removal of Tot-P in CBC and FBC filters increased early in the experiment and then remained high at around 90 % (Figure 6b).

During the whole experiment the UBC and PBC filters had higher mean Tot-P effluent concentrations (2.09 ± 0.74 and 1.25 ± 0.37 mg/L) and lower removal efficiencies (43 ± 24 and 65 ± 14 %) compared to the CBC and PBC filters (Table 7). In contrast CBC and FBC had low outflowing concentration of Tot-P (0.37 ± 0.27 and 0.30 ± 0.18 mg/L) and displayed high removal efficiency (90 ± 8 and 92 ± 4 %).

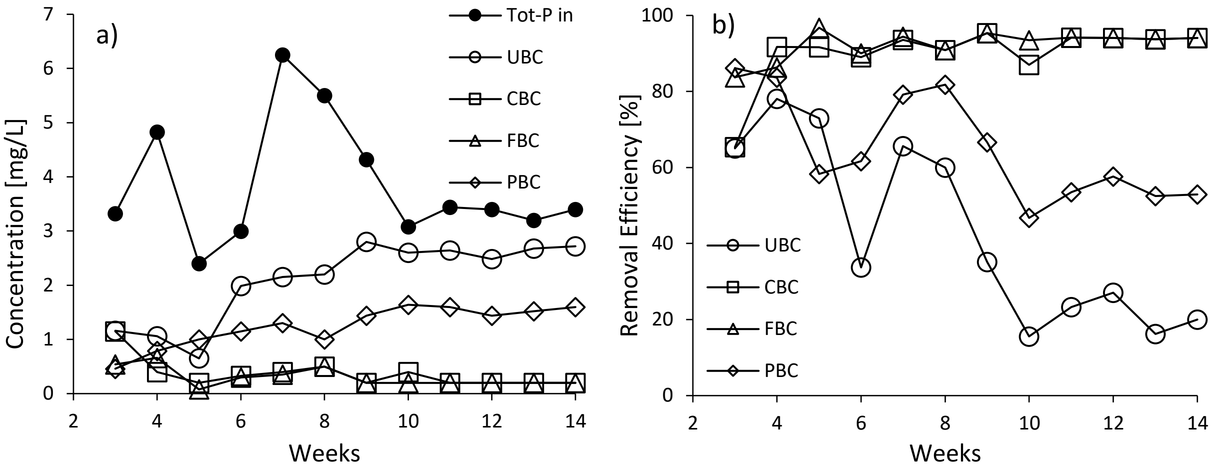


Figure 6 a) The Tot-P concentrations in the influent and in the effluent and **b)** the removal efficiency of the untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC).

The PO_4-P concentration were lower than the Tot-P concentrations and varied in the influent between 1.5 and 5.2 mg/L throughout the experiment with a mean value of 3.18 ± 1.04 mg/L (Figure 7). The concentration and removal efficiency of PO_4-P showed a similar trend to Tot-P. CBC and FBC did however display a higher removal of PO_4-P than Tot-P while UBC and PBC had higher removal efficiency of Tot-P than PO_4-P.

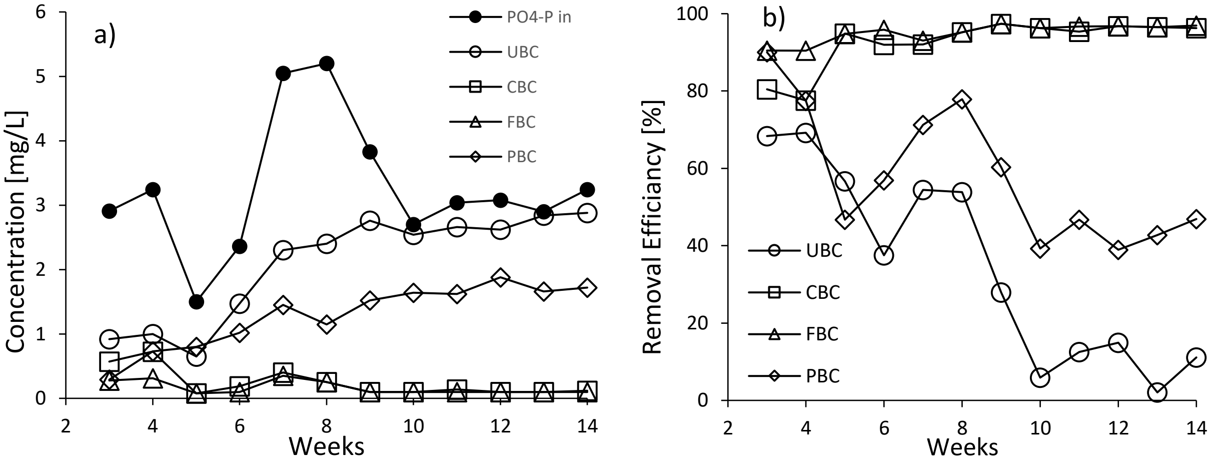


Figure 7 a) The PO_4-P concentrations in the inflow and in the outflow from four different biochar filters and **b)** corresponding PO_4-P removal efficiencies. Untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC).

The COD analysis showed that UBC removed 36 ± 22% of the COD and PBC removed 30 ± 30 %. No clear trend could be red from those data points taken once every second week and the standard deviations were high (Table 7). In average the CBC and FBC had a higher concentration of COD in the effluent than in the influent, resulting in negative removal efficiencies -122 ± 186 % and -100 ± 141 %.

The pH varied in filter effluents. The influent to the filters was neutral with pH 7.1 ± 0.4. The UBC filter effluent was just below neutral (pH 6.7 ± 0.5) while effluents from CBC and PBC discharged an effluent with higher pH (7.8 ± 0.4). The largest pH change was observed for FBC which had an average effluent pH of 2.6 ± 0.9 over the experimental period (Table 7).

The appearance of the effluent from the filters differed from each other and changed over time. Initially the UBC and PBC effluents were turbid and greyish. The CBC effluent had a red-brown color and the FBC effluent was yellow, both turbid. Over time the color and turbidity of UBC, PBC and FBC disappeared but CBC kept its red-brown color. On the surface of the effluent beaker of CBC a precipitate formed and kept forming during the whole experiment**.**

Table 7 The influent and effluent mean concentration (Conc) ± standard deviation and corresponding removal efficiencies (E) of Tot-P, PO_4-P, COD and pH for the untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC).

Type of water	**Tot-P**		**PO_4-P**		**COD**		**pH**
	Conc (mg/L)	**E** (%)	**Conc** (mg/L)	**E** (%)	**Conc** (mg/L)	**E** (%)	
Influent	3.84±1.14	-	3.18±1.04	-	320.8±116.4	-	7.1±0.4
UBC	2.09±0.74	43±24	2.09±0.83	32±25	206.2±113.5	36±22	6.7±0.5
CBC	0.37±0.27	90±8	0.24±0.21	93±7	710.6±480.6	-122±186	7.8±0.4
FBC	0.30±0.18	92±4	0.16±0.10	95±2	641.0±453.5	-100±141	2.6±0.9
PBC	1.25±0.37	65±14	1.29±0.49	58±17	223.4±116.7	30±30	7.8±0.7

The influent Tot-P and PO_4-P displayed a relatively wide variation in concentrations which was also the case for the effluent from the untreated biochar filter (UBC) (Figure 8). Concentrations in the effluent of the PBC filter also fluctuated but varied less than that of the UBC. In contrast CBC and FBC effluent concentrations were low and did not vary much during the experiment.

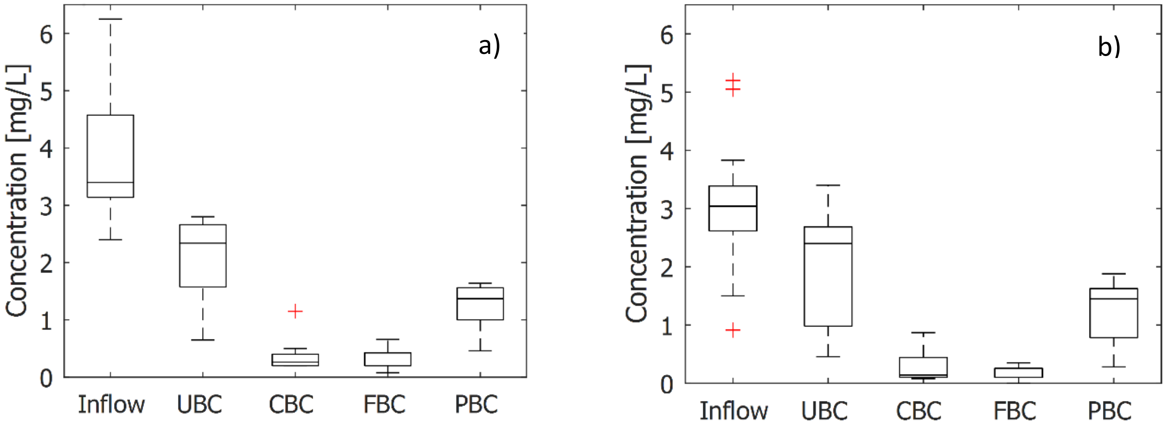


Figure 8 Boxplots of the **a)** Tot-P concentrations and **b)** the PO_4-P concentrations of the untreated biochar filter (UBC), CaO impregnated biochar filter (CBC), $FeCl_3$ impregnated biochar filter (FBC) and the biochar filter mixed with Polonite (PBC). The box is the quartiles of the data set and the medians are shown as a straight line in the box. Max and min values are the whiskers and outliers are shown as red crosses.

3.3 NITROGEN REMOVAL FILTER

The mean concentration of Tot-N in the influent to the vertical aerobic section of the N removal filter was 39.54 ± 8.26 mg/L (Table 8). After the vertical section the effluent concentration of Tot-N had dropped to 21.23 ± 3.36 mg/L. The reduction of Tot-N was stable at around 40 % between week 8 and 14 of the experiment (Figure 9a), resulting in an average removal rate of 42 ± 10 % (Table 8). The influent concentration of Tot-P to the vertical section was stable at 4.62 ± 0.54 mg/L between week 9 and week 14 of the experiment (Table 8). The Tot-P was on average removed by 13 ± 23 % leading to mean concentration in the effluent wastewater of 3.98 ± 0.95 mg/L. The removal of Tot-P in the vertical section was not stable and low points occurred in week 8 and 14 (Figure 9a).

The effluent water from the vertical section became the influent water to the horizontal anaerobic section (Figure 2). The concentration of Tot-N decreased from 21.23 ± 3.36 mg/L in the influent to 12.90 ± 1.45 mg/L in the effluent (Table 8). This corresponded to a reduction of Tot-N of 35 ± 16 %, which was lower than in the vertical section. The Tot-P in the influent to the horizontal filter section, 3.98 ± 0.95 mg/L, decreased to 3.30 ± 0.60 in the effluent. In average, 14 ± 25 % of the Tot-P was removed. Removal rates of Tot-P fluctuated between removal and release during the experiment (Figure 9b).

Together, the two sections removed 62 ± 16 % of Tot-N and 29 ± 8 % of Tot-P during the experiment (Table 8). In week 8, Tot-P concentrations in the effluent was higher than in the influent for both the vertical and horizontal sections (Figure 9a & b). This resulted in large negative removal rates for the total filter during week 8 (Figure 9c). This is why the P results are presented only from week 9 in Table 8.

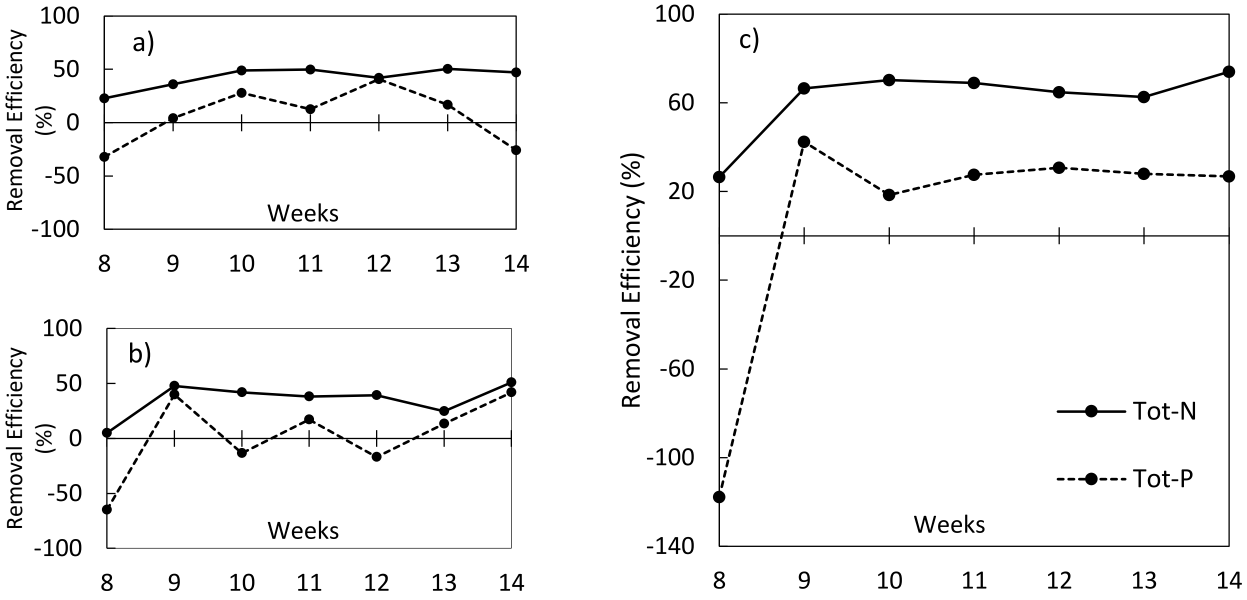


Figure 9 The removal efficiencies of Tot-N and Tot-P in % from **a)** the vertical aerobic section, **b)** the horizontal saturated section and **c)** total nitrogen removal of a two-section biochar filter.

NH_4-N and NO_3-N was also analyzed in the influents and effluents to the vertical and horizontal sections. NH_4-N in the influent to the vertical filter had a higher average concentration than Tot-N (Table 8). It was also clear that NO_3-N concentration increased from 1.60 ± 0.35 mg/L to 6.91 ± 2.23 mg/L while passing the vertical section and thereafter decreased in the horizontal section. The formation of NO_3-N in the vertical section increased between week 8 and 14. This is presented in Figure 14-A4, where the complete dynamics of the N is presented. pH decreased slightly in the whole filter and the two sections removed COD equally well, 30 ± 23 and 30 ± 36 %, respectively. Average removal efficiency of COD was 45 ± 68 % for the entire filter.

Table 8 The average removal efficiencies (%) and concentrations (mg/L) ± standard deviation for all for pollutants measured in the N removal filter. The filter had an aerobic vertical flow section followed by an anaerobic horizontal flow section.

Pollutant	**Concertration (mg/L)**			**Removal efficiency (%)**		
	Inflow	**Vertical section effluent**	**Horizontal section effluent**	**Vertical section**	**Horizontal flow section**	**Total Removal efficiency**
pH	7.1±0.1	6.7±0.4	6.8±0.4			
Tot-N	39.54±8.26	21.23±3.36	12.90±1.45	42±10	35±16	62±16
Tot-P*	4.62±0.54	3.98±0.95	3.30±0.60	13±23	14±25	29±8
NH_4-N	42.67±8.55	14.67±2.66	11.00±1.10	65±8	23±17	74±5
NO_3-N	1.60±0.35	6.91±2.23	2.66±0.98	-341±131	58±23	-64±53
PO_4-P*	4.05±0.74	3.79±0.96	2.97±0.56	3±29	19±23	27±10
COD	286.20±116.35	197.80±100.52	152.00±96.43	30±23	30±36	45±68

* Means calculated from week 9

The N removal filter recived wastewater with a verying Tot-N and NH_4-N concentration and more N was removed in the first section than in the second. However, the concentrations in the effluent had smaller variation (Figure 10). The NO_3-N concentration in the intermediate flow varied more than the NO_3-N concentrations in inflow and outflow of the filter. The Tot-P and PO_4-P concentrations in inflow and intermediate flow had a similar variation. The Tot-P concentrations in the outflow was however less varied than the PO_4-P concentraions. COD concentration data had the largest variation of all analyzed pollutants.

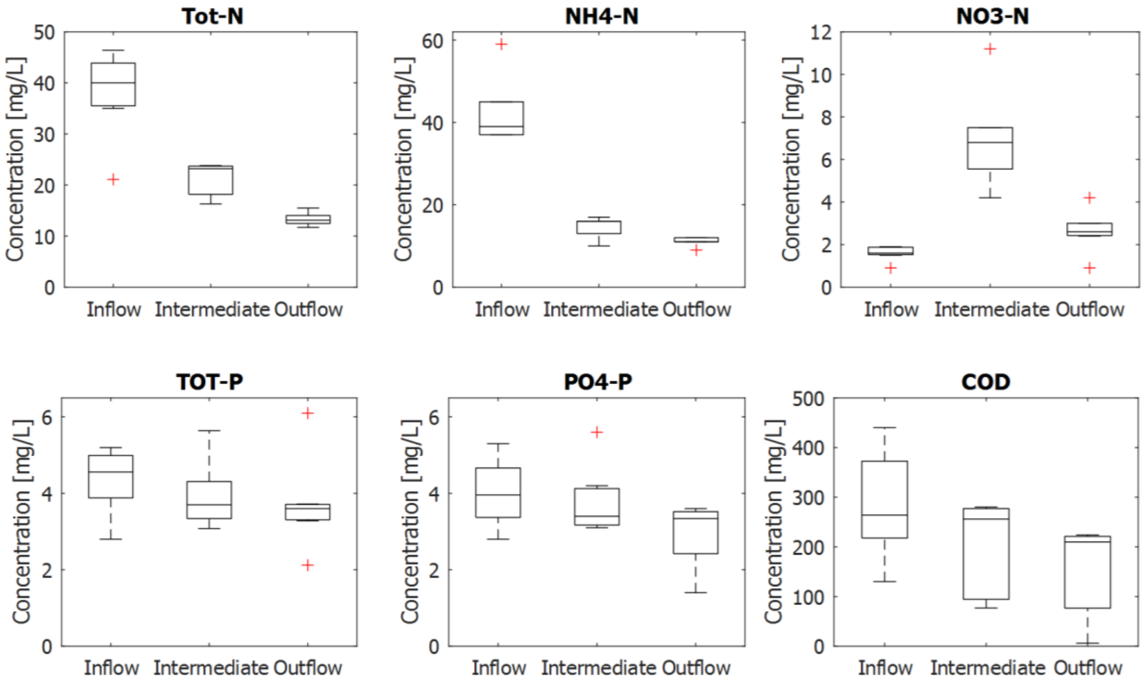


Figure 10 Boxplots showing the change of N and P concentration in the the inflow, intermediate flowand outflow of a two-step biochar filter. The first section of the filter was aerobic and had vertical flow and the second section had horizontal saturated flow.The box is the quartiles with horizontal line in the box showing the median. Max and min values are the whiskers and outliers are presented as red crosses

4. DISCUSSION

4.1 BATCH ADSOPTION EXPERIMENT

In the batch adsorption experiment, four biochar types were shaken with solutions of five different PO_4-P concentrations. CBC had the best P adsorption capacity. PBC and FBC both had a lower but similar adsorption while untreated biochar (UBC) adsorbed the least P. The shape of the adsorption isotherm for CBC (Figure 3) shows that when the equilibrium concentrations are low the increase in equilibrium adsorption was also low. This could indicate dissolved organic compounds being involved in the adsorption at low concentrations (Essington, 2004). The Freundlich model best fitted the PO_4-P adsorption to CBC and PBC biochars which means that the adsorption to these materials was best described as non-uniform. Adsorption to FBC biochar correlated better with the Langmuir adsorption model which indicates that their adsorption can be modeled as homogenous and in a monolayer over the biochar surface. This is in agreement with Li at al. (2016) who found that P removal using wheat straw biochar impregnated with $FeCl_3$ fitted the Langmuir model well. Contrastingly, Chen et al. (2011) reported that P adsorption by untreated and magnetite coated biochar made from orange peel fitted the Freundlich model better. The large standard deviation of the P adsorption on UBC makes it difficult to compare it to the equation models (Figure 3).

The Langmuir adsorption constant k_F was higher for adsorption on PBC than for the other biochar types. This indicates that the affinity between P and PBC was the highest. The Langmuir maximum adsorption Q_m for CBC was negative which is not realistic indicating that this model was not suitable for describing adsorption on CBC (Table 5). FBC had the highest Q_m at 3.2 mg/g but this is still lower than that reported by Liu et al. (2015) who demonstrated an adsorption capacity of 16.58 mg/g for a Fe impregnated biochar made from wheat straw. The biochar in the study by Li et al. (2016) had a smaller diameter than the biochar in this experiment (< 1 mm *vs* 1 - 7 mm) and higher iron to biochar ratio, 0.7 *vs* 0.3, which can explain the difference.

Looking at the Q_e for the kinetic adsorption experiment it is clear that the CBC had the highest equilibrium adsorption at all concentrations tested (Figure 5). In C2 (3.3 mgP/L), i.e. the concentration closest to the average influent wastewater concentration of PO_4-P in the column filters, CBC had the highest Q_e of 0.3 ± 0.03 mg/g after 24 h of shaking. Jung et al. (2016) received a Q_e of 100 mg/g on their Ca modified biochar in a batch sorption experiment. However, the concentration in the experiment by Jung et al. (2016) was 326 mg/L PO_4-P, which makes it inappropriate to compare between the experiments since the concentrations in this study were lower. The higher concentration of P in the solution the more obvious difference between the adsorption characteristics of the different biochar types could be seen (Figure 5). Twenty-four hours was not enough for the FBC biochar to reach an equilibrium adsorption (Figure 4) which means that the Q_e for FBC of 0.264 ± 0.02 mg/g in C2 would most likely be higher and even pass that of PBC (0.277 ± 0.04 mg/g) if longer time would have been given. Alternatively, it could have continued and never reached equilibrium due to a continuous formation of complexes as discussed by Essington (2004). The pseudo second order model was the better fit compared to pseudo first for most biochar types and concentrations (Table 6). This means that the adsorption can be assumed to be mainly chemical as suggested by Ho & McKay (1999 & 1998). The calculated Q_e from the pseudo second order equation was close to the experimental Q_e which implies the accuracy of the model. In previous studies, the second order kinetic model was proven to be the best model for describing P adsorption on magnesium modified biochar. However, $FeCl_3$ modified biochar has shown a better fit for the pseudo first order model by Zhang et al. (2013).

Adsorption and kinetic isotherms behave very different for different types of materials and chemicals, hence, results are difficult to compare. Experimental conditions like beaker size, material properties and preparation, temperature, reaction time etc. have a large influence on the results and these conditions are rarely the same in different studies. Therefore, batch adsorptions experiments are more suitable in comparing adsorption characteristics between materials in the same study (Essington, 2004).

4.2 COLUMN FILTER EXPERIMNET

The inflowing PO_4-P and Tot-P concentrations to the column filters varied considerably as can be seen in Figure 7 and Figure 6 and also in the box plot in Figure 8. The concentration probably varied because the quality of the wastewater from the WWTP differs between days and even changes during the day. These variations can also explain why the average concentration of the inflowing Tot-P, 3.84 mg/L (Table 7) was lower than yearly average of 6 mg/L for WWTP (Kungsängsverket, 2016).

The untreated biochar (UBC) filter had the smallest removal efficiency of Tot-P (43 ± 24 %) of all filters (Table 7). This is lower than what could be expected from a fully functioning vertical soil filter having an estimated Tot-P removal of 70 ± 20 % (Olshammar et al., 2015). The Tot-P reduction in UBC was also in the lower range of what have been shown possible (32 - 89 %) in other filters using untreated biochar (Table 9) (Dalahmeh, 2016). PBC had an average removal of 65 ± 14 % of Tot-P which is comparable of what could be expected from vertical soil filters and also of previously studied biochars. P concentration in the effluent of the UBC and PBC filters continued to increase during the experiment but seemed to become stabilized towards the end. It is difficult to recognize if they would have continued to decrease in efficiency given longer time. The Tot-P removal in CBC and FBC were 90 ± 8 % and 92 ± 4 % respectively and their PO_4-P removal rates were even higher. This is similar to previous batch adsorption studies where Fe modified biochar has been shown to remove of up to 99 % of P (Chen et al., 2011; Liu et al., 2015).

When comparing the Tot-P and PO_4-P removal, both UBC and Polonite biochar removed more Tot-P than PO_4-P (Table 7). The CBC and FBC showed the opposite trend. This means that UBC and PBC removed organic P better while CBC and FBC were more efficient in removing inorganic P. The impregnation in CBC and FBC probably created different surface structures compared to UBC and PBC. PBC should have similar surface to that of UBC since they had the same untreated biochar, which possibly could explain the grouping in the two Tot-P and PO_4-P characteristics.

The initial yellow color of the FBC filter effluent, also seen in the shaking solutions from the batch adsorption experiment, can most likely be explained by $FeCl_3$ treatment that carries a yellow color when dissolved in water. $FeCl_3$ also lowers the pH which can explain the drop in pH seen in the effluent water from the filter and in the PO_4-P solution of the batch adsorption experiment. An average pH of 2.6 ± 0.9 from the FBC filter effluent (Table 7) most likely created unfavorable environment for nitrifying and denitrifying bacteria which must be considered undesirable for wastewater treatment even if low pH favors precipitation reactions between P and iron (US EPA 2002). In contrast, CaO and Polonite increase the pH in aqueous solutions which explains the pH increase in the beakers during the batch sorption experiment (Table 4). The red-brown color of the CBC effluent probably originated from the mother material – willow tree bark. Water that is filtered through bark receives a red-brown color due to the release of organic acids (Dalahmeh et al., 2012). If the color comes from the bark it indicates that the pyrolysis of the biochar was never fully completed as the biochar itself would not release any color. Organic acids present in bark would lower the pH, meaning that the pH might have been even higher in the CBC effluent if the pyrolysis had been complete. Presence of organic acids can explain the shape of CBCs adsorption isotherm and can also be an explanation to the high COD content in the CBC effluent. Ca and Fe ions were most likely released from the CBC and FBC filter materials to the effluents which possibly could explain their high COD contents as calcium and iron compounds can be chemically oxidized in the analysis procedure. To investigate the removal of organic matter it would have been more appropriate to measure biochemical oxygen demand (BOD) or total organic carbon (TOC). TOC sampling occurred but lack of proper equipment and time stopped the analysis. Ca and Fe ions are not likely to affect the COD of PBC and UBC filter effluents to the same extent, yet these filters had lower COD removal rates (36 and 22 %, respectively) than shown in most previous biochar studies (90 %) as reported in Table 9 (Dalahmeh, 2016).

Another problem except for the color of the CBC effluent was the precipitate adding to the effluent beaker surface. It is likely that the precipitate is some calcium phosphate mineral which might lead to problems with clogging in the long run in a full-scale system.

4.3 NITROGEN REMOVAL FILTER

The two sections of the N removal filter removed 62 ± 16 % of the influent N (Figure 9 & Table 9). This was higher than conventional vertical soil filers where removal rates of 30 ± 10 % can be expected (Olshammar et al., 2015) and also higher than alternative OWTP solutions in general (Avloppsguiden, 2009) (Tabel 9). The average total N concentration was lower than that of NH_4-N in the influent which is not realistic. This is likely due to error in analysis during week 11, 12 and 13 (Figure 14c-A4). The increase in NO_3-N concentration in the first and decrease in the second section show that nitrification and denitrification took place (Figure 9a & b). However it was not until the end of the experiment the nitrate removal was high enough to remove almost of the NO_3-N created in the vertical section. The average outflow concentration from the horizontal filer was 2.66 ± 0.98 mg/L. It is likely that the NO_3-N and Tot-N removal capacity would have continued to increase as the biofilm in the filter continued to grow and mature. The P removal in the N removal filter was 29 ± 8 % which was lower than the removal rate observed for UBC in the column experiment and what can be expected from vertical soil filers (Table 9). The relocation of the filter in week 7 seemed to negatively affect the filter performance the following week. When moving the filter some of the water from the lower section had to be emptied and particles were released from the biochar. The disturbance of the microbial community in the biofilm and loose particles was probably the reason why P was released during week 8. After this the removal of Tot-P became more stable (Figure 9c). Moving the filter to the primary sedimentation also meant that the water entering the filter from week 8 was more turbid and contained more particles than before. This could explain why the overall COD removal was relatively low (45 ± 68 %) and varied more compared to vertical soil filters (80 ± 10 %) (Olshammar et al., 2015).

4.4 COMPARING BIOCHARS AND FILTERS

To compare adsorption of P in a batch sorption experiments to a real life systems can be misleading (Brix et al., 2001). Hedstöm (2006) argued that batch sorption experiments may overestimate the P sorption capacity because it is an ideal system with the material saturated in P solutions. Another aspect that was stressed was that biochar pieces can break during the experiment which increases the adsorption surface. Others claim that a shaking experiment severely underestimates the adsorption capacity because it does not take slow reactions of regenerated sorption sites into consideration (USEPA, 2002). In order to fully investigate materials adsorption, a combination between shaking studies and filter studies is recommended (Essington, 2004).

From the shaking experiment it was clear that the CBC had the highest adsorption of P (Table 10). This is in agreement with Seo et al. (2005) who in comparing Fe and Ca treated filter media found that Ca impregnation had the better P removal capacity. However, results from the filter experiment in the present study showed that the CBC is good but not better than FBC (Table 9). One explanation to this can be that the CBC biochar fragmented more than the other biochar types during the batch adsorption experiment. The risk of overestimating adsorption capacity as the biochar is breaking in a batch sorption experiment has been stressed by Hedström (2006). Also if the pyrolysis and impregnation of the CBC biochar was not complete as discussed above, loose CaO particles on the material surfaces might have overestimated the CBC adsorption. If the shaking experiment had been longer the FBC most likely would have reached a higher equilibrium adsorption and the difference in P adsorption capacity between CBC and FBC would have been smaller. It is also difficult to know how the CBC would perform if it had been produced differently.

Both the filter experiment and the batch adsorption experiment concordantly showed that PBC had a better P removal than UBC. The filter experiment showed that by mixing untreated biochar with Polonite, the Tot-P removal became 1.5 times higher compared to the mother material. Batch sorption experiment also showed that the PBC had three times higher P removal than UBC.

Table 9 Comparison between the results of pollutant removal (%) from filter experiments and literature for biochar filters Dalahmeh (2016)* and vertical soil filters Olshammar et al., (2015)** (mean ± standard deviation). The filter experiments comprised column with untreated biochar (UBC), biochar impregnated with calcium oxide (CBC) or ferric chloride (FBC) and untreated biochar mixed with Polonite (PBC). The N removal filter was constructed with a vertical unsaturated flow section followed by a vertical saturated flow section.

Chemical	**Results**					**Literature**	
	UBC	**CBC**	**FBC**	**PBC**	**N-Removal filter**	**Removal in Biochar Filters***	**Removal in Vertical Soil Filters ****
COD	36 ± 22	-122 ± 186	-100 ± 141	30 ± 30	45 ± 68	> 90	80 ± 10
Tot-P	43 ± 24	90 ± 8	92 ± 4	65 ± 14	29 ± 8	32 – 66	70 ± 20
Tot-N					62 ± 16	62 – 88	30 ± 10

A factor that affects the P and N removal is the volume and depth of the filters. The column filters were 50 cm tall which is similar to the 55 and 60 cm biochar filters compared with (Dalahmeh, 2016). The unsaturated filter section in the N removal filter was 30 cm deep which is smaller than the vertical soil filters (Olshammar et al., 2015). It is possible that a larger N removal filter might have had a better N removal.

If for instance the CBC or FBC would be used in real-scale filters the amount of filter material do not need to be high since the removal efficiency is high. It is possible that impregnated biochar in a filter would be more suitable as a separate P filter module connected to a larger system such as the N removal filter. To use the N filter in larger scale would require some planning on where to locate the filter. Alternately the unsaturated section or the whole filter system could be installed on top of a soil profile with a pump feeding the filter with wastewater from a septic tank.

4.4 POSSIBLE SUORCES OF EXPERIMENTAL ERROR

In the second week of the column experiment large hydrophobic (dry) areas in the column filters were observed and the filters were therefore washed with distilled water which enabled wastewater to flow through the entire filter volume. It could not be excluded that the washing could have removed some of the impregnation on FBC and CBC lowering their removal capacity.

The N removal filter was relocated due to interference of $FeCl_3$ on the N samples. After that the N removal filter had been relocated analysis results became more stable. However it is possible that some residual $FeCl_3$, used as P precipitation chemical, from the wastewater got adsorbed and stayed in the filter and further influenced the analysis. Initially, N parameters were also measured in the influent and effluent of the column filters. However, it soon became clear that ions and high COD from the filters themselves interfered with the kits for chemical analyses, giving unrealistic and highly fluctuating results. It was therefore decided to stop the N measurements in week 5 and to only present P data as the analysis kit for P was not as affected by high COD. In conclusion, there is a risk that some of the results in this report might be affected by intrinsic COD and ions from the filter materials. In future studies, when sampling water from impregnated filters, it is important to consider the potential problems the impregnation itself might cause on the analysis.

5. CONCLUSIONS

The batch adsorption and filter experiments in this study demonstrates that modification of biochar made from hard wood bark can improve phosphorus removal capacity. Especially modification by impregnation before pyrolysis can improve the phosphorus removal compared to unmodified biochar or biochar mixed with Polonite. These materials are promising replacements or additions to vertical soil filters.

The column filters with biochar impregnated with ferric chloride and calcium oxide showed phosphorus removal rates of 93 ± 7 % and 95 ± 2 % which was higher than untreated biochar and biochar mixed with Polonite which removed 32 ± 25 % and 58 ± 17 %, respectively.

The Freundlich adsorption model best fitted the P adsorption onto CaO impregnated and Polonite mixed biochar. Adsorption to untreated and $FeCl_3$ biochar correlated better with the Langmuir adsorption model. The adsorption over time for all biochar types was best described by pseudo 2^{nd} order kinetic model.

The effluent from ferric chloride impregnated biochar had low pH. The effluent from the calcium oxide impregnated biochar had some precipitation in it and a brown-red color and the biochar was probably not completely prepared. The low pH, color and precipitation can be a problem if the materials are to be used in full-scale treatment system.

Biochar filter consisting of a vertical flow aerobic section followed by a horizontal section with saturated flow reached a high total nitrogen removal rate of 62 ± 16 %, a removal rate higher than that of conventional vertical soil filters as well as most alternative onsite wastewater treatment systems.

5.1 SUGGESTIONS FOR FURTHER EXPERIMENTS

For further studies it would be interesting to see how impregnated biochar filters and N removal units will perform in a long-term column study. Improved filtration or sedimentation of the inflowing wastewater to the N removal filter would make a more realistic set up and possible better COD treatment. Clogging effects, not investigated in this study, and changes in flow patterns through the filters caused by clogging would be another important area to investigate in order to evaluate the life time of filter materials. It would be worth considering redoing the calcium oxide impregnation of the biochar to see if the observed color and precipitation effects would disappear. It would also be interesting to expose calcium oxide biochar to higher P concentration in a batch adsorption experiment to see if the adsorption isotherm will show signs of a decreasing equilibrium adsorption (Q_e). A longer batch adsorption experiment to investigate the $FeCl_3$ equilibrium adsorption would also be interesting.

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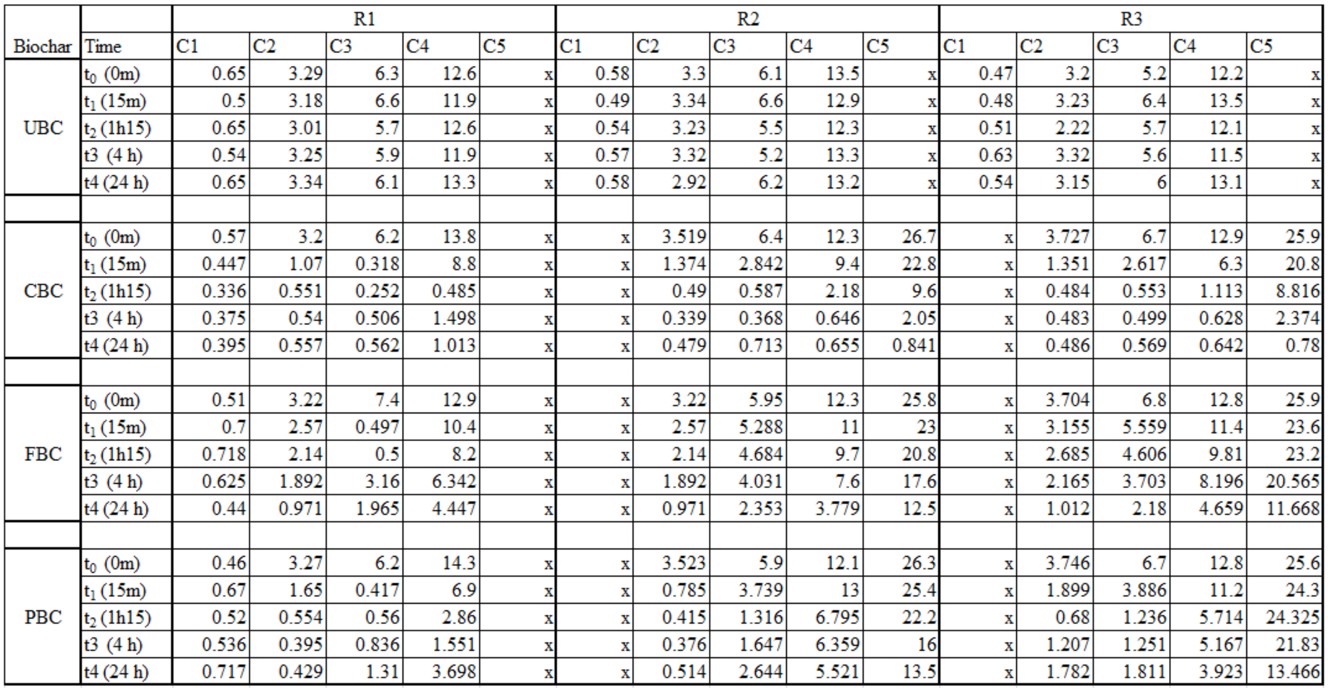
7. APPENDIX

APPENDIX I - Shaking experiment

All the data from the shaking experiment can be seen in Table 8. The concentrations in this table were then adjusted for the volume chance of the beakers when sampling took place. The mean concentrations adjusted for the volume change can be found in Table 3 in the Result section. The UBC did not get exposed or C5 because it showed little adsorption. CBC, FBC and PBC did not get more than one replicate for C1 because the concentration were considered too low to give interesting data.

Table 10 Results from the shaking experiment with all replicated (R1-R3), concentrations (mg/L) (C1-C5) and biochar types UBC, CBC, FBC and PBC. The concentrations in the table have not been adjusted for the change of volume that took place at each sampling time.



		R1					R2					R3				
Biochar	Time	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
UBC	t_0 (0m)	0.65	3.29	6.3	12.6	x	0.58	3.3	6.1	13.5	x	0.47	3.2	5.2	12.2	x
	t_1 (15m)	0.5	3.18	6.6	11.9	x	0.49	3.34	6.6	12.9	x	0.48	3.23	6.4	13.5	x
	t_2 (1h15)	0.65	3.01	5.7	12.6	x	0.54	3.23	5.5	12.3	x	0.51	2.22	5.7	12.1	x
	t3 (4 h)	0.54	3.25	5.9	11.9	x	0.57	3.32	5.2	13.3	x	0.63	3.32	5.6	11.5	x
	t4 (24 h)	0.65	3.34	6.1	13.3	x	0.58	2.92	6.2	13.2	x	0.54	3.15	6	13.1	x
CBC	t_0 (0m)	0.57	3.2	6.2	13.8	x	x	3.519	6.4	12.3	26.7	x	3.727	6.7	12.9	25.9
	t_1 (15m)	0.447	1.07	0.318	8.8	x	x	1.374	2.842	9.4	22.8	x	1.351	2.617	6.3	20.8
	t_2 (1h15)	0.336	0.551	0.252	0.485	x	x	0.49	0.587	2.18	9.6	x	0.484	0.553	1.113	8.816
	t3 (4 h)	0.375	0.54	0.506	1.498	x	x	0.339	0.368	0.646	2.05	x	0.483	0.499	0.628	2.374
	t4 (24 h)	0.395	0.557	0.562	1.013	x	x	0.479	0.713	0.655	0.841	x	0.486	0.569	0.642	0.78
FBC	t_0 (0m)	0.51	3.22	7.4	12.9	x	x	3.22	5.95	12.3	25.8	x	3.704	6.8	12.8	25.9
	t_1 (15m)	0.7	2.57	0.497	10.4	x	x	2.57	5.288	11	23	x	3.155	5.559	11.4	23.6
	t_2 (1h15)	0.718	2.14	0.5	8.2	x	x	2.14	4.684	9.7	20.8	x	2.685	4.606	9.81	23.2
	t3 (4 h)	0.625	1.892	3.16	6.342	x	x	1.892	4.031	7.6	17.6	x	2.165	3.703	8.196	20.565
	t4 (24 h)	0.44	0.971	1.965	4.447	x	x	0.971	2.353	3.779	12.5	x	1.012	2.18	4.659	11.668
PBC	t_0 (0m)	0.46	3.27	6.2	14.3	x	x	3.523	5.9	12.1	26.3	x	3.746	6.7	12.8	25.6
	t_1 (15m)	0.67	1.65	0.417	6.9	x	x	0.785	3.739	13	25.4	x	1.899	3.886	11.2	24.3
	t_2 (1h15)	0.52	0.554	0.56	2.86	x	x	0.415	1.316	6.795	22.2	x	0.68	1.236	5.714	24.325
	t3 (4 h)	0.536	0.395	0.836	1.551	x	x	0.376	1.647	6.359	16	x	1.207	1.251	5.167	21.83
	t4 (24 h)	0.717	0.429	1.31	3.698	x	x	0.514	2.644	5.521	13.5	x	1.782	1.811	3.923	13.466

APPENDIX II - Adsorption isotherms

The graphs that provided all Langmuir and Freundlich parameters are shown in Figure 12 & Figure 13. The linear equation of Langmuir model (Equation 4) is Ce plotted vs Ce/Qe. The linear plot provided the parameters Q_m and k_L where the slope was $1/Q_m$ and the intercept $1/Q_mk_L$ and they are presented in Table 5.

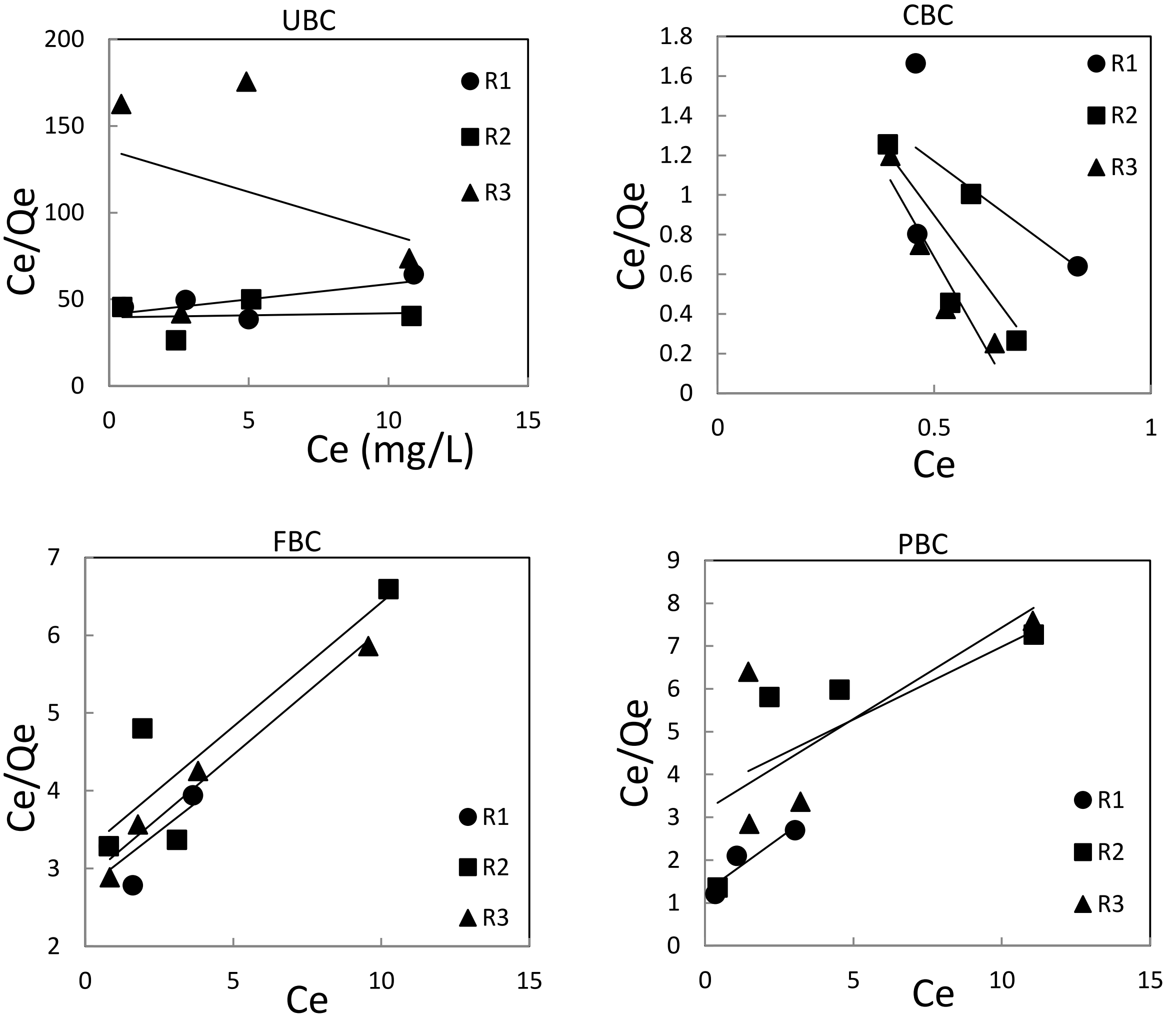


Figure 11 Linear plots of the linearization of the Langmuir equation.

The linear equation of the Freundlich model (Equation 5) is expressed as $\ln Q_e$ vs $\ln C_e$. The slope is 1/n and intercepts in $\ln k_F$. The parameters are all presented in Table 5 in the result section.

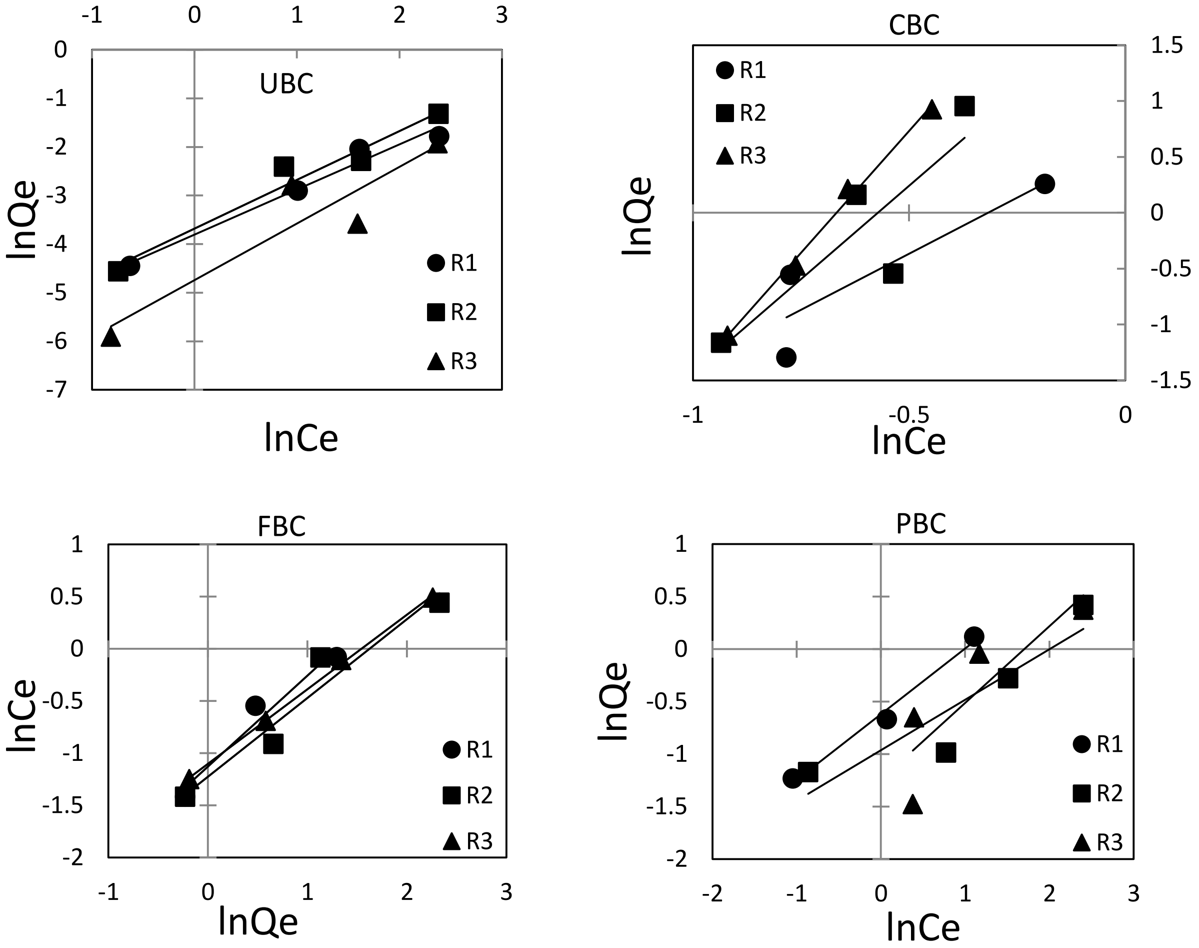


Figure 12 Plots of the linear version of Freundlich model for all biochar types.

APPENDIX III - Kinetic isotherms

Model parameters derived from calculated pseudo first and second order equation 6 & 7 (Table 11).

Table 11 All the calculated parameters for the kinetic isotherms

Concentration	Biochar type	Pseudo 1st order model parameters			Pseudo 2nd order model parameters			Experimental
		Q_e (mg/g)	R^2	k_1 (min^{-1})	Q_e (mg/g)	R^2	k_2 (g/mg/min)	Qe (mg/g)
C2	**UBC**	0.064	0.77850	0.004	0.068	0.9107	-0.021	0.069
	CBC	0.156	0.83597	0.028	0.307	1.0000	1.717	0.307
	FBC	0.229	0.91907	0.004	0.281	0.9965	0.036	0.264
	PBC	0.266	0.99700	0.097	0.264	0.9998	-0.499	0.277
C3	**UBC**	0.123	0.85430	0.021	0.085	0.9913	-0.593	0.086
	CBC	0.586	0.99970	0.063	0.594	1.0000	1.657	0.593
	FBC	0.456	0.95767	0.005	0.516	0.9970	0.055	0.494
	PBC	0.385	0.99700	0.049	0.468	0.9995	-0.496	0.469
C4	**UBC**	0.182	0.55703	0.664	0.199	0.9940	-0.081	0.194
	CBC	1.015	0.98263	0.021	1.250	0.9997	0.075	1.237
	FBC	0.815	0.95843	0.005	0.916	0.9978	0.014	0.914
	PBC	0.847	0.87223	0.029	0.950	0.9951	-0.047	0.947
C5	**UBC**	-	-	-	-	-	-	-
	CBC	2.409	0.99200	0.013	2.654	0.9988	0.008	2.564
	FBC	1.467	0.96665	0.003	1.774	0.9887	0.004	1.594
	PBC	1.494	0.99450	0.005	1.756	0.9814	0.002	1.489

Linearization of pseudo 2nd order equation gave liner plots with t/Q as y-axis and t as x-axis (Figure 13a-d). The plots have the slope $1/Q_e$ and intercept $1/k_2Qe$ and the parameters Q_e, k_2 and correlation R^2 are presented in Table 6 in and Table 11. Pseudo 2nd had the best fit for all biochar and concentrations except for PBC and C5 (Figure 13e). Pseudo 1st equation gave a linear plot with $\ln(Q_e\text{-}Q_t)$ as y-axis. The slope is k_1 and intercept $\ln(Q_e)$ and k_1 and Q_e are presented in Table 6 in the Result section and in Table 11.

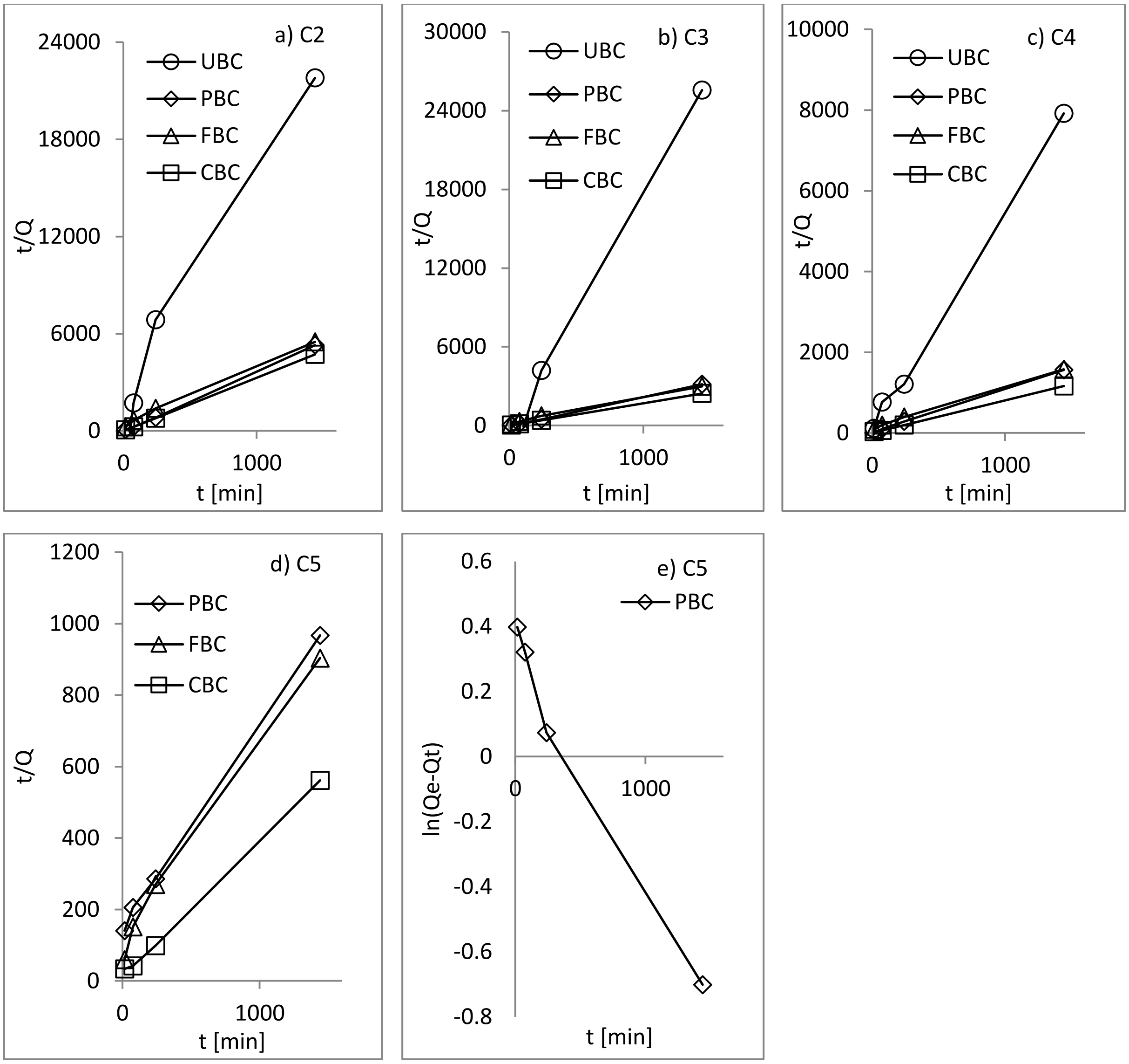


Figure 13 a-d) The linear plots of pseudo 2nd order kinetic model for C1, C2, C3, C4 and C5 where t/Q has the unit min/mg/g. **e)** The pseudo 1st order kinetic model linear plot for C5 and Polonite (PBC) with y-axis ln(Qe-Qt) (mg/g).

APPENDIX VI - Filter experiments

The removal efficiency of NH_4-N in the vertical section of the N removal filter was stable around 50 % from week 9 to 14 of the experiment (Figure 14a). In the same filter section, NO_3-N was not removed but created. As the experiment proceeded higher NO_3-N were measures in the outflow of the vertical filter section. In the Horizontal section, the NH_4-N removal varied more than in the previous section but had an average removal around 40 % (Figure 14b). The NO_3-N removal was not stable and increased during the experiment (Figure 14b). In the whole filter (Figure 14c), NH_4-N and Tot-N displayed stable removal whereas the filter had an increasing removal of NO_3-N. Tot-N removal is also presented in the result section (Figure 9).

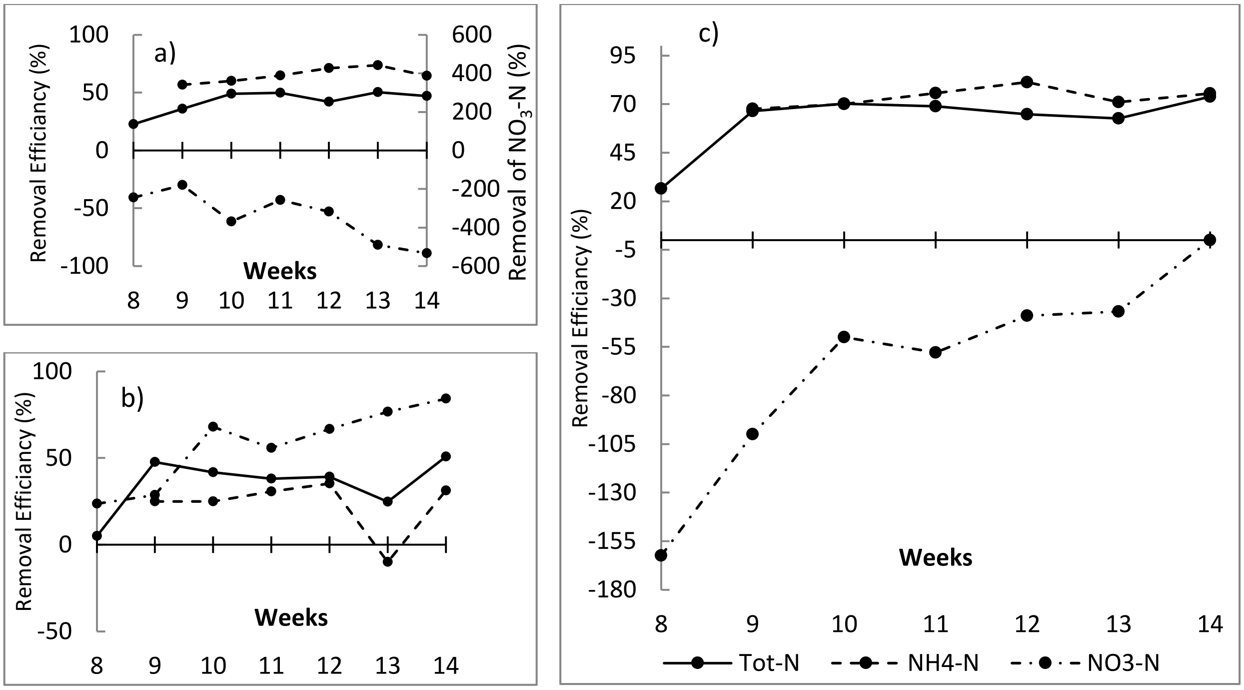


Figure 14 The variation of the removal of NH_4-N, NO_3-N and Tot-N in the nitrogen removal filters **a)** First unsaturated section with vertical flow, **b)** second saturated section with horizontal flow and **c)** total filter with both sections combined.

Appendix F: Ranking Sensitivity Analysis

A sensitivity analysis was conducted on the weights used in the attribute ranking to evaluate the impacts of modifying the weights on the technology ranking results. The attribute ranking was assessed against the total nitrogen (TN) cost-effectiveness in a series of plots for the sensitivity analysis. The TN cost-effectiveness value remained the same since it was based on the information provided by the vendors for each technology. The highest ranked, most cost-effective technologies fall in the lower left (LL) portion of the plots. The goal of the sensitivity analysis was to determine if changing the attribute scores or weights affected which technologies were the highest ranked (in other words, falling within the LL plot sector).

F.1. Sector Plot Analysis

Figure F-1 shows the original ranking that was discussed in **Section 3.3**. As described in **Section 4.0**, the technologies with greatest cost-effectiveness and performance attributes occurring in the LL sector included treatment wetlands (STA), alum treatment (offline), Hybrid Wetlands Treatment Technology (HWTT), sand filtration, and Bold & Gold®.

Figure F-2 shows the alternatives ranked only by their scalability score. This ranking shows treatment wetlands, alum treatment, and sand filtration remaining in the LL sector, with the addition of Air Diffusion Systems (ADS), and the movement of HWTT and Bold & Gold® out to the lower right (LR) sector. The change in ranking for ADS is attributed to the proven ability and technical feasibility to install air diffusion systems in large reservoirs. The movement of HWTT and Bold & Gold® out of the LL sector is attributed to the smaller scale of existing installations.

Figure F-3 shows the alternatives ranked by their performance confidence scores. Systems with prior, long-term applications resulting in proven nutrient reductions, either in the history of Florida surface water treatment, such as treatment wetlands, HWTT, and alum treatment, or global water management, such as sand filtration, remained in the LL sector. ElectroCoagulation was present also in the LL sector, reflecting the high level of control of TN and TP anticipated with its application. Bold & Gold® moved to the LR sector, which is attributed to the need for additional performance information for nitrogen removal. ADS scored low on this attribute given the relative lack of information on nutrient reduction using this technology in Florida and elsewhere.

Figure F-4 shows the alternatives ranked by their relative abundance of case histories in Florida. Treatment wetlands, HWTT, alum treatment, sand filtration, Bold & Gold®, and ADS were in the LL sector. Other technologies moved towards this sector. Notably, MPC-Buoy, with no current Florida applications, remained in the upper right sector.

Figure F-5 shows the alternative ranked by the expected production of residuals and need for residuals management. In this scenario, treatment wetlands, sand filtration, and ADS remained in the LL sector. Bold & Gold® and HWTT moved to the border of the LL and LR sectors, as alum treatment moved to the LR sector, reflecting the expected need to manage a significant quantity of residuals. ElectroCoagulation and NutriGone™ showed lower scores on the x-axis, reflecting the lower amount of residuals to be produced (ElectroCoagulation) or an expected market for the residuals (NutriGone™).

These comparisons yielded results that indicate that the scoring and comparison technology is sensitive to input but the technologies that ranked highest in the initial ranking (i.e., treatment wetlands, HWTT, alum treatment) retained a favorable ranking consistently under different scoring emphases. Of the other technologies, Bold & Gold®, sand filtration, and ADS were more likely to enter the preferred LL sector.

F.2. Weighting Comparison

As another test of the method sensitivity, the original ranking was weighted differently in accordance with emphasis on TN, TP, or TSS removal (**Table F-1).** The original ranking is shown with a balanced emphasis for TN, TP, and TSS removal, in this case assigned a 40%-40%-20% weight (abbreviated here as 4-4-2). Adjacent to that, the rankings vary based upon a complete emphasis for TN removal (0-10-0), TP removal (10-0-0), and TSS removal (0-0-10). A review of the findings indicates that alum treatment, treatment wetland, and HWTT rankings were little changed based upon nutrient removal emphasis. Sand filtration, Bold & Gold®, and ADS maintained middle rankings, and the remaining technologies showed little variation from their relatively lower rankings.

F.3. Sensitivity Analysis Conclusion

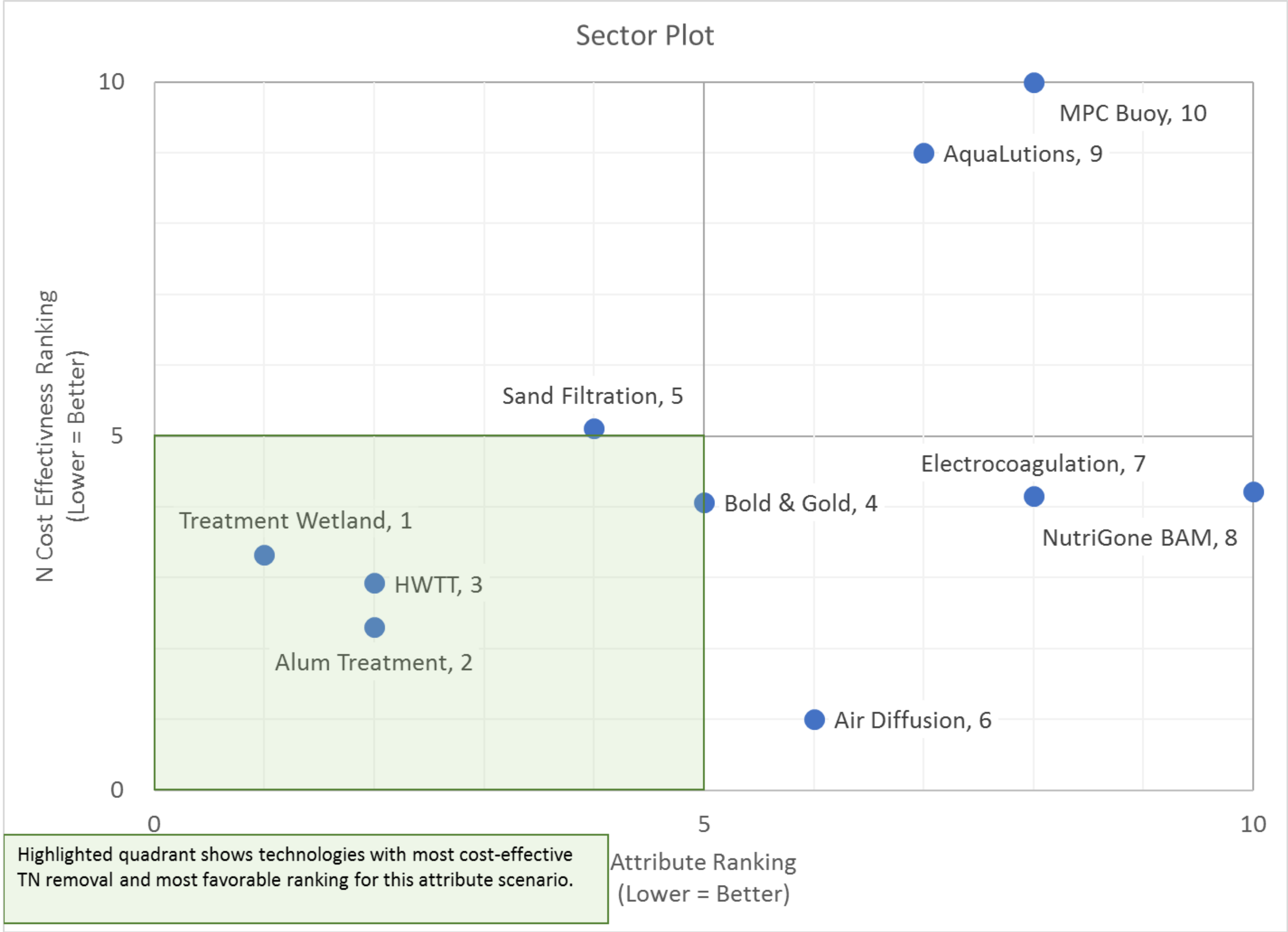
Taken together, the two approaches to the sensitivity analysis of the scoring and ranking methodology show that the consistently top-ranked technologies for this application at the C-43 WBSR are alum treatment, treatment wetland, and HWTT. Sand filtration, Bold & Gold®, and ADS show potential as potentially complementary technologies.

Table F-1. Comparison of Composite Ranking by Weighting Scenario

Technology	4-4-2	0-10-0	10-0-0	0-0-10
Alum Treatment	1	1	1	1
Treatment Wetland	2	2	2	2
HWTT	3	3	3	3
Bold & Gold®	4	5	4	6
Sand Filtration	5	6	5	7
Air Diffusion	6	4	9	4
Electrocoagulation	7	7	6	8
NutriGone™	8	8	7	9
AquaLutions	9	9	8	10
MPC Buoy	10	10	10	5

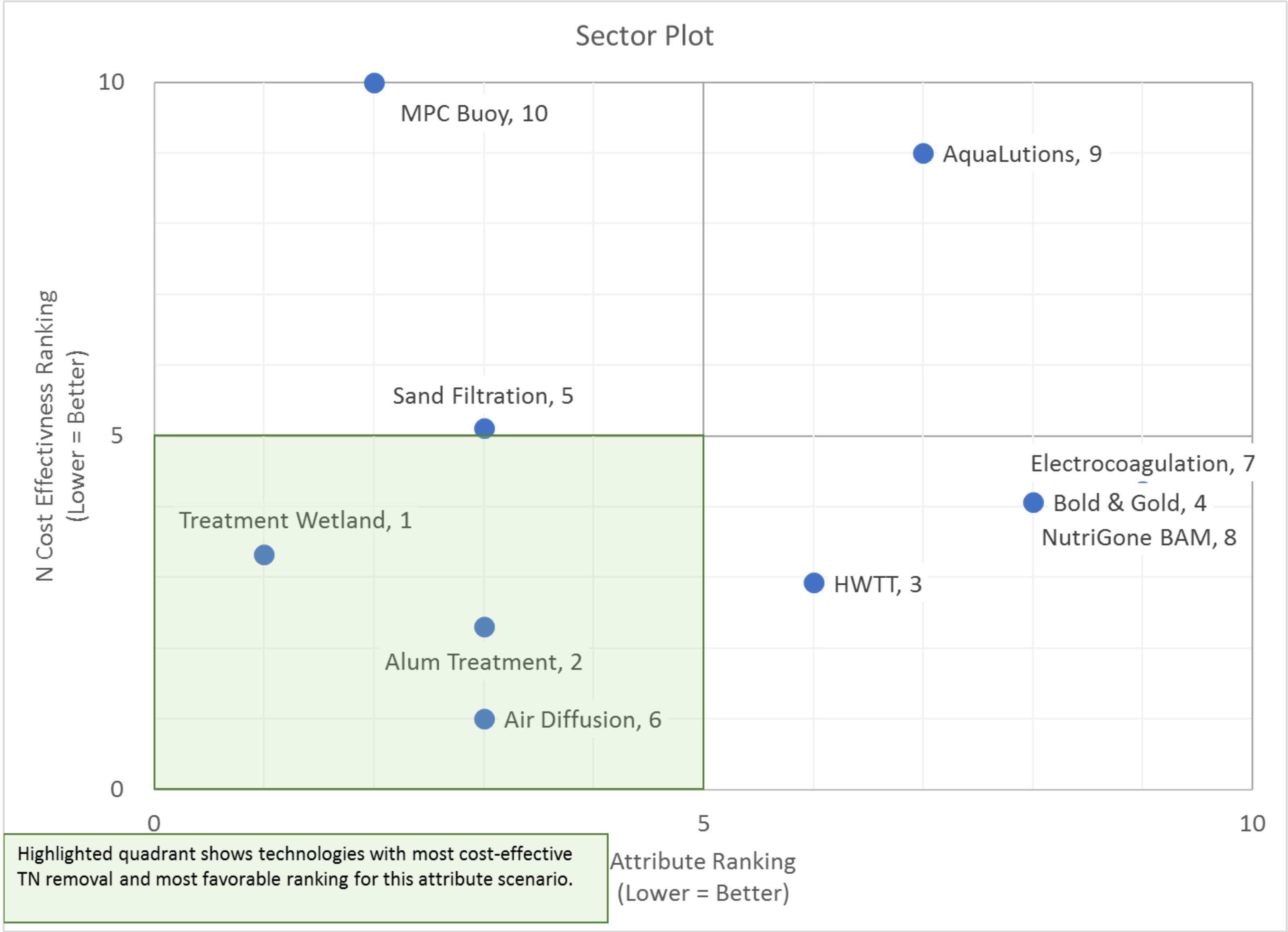
Scenario Notes:

- 4-4-2: Baseline scenario, with ranking consisting of 40%, 40% and 20% preference for removal of TP, TN and TSS, respectively.
- 0-10-0: 100% weight on TN removal effectiveness.
- 10-0-0: 100% weight on TP removal effectiveness.
- 0-0-10: 100% weight on TSS removal effectiveness.



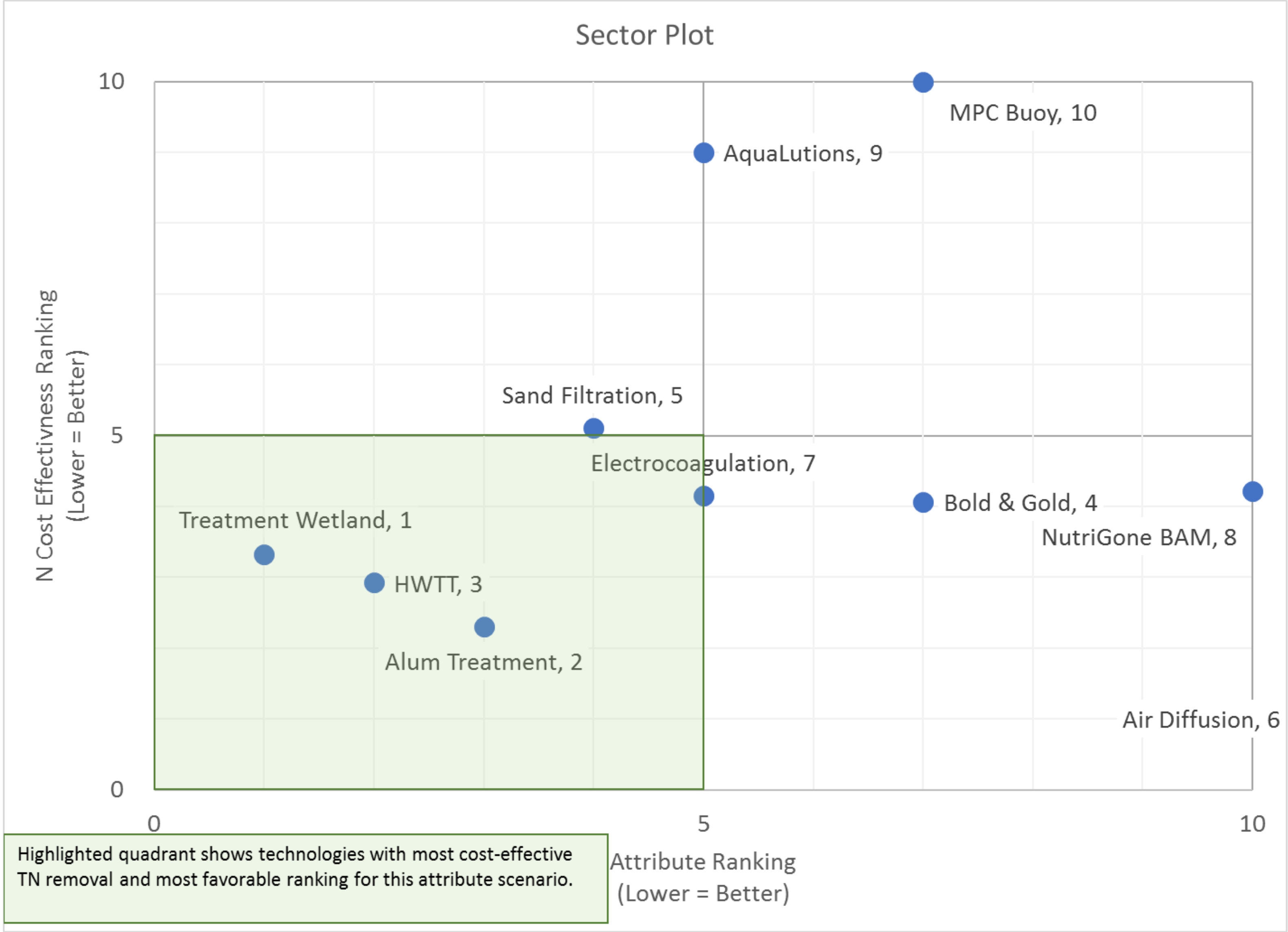
Highlighted quadrant shows technologies with most cost-effective TN removal and most favorable ranking for this attribute scenario.

Figure F-1. Original Ranking



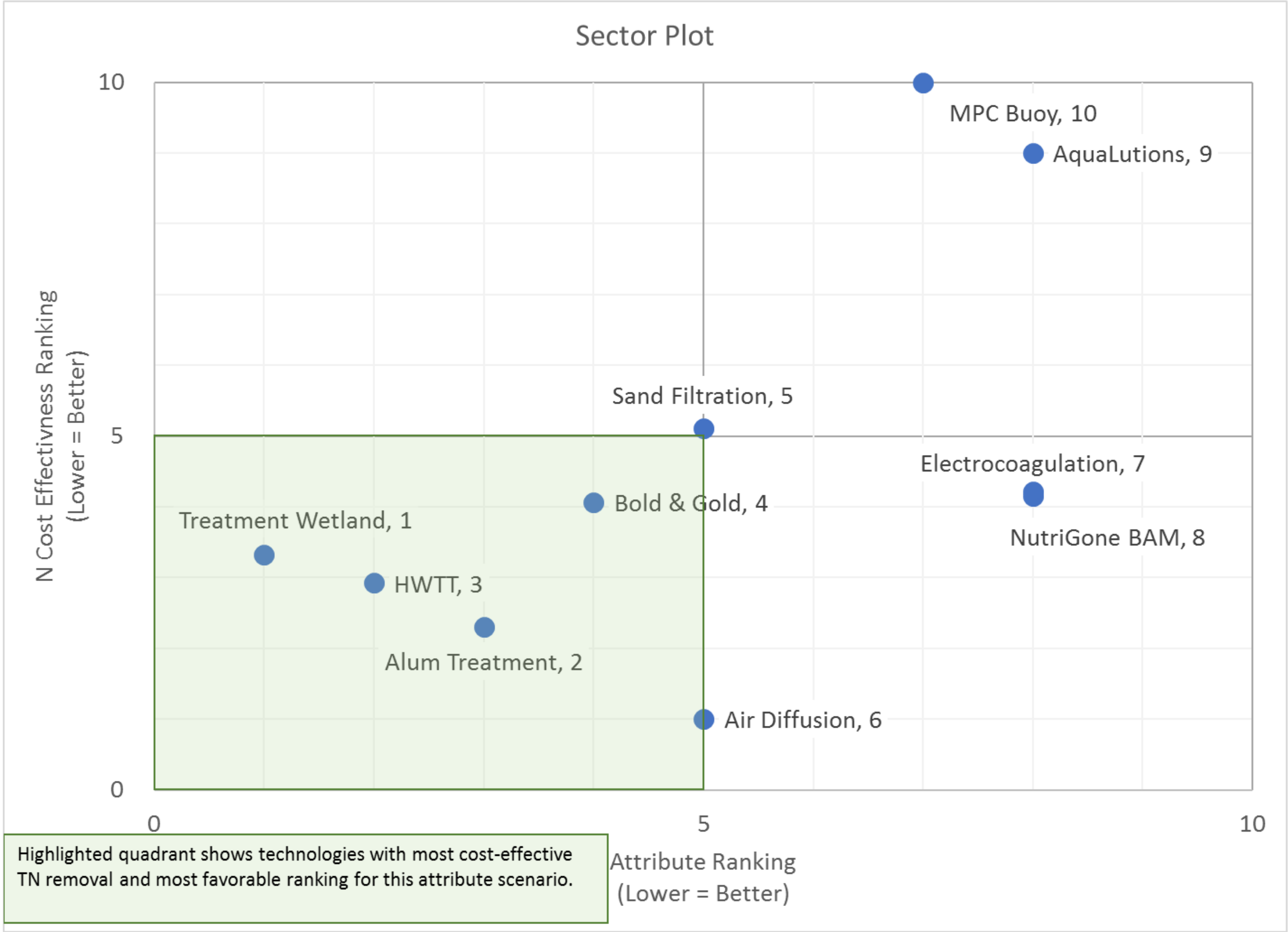
Highlighted quadrant shows technologies with most cost-effective TN removal and most favorable ranking for this attribute scenario.

Figure F-2. **Ranking Based Solely on Scalability Score**



Highlighted quadrant shows technologies with most cost-effective TN removal and most favorable ranking for this attribute scenario.

Figure F-3. **Ranking Based Solely on Confidence Score**



Highlighted quadrant shows technologies with most cost-effective TN removal and most favorable ranking for this attribute scenario.

Figure F-4. **Ranking Based Solely on Case History Score**

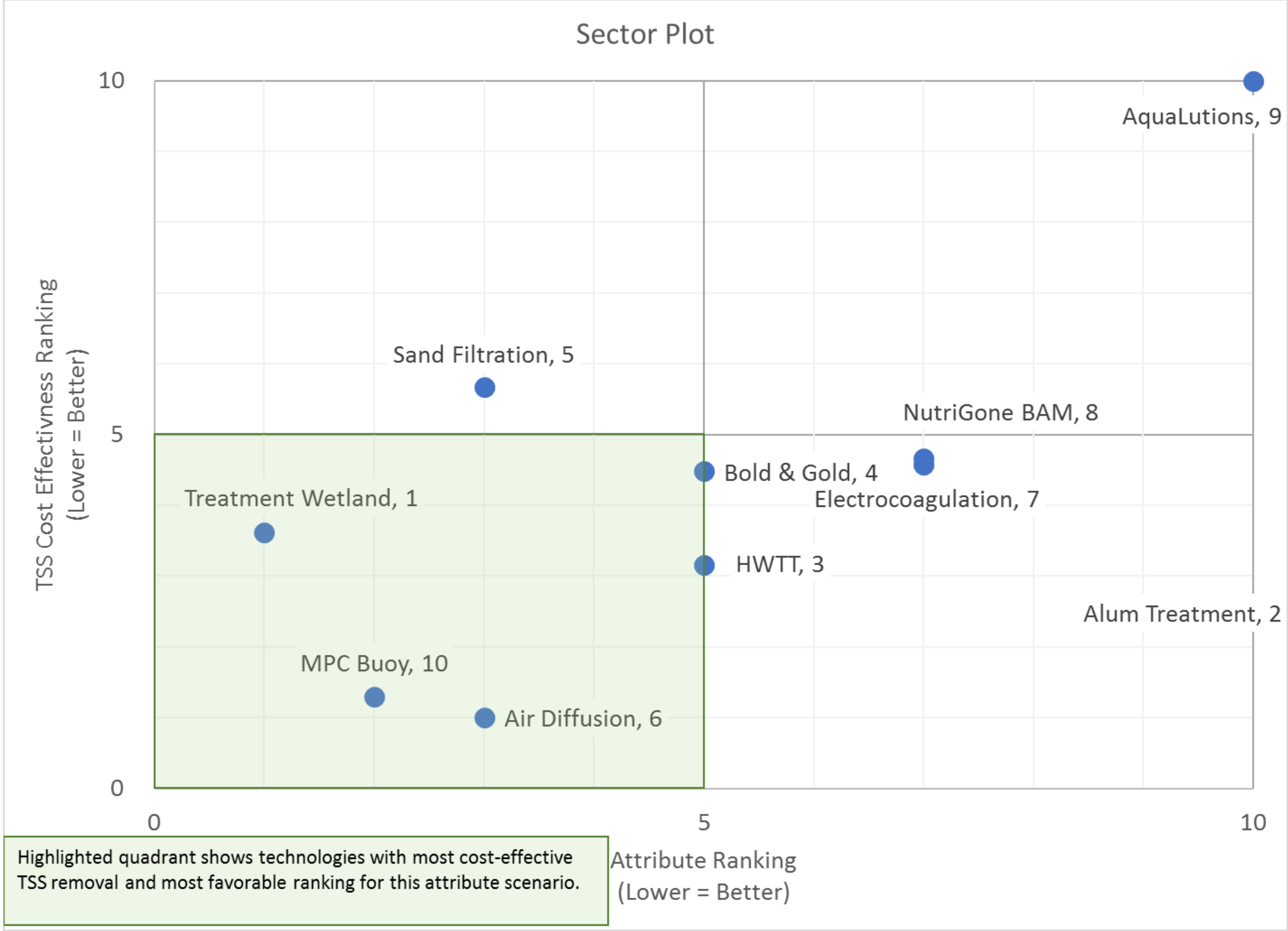


Figure F-5. **Ranking Based Solely on Residual Management Score**

Appendix G: C-43 Water Quality Alternative Treatment Technology – Pilot Study Preliminary Results

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

C-43 Water Quality Alternative Treatment Technology – Pilot Study Preliminary Results

November 5, 2020

Prepared by

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EXECUTIVE SUMMARY

The C-43 Water Quality Alternative Treatment Technologies Pilot Study was initiated to further investigate two treatment technologies that ranked highly in the C-43 West Basin Storage Reservoir Water Quality Feasibility Study. Bold&Gold® CTS and alum treatments were both identified as cost-effective nutrient removal technologies that may be used to help prevent algal blooms in the Reservoir. However, the nutrient removal efficiencies for both technologies were assessed using source water with a very different chemical composition than the C-43 Canal. This study looked at nutrient removal efficiencies using C-43 Canal water that is representative of the water to be stored in the Reservoir.

Bold&Gold® CTS is a bioactivated medium composed of clay, tire crumb, and sand. It was installed in two mesococms tanks located on the Boma property. Two additional tanks were filled with just sand, and two tanks with no media were used as controls. Water flowed into the tanks over a 20-day period, and water quality samples were collected at a high frequency to assess nutrient removal efficiency. Concurrently, aluminum sulfate, referred to as alum, was added to water collected from Boma, the Hilliard Canal, and the S-77 structure to assess nutrient removal capacity for the C-43 Canal water as well as two water sources for the Canal, the watershed and Lake Okeechobee. Samples were collected once a week for 3 weeks for “jar” tests to determine optimum dosing level and nutrient removal at the optimum dosing level.

Bold&Gold® CTS did very well removing nitrate-nitrite, averaging 98% removal from the very start of the study. However, other chemical components were either not removed more efficiently than the Sand and Control treatments, or water flowing through the media picked up addition compounds making the outflow concentration higher than the inflow concentration. This was especially true for total organic (TOC) carbon, which increased in concentration by over 40% with 7 days of flow. However, this production of TOC declined with time, and likely represents the “first flush” of the system. According to the manufacturer, 90 days of flow are required to reach optimum nutrient removal conditions.

Alum dosing was highly effective for removing a wide range of nutrient components. Total organic carbon reduction averaged 58%, total nitrogen reduction averaged 43%, and total phosphorus reduction averaged 90%. Importantly, DON reduction averaged 54%, much higher than has been achieved using wetland mesocosms (J-Tech, 2019).

These results represent wet season only, and for Bold&Gold® CTS, only the initial conditions as opposed to optimum conditions. This study is being extended and expanded to capture optimum conditions for Bold&Gold® CTS, higher flow rates that are more representative of the flows recommended under the Water Quality Feasibility Study for Bold&Gold® CTS, and dry season conditions for both Bold&Gold® CTS and alum. In addition, heavy metals and polyaromatic hydrocarbons will be analyzed to assess any potential risks from the tire crumb. For dry season sampling, two types of alum, aluminum sulfate and aluminum chlorohydrate, will be used in the jar tests to compare performance of each type. This expanded study will provide a more accurate assessment of these treatment technologies under a variety of conditions.

TABLE OF CONTENTS

ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASUREMENT

°C	degrees Celsius
%	percent
D	depth
ft	foot, feet
ft^2	square foot
$gal/min/ft^2$	gallons per minute per square foot
L	length
mg/L	milligrams per liter
µg/L	micrograms per liter
W	width
BAM	biosorption activated media
CHNEP	Coastal and Heartland National Estuary Program
District	South Florida Water Management District
DOC	dissolved organic carbon
DON	dissolved organic nitrogen
ECS	Environmental Conservation Solutions, LLC
EPA	Environmental Protection Agency
FDEP	Florida Department of Environmental Protection
NELAC	National Environmental Laboratory Accreditation Conference
NH3	ammonia
NOx	nitrate/nitrite
PN	particulate nitrogen
POC	particulate organic phosphorus
PP	particulate phosphorus
PVC	polyvinyl chloride
SRP	soluble reactive phosphorus
TC	total carbon
TDKN	total dissolved Kjeldahl nitrogen
TDP	total dissolved phosphorus
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended solids
WBSR	West Basin Storage Reservoir
WQTTP	Water Quality Treatment Technologies Project

INTRODUCTION

A lot of attention has been paid to reducing nutrients in the Caloosahatchee River and Estuary, also known as the C-43 Canal. Since 2008, the South Florida Water Management District (the District) has been working on nutrient removal technology development, focusing primarily on nitrogen removal. One project is the C-43 Water Quality Treatment Technology Project. The goal of this project is to demonstrate and implement cost-effective wetland-based treatment and is being conducted in phases to develop the science of nitrogen removal before full-scale implementation. Another project is the C-43 West Basin Storage Reservoir (WBSR) Water Quality Component. A Feasibility Study was conducted as a first step to examine available treatment technologies, including a cost/benefit analysis.

The C-43 Water Quality Treatment Technologies Project (WQTTP) Phase 1 – Mesocosms and Bioassays study found the Caloosahatchee River water nitrogen to be composed in large part of dissolved organic nitrogen (DON), which can be very recalcitrant. This fraction of nitrogen can compose up to 80% of the total nitrogen (TN) concentration in the river. Its recalcitrant nature poses challenges for any treatment technology to remove. Phosphorus in the Caloosahatchee River is also highly organic, averaging about 50% of the total phosphorus (TP) concentration. The mesocosm experiment, using both emergent and submerged aquatic plant communities, was able to achieve nutrient removal efficiencies of 29% - 36% for TN, 0% - 13.6% for DON, and 72% - 86% of TP (J-Tech, 2019).

As part of the C-43 WBSR Water Quality Feasibility Study, several alternative treatment technologies were evaluated for incorporation into the Water Quality Component. Two alternative treatment technologies ranked high in the cost/benefit analysis; Bold&Gold® CTS and alum. The nutrient removal efficiencies for both products were based on source water comprised of more inorganic than organic forms of nitrogen than is found in the Caloosahatchee River water. Therefore, it is important to understand how well these alternative treatment technologies remove nutrients from the highly organic Caloosahatchee River water.

Bold&Gold® CTS is a biosorption activated media (BAM) used to remove TN, TP, total suspended solids (TSS), and pathogens from water. Sand is used in Bold & Gold® CTS media to filter suspended solids and harmful colloidal bacteria and to increase infiltration rates. Clay is used in Bold & Gold® CTS media to help retain moisture to create an anaerobic environment for denitrification and to provide surface area for the attachment of the microbes. And recycled tire is used in Bold & Gold® CTS media to provide a carbon source for the denitrification process and surface area for the adsorption process. Bold & Gold® CTS media is a patented product developed by the Stormwater Management Academy at the University of Central Florida and is manufactured by Environmental Conservation Solutions, LLC (ECS) (ECS, 2020). According to ECS, full efficiency is not achieved until 90 days of flow, and its effective lifespan depends upon the target nutrient. Nitrogen, since biologically driven, is believed to have an infinite lifespan, while phosphorus's lifespan depends upon concentration and flow rate.

Alum, or aluminum sulfate, is a flocculant used to clarify water and remove nutrients, primarily phosphorus. It is commonly used in lakes to precipitate out nutrients, which then settle on the lake bottom making it unavailable for algal growth. Alum also has been used as a pre-treatment addition to surface water before flowing through treatment wetlands. It has generally been found safe and non-toxic at the concentrations used. Alum can have a 15- to 30-year lifespan if dosed correctly (Huser et al 2016).

The objective of this study is to evaluate the nutrient removal efficiency of Bold&Gold® CTS and alum using Caloosahatchee River water. This was done using two approaches.

1) To evaluate Bold&Gold® CTS, the District established a mesocosm study at the Boma property using 6 fiberglass tanks measuring 16’ L x 7’10” W x 4’ D (128 ft^2 surface area). Two tanks contained 2 ft of Bold&Gold® CTS capped with 1 ft of sand, 2 tanks contained 3 ft of sand, and 2 tanks contained no media. Water was added to the surface of each tank, allowed to flow through the media, and then collected using a stilling well. Samples were also collected from the head tank representing the C-43 source water. During this preliminary phase, multiple samples were collected over the course of a 1-month period to assess removal of nitrogen and phosphorus.
2) To evaluate alum, water was collected once a week for 3 weeks from 3 different sources: the C-43 Canal at Boma; the Hilliard Canal, which is a tributary east of the Boma property; and at the S-77 structure at Lake Okeechobee (Figure 1). These samples were used to conduct “jar” tests for alum dosing and nutrient removal.

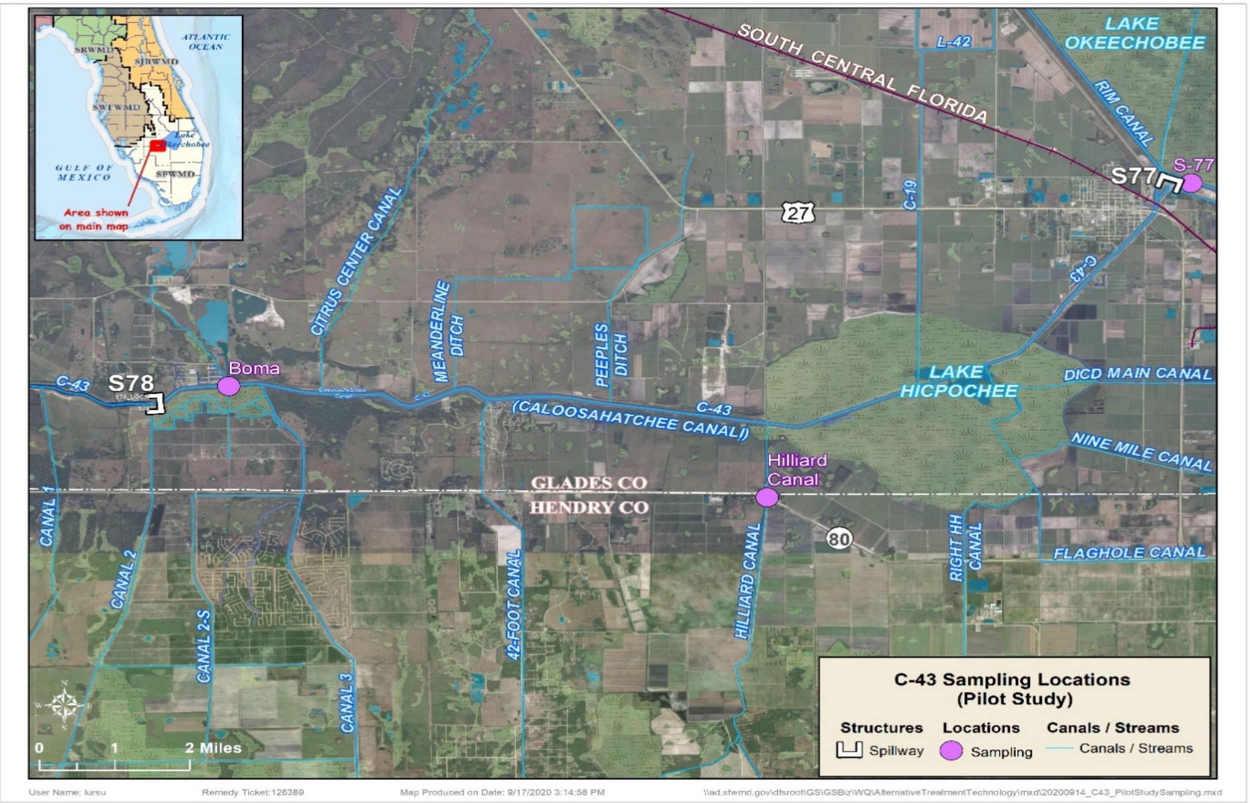

Figure 1. Map of C-43 Pilot Study Sampling Locations.

MATERIAL AND METHODS

SITE DESCRIPTION

Boma

The Boma property is located just upstream of the S-78 structure, Ortona Lock and Dam. A water quality testing facility was established by the District in 2016 consisting of 12 mesocosm tanks, 1 head tank, and 2 sub-head tanks (Figure 2). Water was pumped from the C-43 Canal to the head tank for gravity distribution to the sub-head tanks, which in turn flowed to each mesocosm. At the end of the C-43 WQTTP – Phase 1 study, the 6 tanks closest to the head tank were cleaned of their contents and made available for other studies.

Each of the 6 tanks received red river rock to approximately a 1 ft depth (Figure 3a) and then covered with geofabric to prevent sand migration into the rock layer (Figure 3b). Two PVC wells were installed at the end of each tank for sample water collection (Figure 3b). The 2 Control tanks has this configuration and no other media were added to the tanks. For the 2 Sand tanks, 3 ft of sand was applied on top of the geofabric. For the 2 Bold&Gold® CTS tanks, 2 ft of medium was applied and then capped with 1 ft of sand. Rock, sand, and medium were obtained from ECS.

Figure 2. Aerial overview of mesocosm tanks, head tank and sub-head tanks.

Once all the material was in place, a water distribution system was built off the existing inflow spigot. It was comprised of 7 Rainbird® hoses with small holes periodically placed to allow for drip irrigation along the length of the hose. The 7 hoses were connected to the inflow with a series of t-connectors and black irrigation hose (Figure 4). All hoses were flushed thoroughly before water was applied to the tanks. Flow rate was estimated to be 0.005 gal/min/ft^2. This is an order of magnitude lower than the 0.052 gal/min/ft^2 flow rate used by ECS in the C-43 WSBR Water Quality Feasibility Study. All tanks consisted of rock, geofabric, water distribution system, and PVC wells, with Sand and Bold&Gold® CTS tanks also filled with medium as described above (Figure 5). Control tanks were covered with shade cloth to deter algal growth.

Figure 3. a) Red river rock being loaded into mesocosm tank. b) Geofabric covering red rock with 2 PVC sample collection wells at the end of the mesocosm tank.

Figure 4. Water distribution system.

Figure 5. Completed Bold&Gold® CTS mesocosm tank.

Water samples for the alum jar studies were collected from the head tank.

Hilliard Canal

The Hilliard Canal is fed by agricultural runoff as active farming fields are on all sides of the canal. A variety of row crops are grown in each of the fields. A tilapia fish farm is located on the eastern side of the canal, and a campground is farther upstream. The canal is not considered an impaired water body by Florida Department of Environmental Protection (FDEP) and considered in the "Good" range for water quality (CHNEP, 2020). Water samples for the alum jar studies were collected on the north side of the S80 bridge crossing the canal.

S-77 Structure

Water samples for the alum jar studies were collected from the Alva Ward Boat ramp located just east of the S-77 structure. Water was collected from the Lake Okeechobee Rim canal and is representative of Lake water flowing through the S-77 structure into the C-43 Canal.

MESOCOSM WATER QUALITY SAMPLING

Water samples were collected from the mesocosms over a 3-week period (Table 1). Inflow to the mesocosms began on September 10, 2020. There was a 3-day pause in water delivery to the mesocosms due to electrical issues at the site starting on September 25th. Flow was resumed on September 28th, and sampling resumed on the 30th.

Water samples were collected from the wells using a peristaltic pump (Figure 6a). Collection tubing was run to the bottom of the well, and water was flushed through the tubing for several minutes. The collection bottle was rinsed twice with sample water before filling. Aliquots of sample were then processed from the collection bottles per the requirements for each analyte (Figure 6b, Table 2). Samples were then placed on ice and transported to DB Environmental's NELAC-certified Laboratory for analysis.

Table 1. September mesocosm sampling schedule.

Monday	Tuesday	Wednesday	Thursday	Friday
	1	2	3	4
7	8	9	**10**	11
14	**15**	**16**	**17**	18
21	**22**	**23**	**24**	25
28	29	**30**		

Note: Bold dates represent sample collection. September 10th, flow to mesocosms began.

Figure 6. a) Water sample collection with peristaltic pump, b) Sample processing.

ALUM JAR TEST SAMPLING

Alum jar test samples were collected on September 8, 15, and 22nd at each of the three sample locations. Two 5-gallon buckets were used to collect the "raw" water samples. Each bucket was rinsed with site water twice before filling the bucket two-thirds full and capping with a locking top. Samples from the Boma site were collected from the head tank of the mesocosm facility. Samples from the Hilliard Canal site were collected with dip buckets from the northern side of the S80 bridge. Samples from S-77 were collected with dip buckets from the Alva Ward boat ramp dock. Samples were then transported to DB Environmental's NELAC-certified laboratory for analysis. Analytes were the same as Table 2 and additionally were sampled from sulfate and total dissolved aluminum.

Details regarding jar test methodology can be found in the Appendix.

DATA ANALYSIS

Mesocosm data were evaluated by subtracting the mesocosm results from head tank results and assessing either % reduction or concentration reduction of an analyte. Concentration reduction was used when the head tank concentration was below detection. Positive numbers indicate reduction, and negative numbers indicate production of the analyte. Data for each of the Controls, Sand, and Bold&Gold® CTS mesocosm tanks were averaged and standard deviations calculated. Each analyte was then graphed over days since flow began. No statistical tests were conducted.

Several nutrient fractions were calculated based on the results of the measured analytes. Particulate organic carbon (POC) was the difference between total organic carbon (TOC) and dissolved organic carbon (DOC). Particulate nitrogen (PN) was the difference between TN and total dissolved nitrogen, which was calculated as the sum of total dissolved Kjeldahl nitrogen (TDKN) and nitrate-nitrite (NOx). Dissolved organic nitrogen is the difference between TDKN and ammonia (NH3). Particulate phosphorus (PP) is the difference between TP and total dissolved phosphorus (TDP).

Table 2. Analyte Processing.

Parameter	Analysis Method	Minimum Sample Volume to Collect (mL)	Preservation	Holding Time
Total Kjeldahl Nitrogen (TKN)	EPA 351.2 *	30	pH< 2 (sulfuric acid), 4˚C	28 days
Nitrate/Nitrite as N (NOx-N)	SM 4500NO3 H-2011 *	30	filter through 0.45 micron membrane filter, pH< 2 (sulfuric acid), 4ºC	28 days
Total Dissolved Kjeldahl Nitrogen (TDKN)	EPA 351.2 *	30	filter through 0.45 micron membrane filter, pH< 2 (sulfuric acid), 4ºC	28 days
Ammonia-N (NH3-N)	EPA 350.1 *	30	filter through 0.45 micron membrane filter, pH< 2 (sulfuric acid), 4ºC	28 days
Total Phosphorus (TP)	SM 4500-P F	40	pH< 2 (sulfuric acid), 4˚C	28 days
Total Dissolved Phosphorus (TDP)	SM 4500-P F	40	filter through 0.45 micron membrane filter, pH< 2 (sulfuric acid), 4ºC	28 days
Soluble Reactive Phosphorus (SRP)	SM 4500-P F or DBE SOP OPO4	20	filter through 0.45 micron membrane filter, 4ºC	48 hours
Total Organic Carbon (TOC)	SM 5310 B	20	pH< 2 (hydrochloric acid), 4ºC	28 days
Dissolved Organic Carbon (DOC)	SM 5310 B	20	filter through 0.45 micron membrane filter, pH<2 (hydrochloric acid), 4ºC	28 days

RESULTS

MESOCOSM WATER QUALITY

Initial Concentrations

Inflow water quality composition to the mesocosm tanks was typical of wet season C-43 Canal water chemistry (Table 3). Most of the carbon is in dissolved organic form, and DON composed 69% of TN on average. Ammonia being below detection is unusual, as wet season concentrations tend to range from 0.012 mg/L to 0.032 mg/L (J-Tech, 2019).

Table 3. Head Tank Water Quality

Date	TOC mg/L	DOC mg/L	TN mg/L	PN mg/L	DON mg/L	NOx mg/L	NH3 mg/L	TP µg/L	PP µg/L	TDP µg/L	SRP µg/L
9/14/2020	20	20	1.70	0.0	1.30	0.470	< 0.010	148	23	125	108
9/15/2020	20	20	1.60	0.1	1.10	0.420	< 0.010	146	32	114	95
9/16/2020	20	19	1.70	0.2	1.10	0.440	< 0.010	141	32	109	91
9/17/2020	20	20	1.70	0.2	1.10	0.390	< 0.010	134	33	101	88
9/21/2020	22	22	1.60	0.0	1.20	0.440	< 0.010	201	35	166	144
9/22/2020	21	21	1.60	0.1	1.10	0.370	< 0.010	204	39	165	142
9/23/2020	23	21	1.80	0.2	1.20	0.380	< 0.010	184	31	153	136
9/24/2020	22	22	1.90	0.2	1.20	0.510	< 0.010	173	27	146	129
9/30/2020	20	20	1.50	0.2	1.10	0.220	< 0.010	162	43	119	98

Carbon

Total organic carbon was higher in the outflow water than the inflow for all treatments initially and continued for the duration of the study for both Sand and Bold&Gold® CTS (Figure 7). The greatest outflow of TOC occurred 7 days after flow began, with concentrations over 40% higher than inflow in the Bold&Gold® CTS mesocosms. However, after day 7, removal efficiency began to improve with outflow concentrations only 10% higher than inflow by day 20 in the Bold&Gold® CTS mesocosms. The Sand mesocosms varied between 5% and 20% higher outflow concentration than inflow with no temporal trend. The Control had a slight increase in efficiency over time with a small reduction in TOC concentration. The DOC graph had similar trends, as the majority of TOC was DOC. Particulate organic carbon composed a very small percentage of both inflow and outflow concentrations.

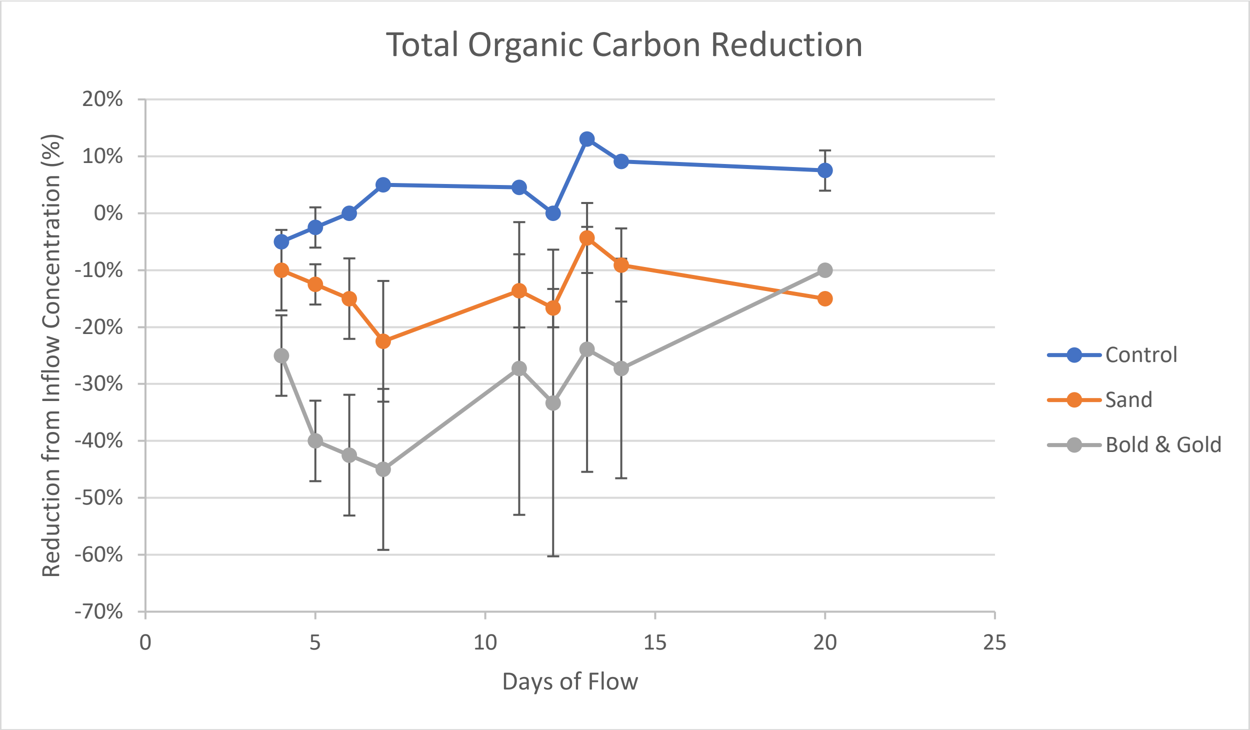

Figure 7. Total Organic Carbon Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

Nitrogen

Bold&Gold® CTS mesocosms had slightly better TN reduction efficiency than Sand and the Control, ranging from 20% to 45% removal (Figure 8). However, there was no clear temporal trend in removal. In fact, removal declined from 39% to 23% during the period when flow was interrupted for 3 days. Sand efficiency declined even more dramatically during this period, decreasing from 29% removal to 10% production. The Control ranged from 9% to 31% removal with no temporal trend.

Particulate nitrogen in the inflow was either not detected or was at very low concentrations (0.1 to 0.2 mg/L). Concentrations in outflow also tended to be very low (Figure 9). There was no difference between treatments, and no temporal trends were noted.

Dissolved organic nitrogen removal was very similar between treatments ranging from 32% reduction to 20% production (Figure 10). No temporal trends were noted.

Nitrate-nitrate reduction was very different between treatments (Figure 11). The Bold&Gold® CTS mesocosms achieved between 95% and 98% reduction for the duration of the study and was not affected by the flow interruption. The Sand treatment, however, was increasing from 0% to 35% removal before the interruption, then falling to over 100% production after the interruption. The Control treatment averaged 56% removal with no temporal trend detected.

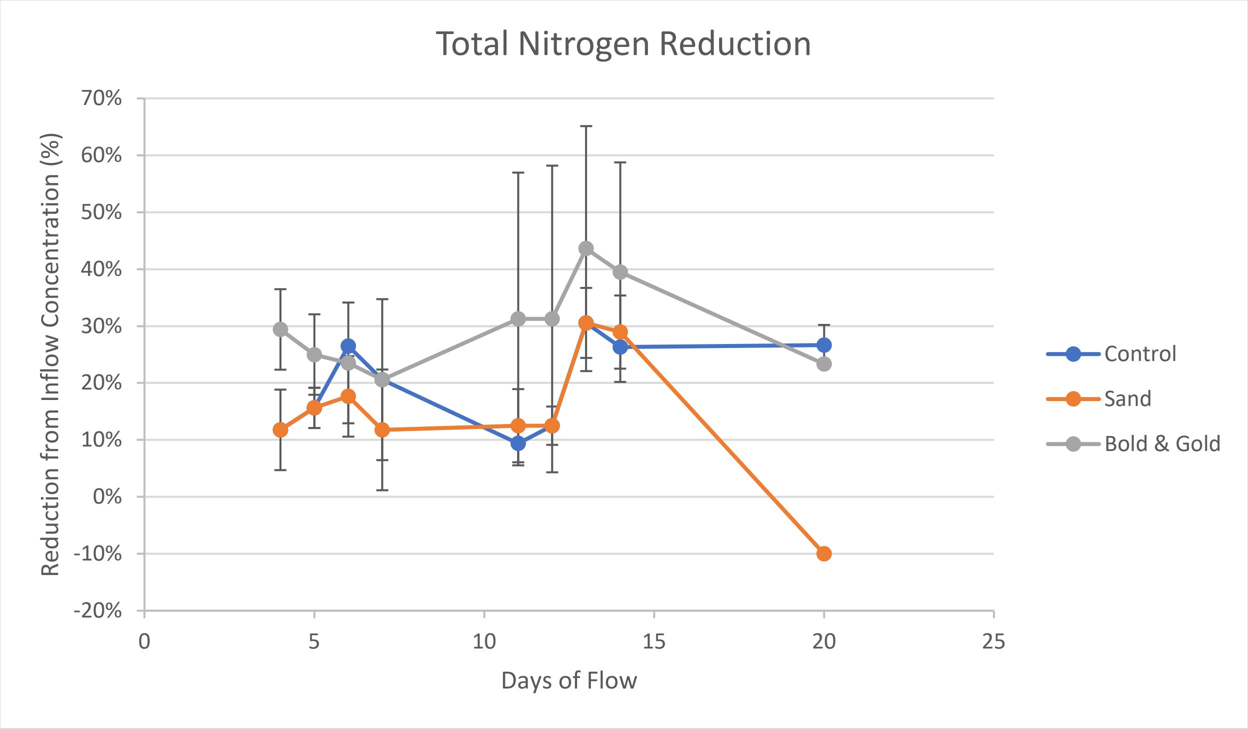

Figure 8. Total Nitrogen Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

Ammonia concentration was below detection in both the inflow and outflow water for most mesocosm tanks for the duration of the study. However, one Bold&Gold® CTS mesocosm produced NH3 concentrations ranging from 0.046 to 0.067 mg/L the first week of sampling, and both Bold&Gold® CTS mesocosms producing concentrations ranging from 0.043 to 0.044 mg/L after the flow disruption, resulting in dramatic % production (Figure 12). The Sand treatment had outflow concentrations below detection until after the flow interruption, when outflow concentration ranged from 0.040 to 0.100 mg/L.

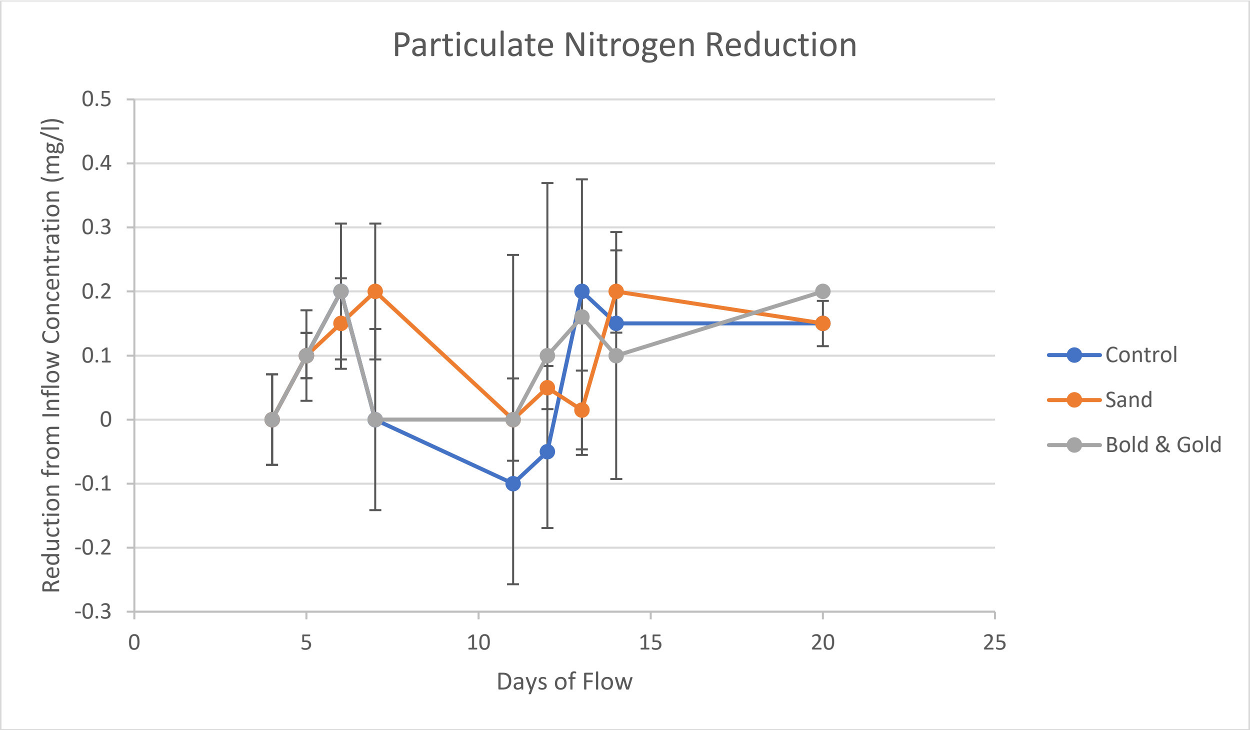

Figure 9. Particulate Nitrogen Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

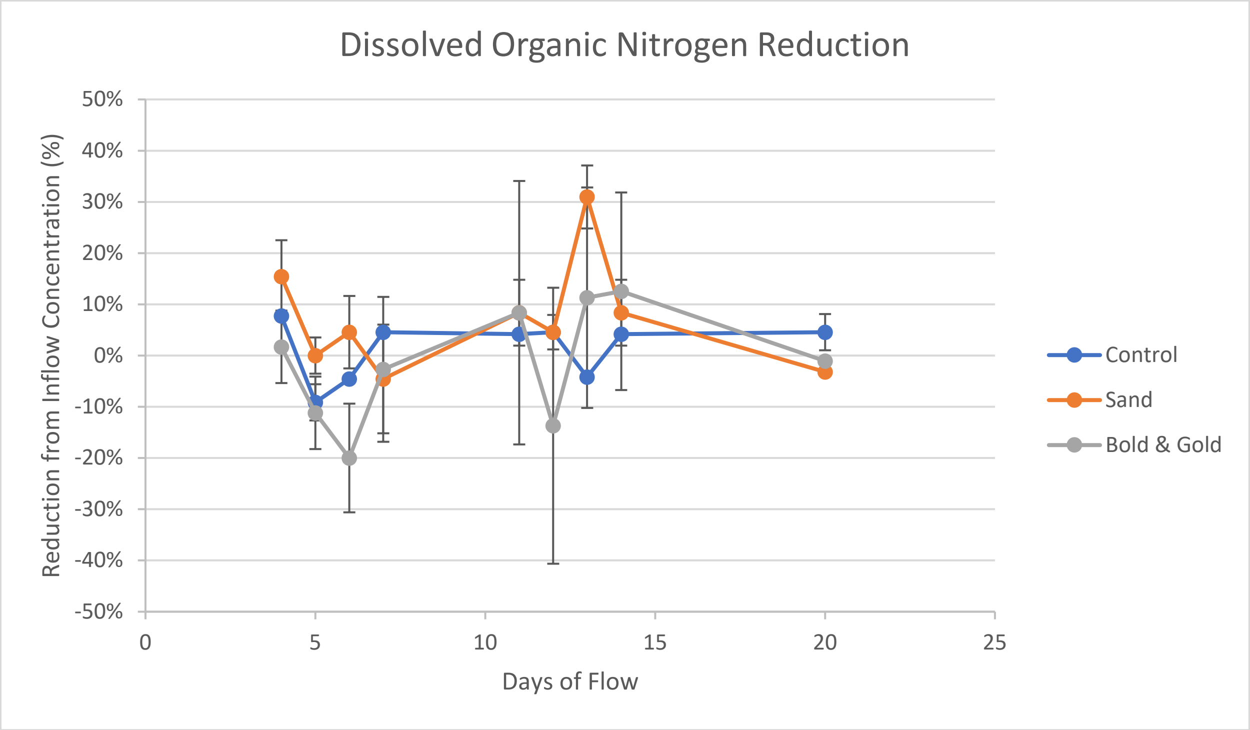

Figure 10. Dissolved Organic Nitrogen Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

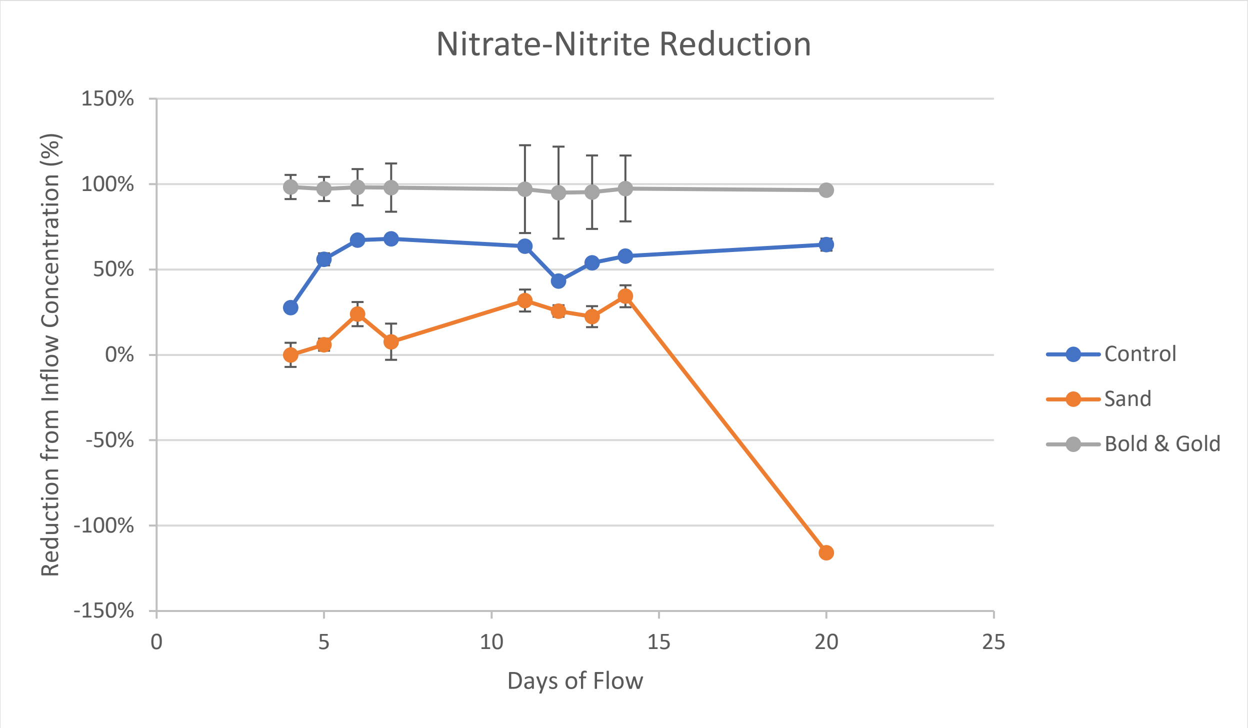

Figure 11. Nitrate-Nitrite Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

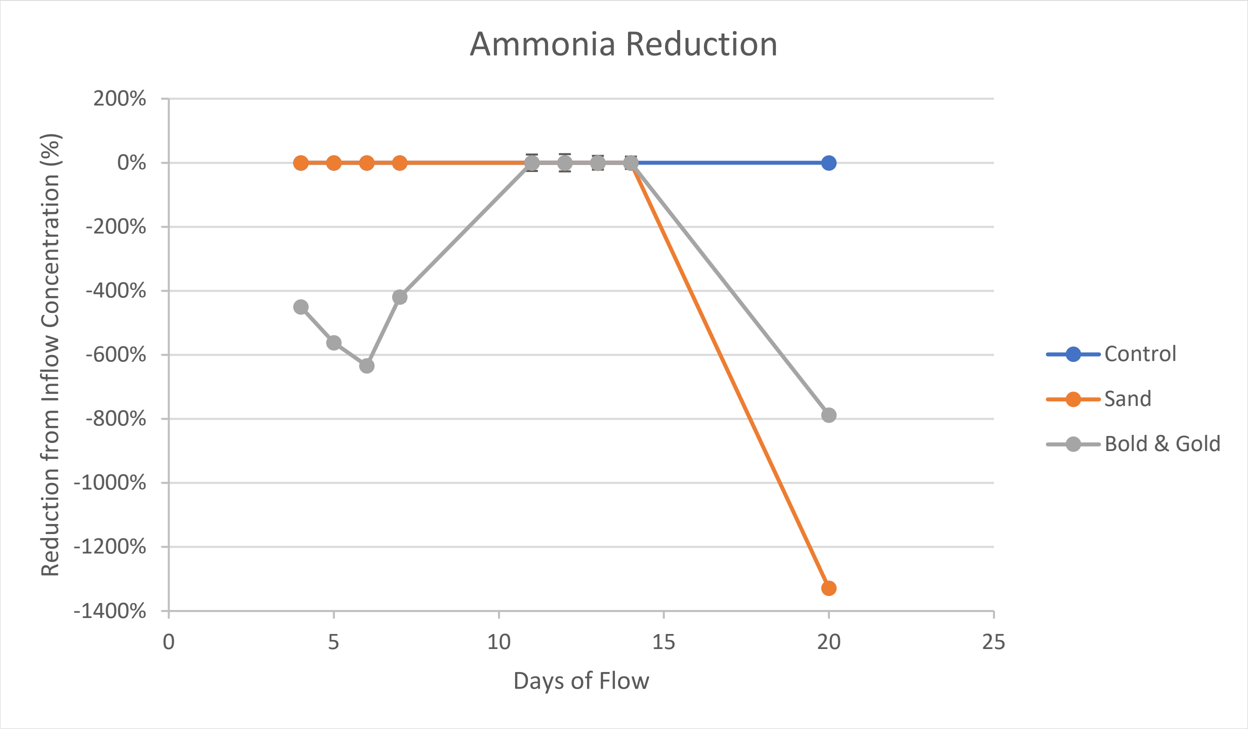

Figure 12. Ammonia Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

Phosphorus

The Sand treatment initially removed TP more efficiently than the Control or Bold&Gold® CTS, but this efficiency declined with time, especially after the flow disruption (Figure 13). The Control TP removal ranged from 27% to 53% of initial concentration, increasing with time. Bold&Gold® CTS mesocosms initially removed very little TP with a small amount of production but then increased to 44% removal before declining back to near 0%.

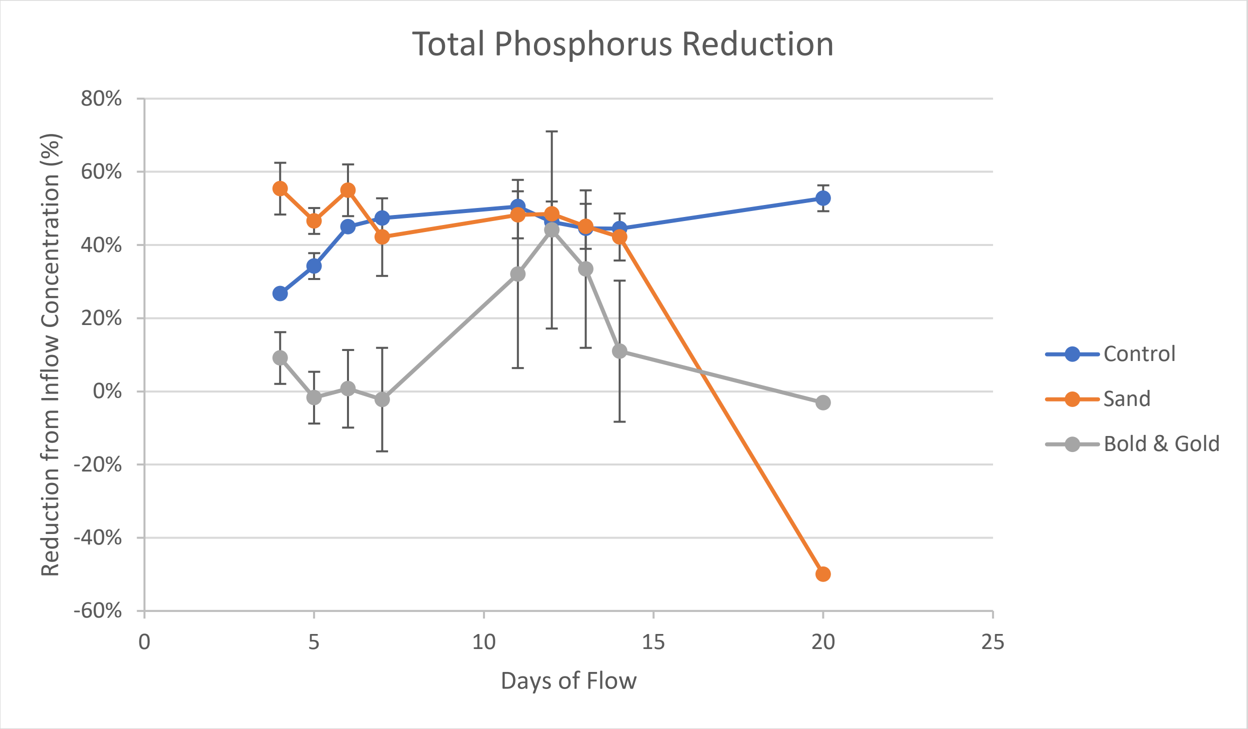

Figure 13. Total Phosphorus Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

Bold&Gold® CTS mesocosms produced PP initially, decreasing in production until the flow disruption (Figure 14). Production ranged from 352% to 60% of initial concentration over the course of the study. The Sand treatment was a little better, with PP production ranging from 22% to 316% of initial concentration and was greatly impacted by the flow disruption. The only treatment to remove PP was the Control, which ranged from 26% to 67% removal increasing over time.

The Sand treatment removed soluble reactive phosphorus (SRP) slightly better than Bold&Gold® CTS initially, but removal efficiency declined with time (Figure 15). Bold&Gold® CTS SRP removal efficiency also declined with time in general, although it was variable. In contrast, the Control treatment SRP removal was low initially, increasing with time such that each treatment removed approximately the same amount of SRP after 20 days of flow.

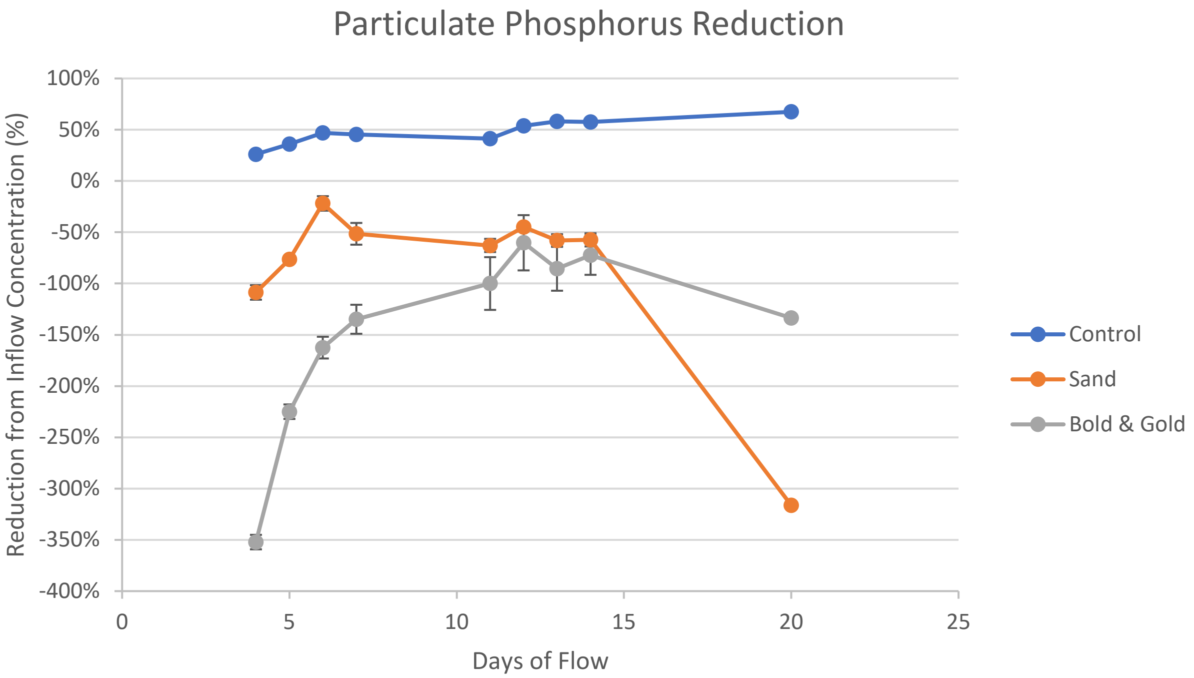

Figure 14. Particulate Phosphorus Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

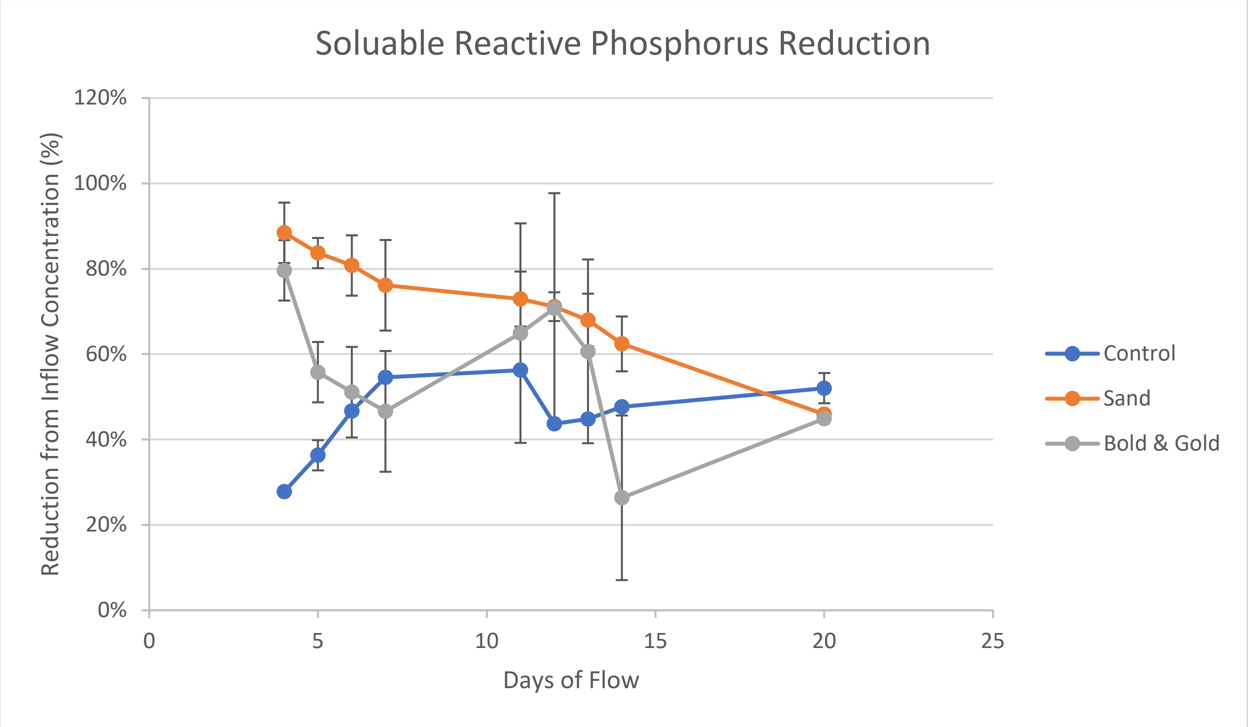

Figure 15. Soluble Reactive Phosphorus Reduction with time. Error bars are one standard deviation. Negative reduction indicates higher outflow concentrations than inflow. Flow disruption occurred between day 15 and 17.

Other Observations

The color of the water from the Bold&Gold® CTS mesocosms was orange, while the other mesocosms was not to the same degree although all tanks had the red river rock (Figure 16). The water also had a strong organic sulfur smell. Sulfur concentration was not measured during this initial phase, but the parameter has been added for the extended phase. In addition, small black specks were occasionally found in the Bold&Gold® CTS samples, most likely from the tire crumb.

Figure 16. Filter after processing a water sample from a Bold&Gold® CTS mesocosm

ALUM JAR TESTS

Alum, at the target dose, was very effective at reducing carbon, nitrogen, and phosphorus concentrations at all three sites (Table 4). Total organic carbon reduction averaged 58%, TN reduction averaged 43%, and TP reduction averaged 90%. Importantly, DON reduction averaged 54%. However, both NOx and NH3 increased in concentration with alum addition. Particulate nitrogen concentration in the inflow water was very low, therefore % reduction could not be consistently calculated. When PN was present, alum addition reduced the concentration on average by 79%.

More detail on the results of the alum jar test is in the appendix. One thing of note is the increase in sulfate and dissolved aluminum concentration after dosing. Sulfate concentrations increased 165% to 484% of initial concentration depending upon site, with Boma having the smallest increase and Hilliard Canal having the largest. Increases in dissolved aluminum were even greater, ranging from 188% of initial concentration at S-77 to 2635% of initial concentration at Hilliard Canal. Another thing of note is the alkalinity of the different sites. Boma and Hilliard has sufficient alkalinity to buffer the pH decline with the addition of alum, while S-77 had much lower alkalinity, limiting its ability to buffer alum addition. During this study, there were no lake releases, meaning Boma water quality represented watershed runoff only.

Table 4. Alum Jar Test % Reduction.

Site	Date	TOC	TN	PN	DON	NOx	NH3	TP	PP	SRP
Boma	9/8/20	54	41	--	57	-10	-25	93	71	99
	9/15/20	48	31	--	60	-2	0	90	58	99
	9/22/20	52	33	--	72	-5	0	94	66	99
Hilliard	9/8/20	50	42	--	43	0	0	67	35	94
	9/15/20	50	37	--	45	-6	-59	91	81	97
	9/22/20	50	27	65	47	-6	-14	92	89	98
S-77	9/8/20	72	56	82	55	-23	-11	95	82	99
	9/15/20	67	61	--	52	-11	-19	90	87	92
	9/22/20	68	57	89	59	-25	-13	94	78	98

CONCLUSION

The mesocosm study has not yet produced definitive results, as results to-date represent start-up conditions only. According to ECS, 90 days of flow are needed to reach optimum removal capacity. However, several important observations were made. Nitrate-nitrite removal in the Bold&Gold® CTS mesocosms was immediate and consistent over time. Because of this, TN removal was slightly higher in the Bold&Gold® CTS mesocosms than the other treatments. Also, the technology appears to be sensitive to changing flow conditions, with declining efficiency after a disruption in flow.

Alum dosing, one the other hand, resulted in high levels of nutrient removal including DON, the dominant form of nitrogen in the C-43 Canal surface water. Of concern, however, is the increase in the highly bioavailable NOx and NH3 concentrations and sulfate and dissolved aluminum concentrations. Based on the EPA's Aquatic Life Criteria spreadsheet model for aluminum toxicity (2020), concentrations in the supernatant (47-251 µg/L, see Appendix) are well below the Criterion Continuous Concentration of 960 µg/L total aluminum calculated using water quality measured at the S-78 structure. Sulfate concentrations are also well below the Florida Drinking water standard of 250 mg/L (FDEP, 2020). Therefore, these residuals are unlikely to be an issue for discharge to the C-43 Canal. One thing to note is that the jar tests were conducted when no lake releases were occurring. The alkalinity of the S-77 samples indicate that alum dosing may have to be reduced during high releases to prevent a dangerous drop in pH.

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APPENDIX

TASK 2: ALUM 'JAR' TESTS SUMMARY REPORT

C-43 Water Quality Alternative Treatment Technology – Pilot Study

October 29, 2020

To: Cassondra Armstrong, South Florida Water Management District

From: DB Environmental

This report was prepared in fulfilment of Work Order 4600004012-WO08

1 Introduction

DB Environmental was retained by the South Florida Water Management District (SFWMD) to perform laboratory trials to evaluate the effectiveness of aluminum sulfate (alum) additions for removing contaminants from three surface waters.

Based on our prior jar testing efforts with south Florida surface waters, aluminum sulfate (alum) generally can be quite effective for removing both phosphorus (P) and nitrogen (N). Successful use of alum, however, does require that the water source contain at least moderate alkalinity concentrations, since alkalinity is consumed during the coagulation process when alum, an acidic substance, is added. Water pH levels therefore can decline markedly in waters with low alkalinity in response to alum additions.

Another general observation is that coagulant additions are broadly effective for P removal, but N removal effectiveness is strongly influenced by speciation. For example, even though ammonia/ammonium (NH_x-N) and nitrate + nitrate (NO_x-N) are readily removed in most treatment wetland configurations, neither are appreciably removed by the chemical coagulation process. By contrast, particulate N is readily removed, and dissolved organic N exhibits moderate removal by chemical coagulation.

This report provides a summary of the effectiveness of alum for removing P, N and other constituents from three south Florida surface waters, each provided on three separate collection dates in September 2020.

2 Methods

Bench-scale amendment dosing trials, commonly referred to as jar tests, were conducted for surface waters collected by SFWMD personnel from three sites in South Florida: BOMA; Hilliard Canal at SR 80; and S-77.

Source waters for the jar tests were delivered to DBE's laboratory by SFWMD personnel during three consecutive weekly events. Collection dates were 9/8/20, 9/15/20 and 9/22/20. The collection vessels (two 5 gal. plastic buckets for each site) were transported to DBE's laboratory on the day of collection, with covers provided to avoid direct exposure to sunlight. The buckets were refrigerated upon receipt at the lab, and stored at ≤ 6 °C. The buckets were brought to room temperature prior to subsampling for jar testing.

Each initial water ("raw water") was analyzed for total kjeldahl nitrogen (TKN), dissolved TKN, NO_x-N, NH_x-N, total P (TP), total dissolved P (TDP), soluble reactive P (SRP), total organic carbon (TOC), dissolved organic carbon (DOC), sulfate (SO_4) and total dissolved aluminum (Al). All chemical analyses were performed according to standard methods documented in the DBE Quality Assurance Plan. Raw waters were also analyzed for pH (Thermo Orion A121), turbidity (HACH Turbidimeter Model 2100P), alkalinity (HACH Digital Titrator with 0.16N H2SO4 titrant), and temperature.

Jar tests were conducted for each of the three water collection events, with starting dates of 9/10/20, 9/17/20 and 9/24/20. A modified version of ASTM D2035-19 was followed for the jar testing. Testing for each event included an initial "range finding" phase, followed by testing of the target, or "optimal", alum dose.

The jar tests were conducted in 3.5L-capacity clear plastic (acrylic) square-sided containers, which were filled with untreated site water ("raw water") prior to addition of aluminum sulfate (alum) at specified doses. Alum additions were made to 2L aliquots of each of the source waters, using small volumes of a 10,000 mg Al/L stock alum solution. The stock solution was prepared from reagent grade $Al_2(SO_4)_3 \cdot 18H_20$ (Al sulfate octadecahydrate). Following alum addition, the contents of each container was stirred using a Phipps & Bird Stirrer (model 7790-400) at 120 rpm for one minute (fast mix), then 20 rpm for 20 minutes (slow mix) (Photo 1).

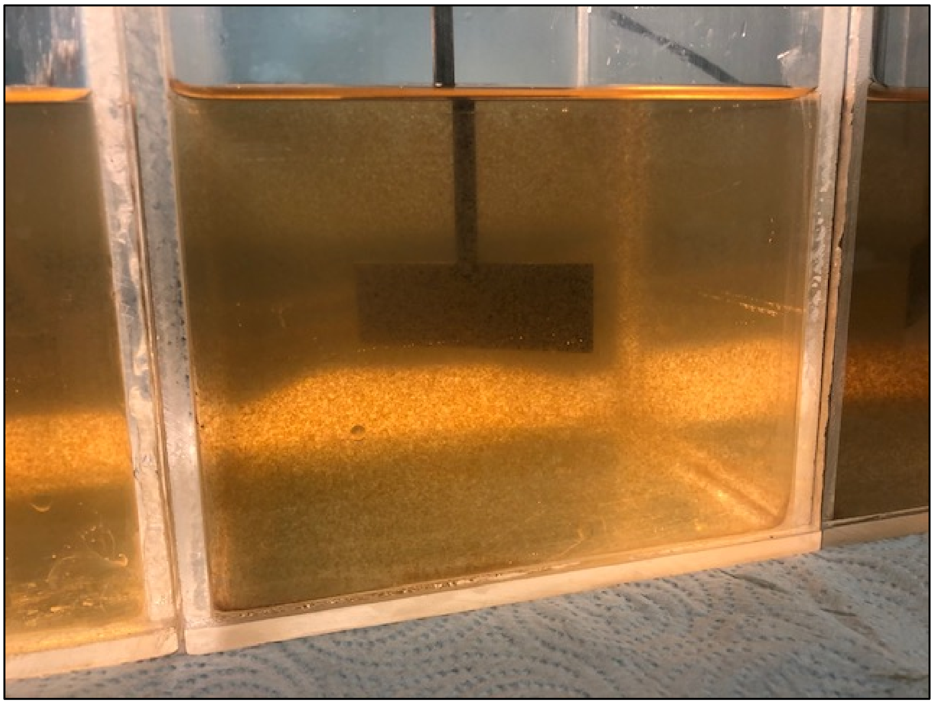

Photo 1. Floc formation during the slow mixing phase of a jar test.

The floc that formed during stirring subsequently was allowed to settle. Settling times ranged from 40 to 100 minutes, depending on floc quality and clarity of the supernatant. After settling, samples were collected from the supernatant solution for analysis of all, or a subset, of the analytes listed above (see below for more detail).

For the range-finding phase of the tests a range of alum doses (> 4 doses, varying from 4 to 20 mg/L, with no replication) was used to determine the optimal dose for each site and event, based on a visual assessment of floc formation and settling characteristics. For each range finding test, the low end of the alum dose range was chosen by selecting the minimum Al concentration that appeared to stimulate discernable floc production. Following settling, supernatant water in the containers with the four most effective dose responses was sampled and analyzed for TP, TKN, TOC, as well as pH, alkalinity, turbidity and temperature. This was followed by testing of the target alum dose (again, based on visual observations of the floc and supernatant, as well as pH levels) for each of the three site waters, which was conducted in duplicate vessels. After floc settling of target doses was complete, the supernatant water was sampled and analyzed for TKN, dissolved TKN, NO_x-N, NH_x-N, TP, TDP, SRP, TOC, DOC, SO_4 and total dissolved Al, along with pH, alkalinity, turbidity and temperature.

3 Synopsis of Findings

The BOMA and Hilliard Canal waters are representative of “high” alkalinity surface waters in the region, while the S-77 water is relatively low in alkalinity (mean values of 185, 191 and 67 mg [as $CaCO_3$]/L, respectively, for the three sampling events in this study) (Table 1).

3.1 BOMA Waters

BOMA waters were the most P enriched (mean TP of 162 µg/L) of the three waters evaluated in this study, and second-most N enriched (1.75 mg/L). BOMA water also exhibited the highest NO_x-N concentration, with this constituent comprising 32% of the TN, on average (Tables 1 through 3).

The range finding component of the jar test (Photo 2) revealed widely different responses by the various supernatant constituents (e.g, P, N and C) to alum dose (Figure 1). Alum doses in the range of 10-14 mgAl/L removed 90% of the TP, whereas the maximum observed percentage TKN removal was 51%, observed at a dose of 12 mgAl/L. TOC behaved in a fashion similar to TKN, with a maximum observed percentage removal of 55%. The increase in TOC removal with increasing alum dose is depicted by the changes in supernatant color in Photo 2.

Following floc settling, supernatant pH generally remained above 6.4 at the highest alum doses, and despite a slight decline in alkalinity with increasing alum dose, this parameter generally remained above 100 mg [as $CaCO_3$]/L (Figure 2).

It should be noted that higher aluminum sulfate doses (the alkalinity of BOMA waters is high enough to support much higher alum dosages than performed in this study), the use of a different coagulant than alum, and/or use of coagulant aids (e.g., polymers) might change the P, N and C removal effectiveness from that observed in this series of tests.

Following range finding, dosing of the target or optimal concentration (again, based on visual aspects of the floc and supernatant) was performed using duplicate vessels. For BOMA waters, target doses for Events 1, 2 and 3 were 12, 10 and 14 mgl/L. Effective removal of all P species (SRP, dissolved organic P [DOP], particulate P [PP]) was achieved in all events, with effectiveness of removal varying in the order SRP > DOP > PP (Figure 3). Particulate P is associated with very fine particles that don't immediately settle, suggesting that even further PP reductions might be possible with supplemental back-end sedimentation and/or filtration. As expected, essentially no removal of dissolved inorganic N species (NO_x-N and NH_x-N) was observed for the BOMA waters at any of the applied alum doses (Figure 4). Therefore, all the TN removal observed in the jar tests represents organic N removal, as reflected in the TKN reduction values.

Also, as expected, increases in sulfate and dissolved aluminum were observed as a consequence of the alum additions (Figure 5). Sulfate would be expected to remain in solution for the long-term, whereas the dissolved aluminum may partition to solids over time and settle out, depending on the pH of the solution.

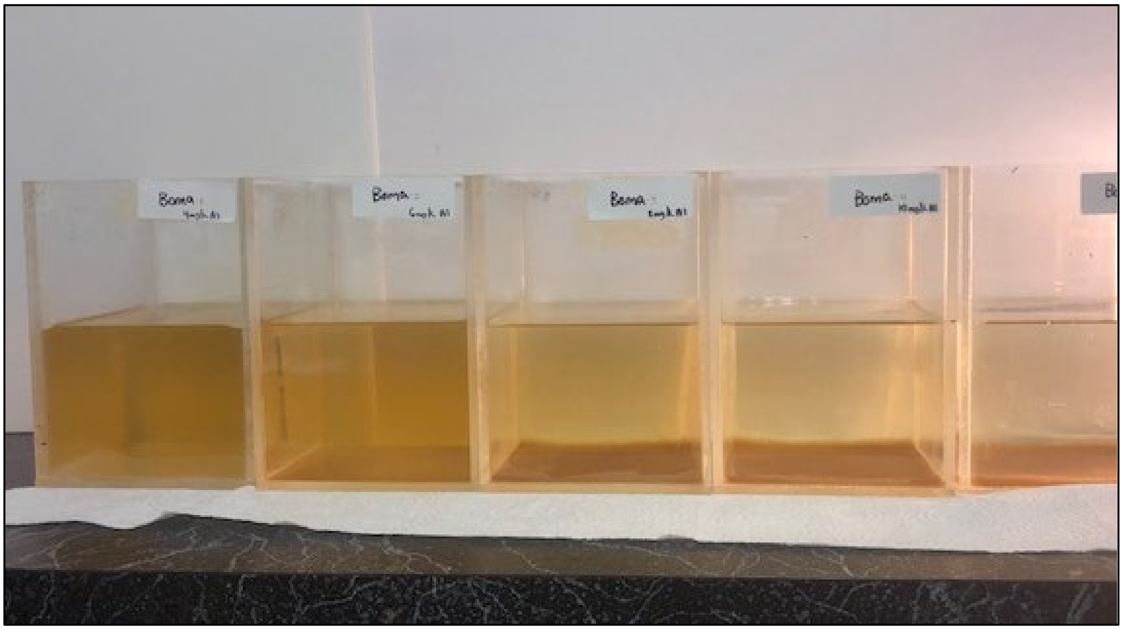

Photo 2. Reduction in water color, and increase in quantity of settled floc, for BOMA waters dosed with increasingly higher alum doses (8, 10, 12, 14, 16 mgAl/L, from left to right).

3.2 Hilliard Canal Waters

Hilliard canal waters contained the lowest concentrations of both P (mean TP of 69 µg/L) and N (mean TN of 1.40 mg/L) of the three waters evaluated in this study. TP and TN concentratons also varied over time, gradually increasing among the three sampling events. N speciation also changed with time, with inorganic N species comprising only 1% of TN during the first event, but 27% during the third event (Tables 1 through 3).

As observed with the BOMA waters, the range finding component of the jar test revealed widely different responses by the various supernatant constituents (e.g, P, N and C) to alum dose (Figure 6). Alum doses in the range of 10-14 mgAl/L removed 82-93% of the TP, whereas the maximum percentage TKN removal was 46%, observed at a doses of 14-16 mgAl/L. TOC behaved in a fashion similar to TKN, with a maximum observed removal of 55% in the same dose range.

Following floc settling, supernatant pH generally remained above 6.4 at the highest alum doses, and despite a slight decline in alkalinity with increasing alum dose, this parameter remained above 113 mg/L (Figure 7).

It should be noted that higher aluminum sulfate doses (the alkalinity of Hilliard waters is high enough to support much higher alum dosages than performed in this study), the use of a different coagulant than alum, and/or the use of coagulant aids (e.g., polymers) might change the P, N and C removal effectiveness from that observed in this series of tests.

Following range finding, dosing of the target or optimal concentration (again, based on visual aspects of the floc and supernatant) was performed using duplicate vessels. For Hilliard waters, target doses for Events 1, 2 and 3 were 14, 12 and 12 mgl/L. Effective removal of all P species (SRP, DOP, PP) was achieved in all events, with effectiveness of removal varying in the order SRP > DOP > PP (Figure 8). The high spike in PP noted for replicate 1, Event 1 (Figure 8) accounts for the higher TP value noted for this particular test/replicate (Figure 6). Particulate P is associated with fine particles and can remain suspended long into the settling period, suggesting that even further PP reductions might be possible with supplemental back-end sedimentation and/or filtration. As noted for the BOMA waters, essentially no removal of dissolved inorganic N species (NO_x-N and NH_x-N) was observed for the Hilliard waters at any of the applied alum doses (Figure 9). Therefore, all the TN removal observed in the jar tests represents organic N removal, as reflected in the TKN reduction values. The decreasing effectiveness of TN reductions from Events 1 through 3 is related in part to reduced TKN (likely organic N) removal, but also to the increased levels of inorganic N species over time in the raw water (Table 2).

Increases in sulfate and dissolved aluminum were observed as a consequence of the alum additions (Figure 10). Sulfate would be expected to remain in solution for the long-term, whereas the dissolved aluminum may partition to solids over time and settle out, depending on the pH of the solution.

3.3 S-77 Waters

S-77 waters were the second-most P enriched (mean TP of 108 µg/L) of the three waters evaluated in this study, and most N enriched (1.79 mg/L). Dissolved inorganic N species (NO_x-N + NH_x-N) were a minor component, ranging from 9-11% among the three events, of TN in the S-77 waters (Tables 1 through 3).

As observed with the BOMA and Hilliard waters, the range finding component of the jar test revealed widely different responses by the various supernatant constituents (e.g, P, N and C) to alum dose (Figure 11). Alum doses in the range of 10-12 mgAl/L removed >90% of the TP and 58-63% of the TKN. TOC exhibitied a maximum observed removal in the range of 62-71%.

The alkalinity of the raw S-77 water was low, averaging 67 mg [as $CaCO_3$]/L, and this led to a marked decline in both alkalinity and pH of the supernatants in response to alum dosing (Figure 12). Another interesting aspect of the range finding was the high turbidity observed (Photo 3) at the lower doses (6 – 8 mgAl/L). This corresponded with elevated PP and TP levels (Figures 10 and 13).

It should be noted that due to the low native alkalinity, aluminum sulfate doses higher than 14 mgAl/L would unlikely provide greater levels of contaminant reduction with S-77 waters. However, the use of a different coagulant than alum, and/or use of coagulant aids (e.g., polymers) might change the P, N and C removal effectiveness from that observed in this series of tests.

Following range finding, dosing of the target or optimal concentration (again, based on visual aspects of the floc and supernatant) was performed using duplicate vessels. For S-77 waters, a target dose of 12 mgAl/L was selected for all three events. Effective removal of all P species (SRP, DOP, PP) was achieved in all events, with extremely low concentrations attained for both SRP and DOP (Figure 13). Modest levels of PP were detected in the supernatant, which potentially could be further reduced with supplemental back-end sedimentation and/or filtration. As expected, essentially no removal of dissolved inorganic N species (NO_x-N and NH_x-N) was observed for the S-77 waters at any of the applied alum doses (Figure 14). Therefore, all the TN removal observed in the jar tests represents organic N removal, as reflected in the TKN reduction values.

As noted with the BOMA and Hilliard waters, increases in sulfate and dissolved aluminum were observed as a consequence of the alum additions (Figure 15). Low pH conditions can lead to increased dissolved Al concentrations, and this is evidenced by the higher concentrations of this constituent in Event 1 vs Events 2 and 3 (Figures 12 and 15).

3.4 Observations on Maximizing Nutrient Removal with Minimal Coagulant Use

A principal goal of jar testing is to determine the minimum alum dose that attains constituent mass removal and/or outflow concentration targets. It is notable that the contaminant removal response to coagulant dose typically is not linear. Using the S-77 Event 3 water test as an example (Figure 11), a dose of 6 mgAl/L provided minimal TP (10%) and TKN (24%) removal, but only a slight alum dose increase of 2mgAl/L (to 8 mgAl/L) provided markedly higher TP (80%) and TKN (48%) percentage removal rates. The visual differences between these doses is depicted in Photo 3. If these supernatant concentration and/or percentage reduction levels meet project targets, then an alum dose of 8 mgAl/L would be selected for use in an operational chemical-based treatment system for this particular water (recognizing that temporal changes in water chemistry may necessitate modifications in coagulant dosing rates over time).

Surface waters with low alkalinities, such as S-77 waters, can be constrained in the magnitude of the alum doses used to achieve coagulation/flocculation. For example, during Event 1, even the lowest alum dose applied (8 mg/L) resulted in a pH of 5.7, which is below the pH criterion for Class III waters. In practice, a pH in the low to mid-5 range during coagulation/flocculation is unlikely to be problematic, as long as there is a reasonable downstream retention time in the treatment system prior to discharge to surface waters, since the pH would tend to become more circumneutral over time. However, it is important to recognize that alkalinity/pH conditions indeed are potentially constraining parameters to the use of alum.

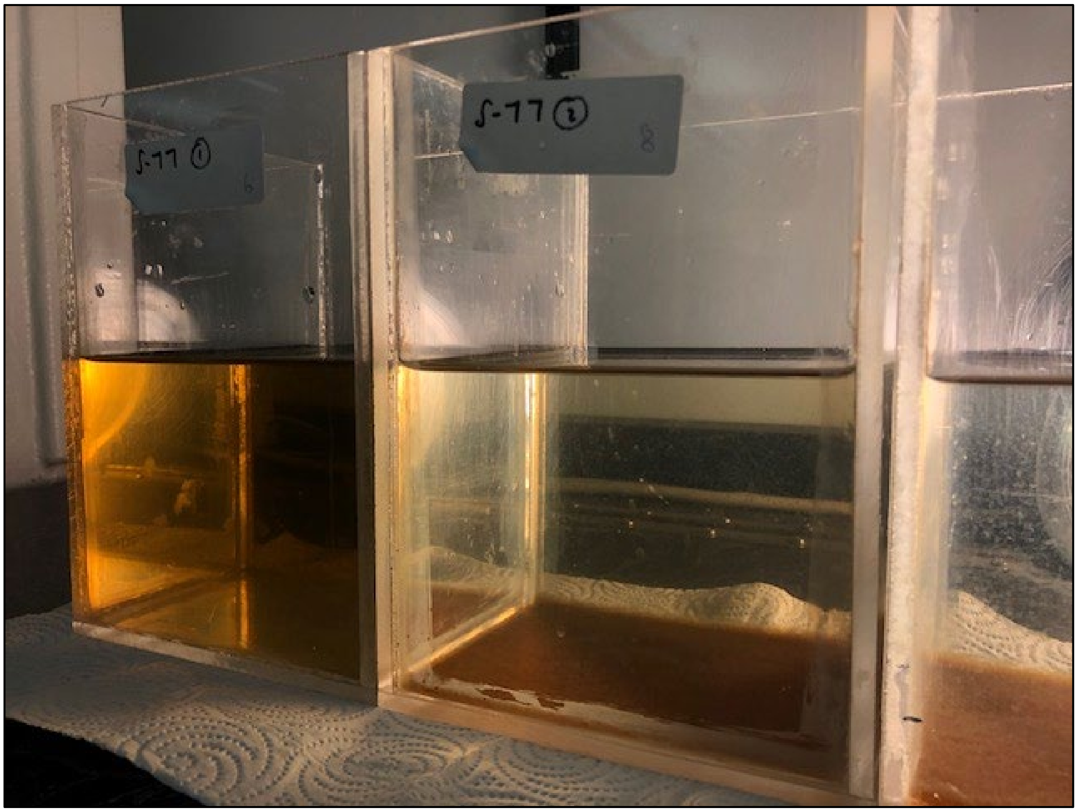

Photo 3. Settled S-77 waters during Event 3, dosed with 6, 8 and 10 mgAl/L (from left to right).

One approach that can improve P and N removal for a given amount of alum applied in any water type, as well as ameliorate some of the constraints imposed by low alkalinity waters, is to lower the "effective" alum dose through recycling of previously-formed flocs. Because the effectiveness of this approach depends on water type, as well as the contaminant of interest, two jar test assessments were performed following the Event 2 and 3 "target-dose" tests to assess the utility of this technique.

The first assessment of previously-formed flocs was performed upon completion of the Event 2 target-dose testing. The supernatant water resulting from target dosing was carefully decanted from the duplicate containers upon completion of the tests, leaving only the settled floc that had formed as a result of the prior alum application. This "previously-formed" floc was used to treat a new 2L aliquot of site water, with no further addition of fresh alum to the container. After addition of the new aliquot of water, the water and previously-formed flocs were slow-mixed for 3 minutes, and then allowed to settle. After floc settling was complete, the supernatant water was sampled and analyzed for pH and TP. This process is depicted in Photo 4. A similar trial was conducted upon completion of Event 3 target dose testing, using only S-77 waters. For this latter effort, pH, TP, TKN and TOC were analyzed in the supernatant waters.

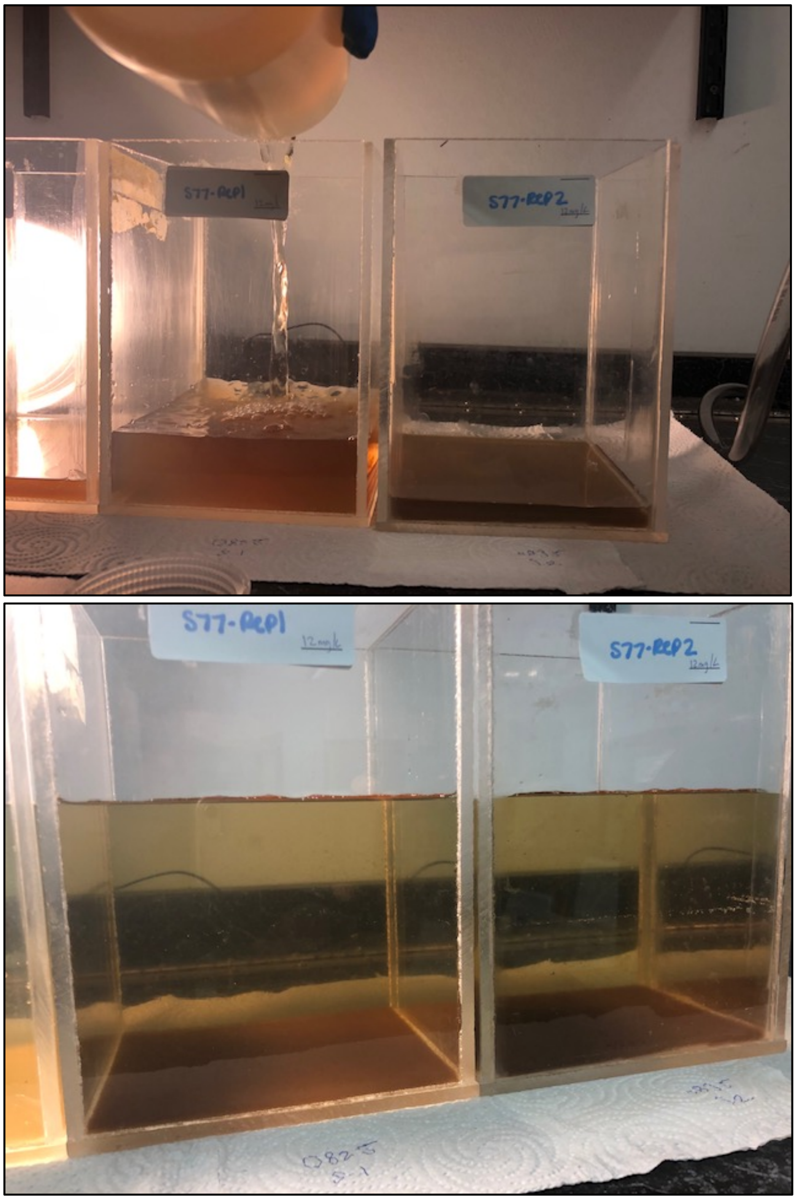

Photo 4. Following the Event 3 target dose testing with S-77 waters, the supernatant was carefully siphoned away, leaving the previously formed floc on the bottom of the two vessels. The right-hand vessel (top photo) depicts the residual floc with the supernatant removed. In the left-hand vessel, a new 2L aliquot of site water is being added to the thin layer of settled floc. Both vessels were filled, and after a 3-minute slow mix period, the floc was again allowed to settle (bottom photo).

Results of the use of “previously-formed” or recycled floc for nutrient removal are depicted in Table 4 and Figures 16 and 17. For the first trial, (Event 2), in which BOMA, Hilliard and S-77 waters were evaluated for pH changes and the TP removal effectiveness of their previously settled flocs, all water types exhibited additional TP removal (ranging from 32 to 49%) with a minimal suppression of raw water pH. For the second trial, using the previously-formed floc from only the S-77 waters (Event 3), percentage reductions of TP, TKN and TOC averaged 60%, 18% and 4%, respectively, with no suppression of pH. The effectiveness of this approach can be clarified by comparing the TP and TKN removal achieved by the 6mgAl/L alum dose (10% TP reduction and 24% TKN reduction) (Figure 17) with the combined percentage removal provided by the target dose of 12 mgAl/L (93.5% TP and 61.5% TKN) and the recycling of the previously formed floc (0 mgAl/L addition, 60%TP and 18% TKN reduction). In both cases, a net “effective” dose of 6 mgAl/L (6 mg/L in one case, (12+ 0)/2 mg/L in the latter case) is utilized, but with floc recycling, the resulting TP and TKN removal is markedly increased (77% TP and 40% TKN reduction).

Floc reuse, through processes such as intermittent dosing and blending of dosed and un-dosed water parcels, is one of the core optimization approaches utilized in the “front-end” of HWTT systems, and indeed is a concept protected by several U.S. patents[1]. This approach provides a clear, direct benefit in that it increases the mass of nutrients that can be removed per unit volume of coagulant, and further, results in lower aluminum and sulfate inputs for a given mass of nutrient removed. An additional benefit is that for a given mass of nutrients removed, there is a lower volume of residuals formed. It should be noted that in an operational setting, this requires careful real-time monitoring to be successful. Indeed, the changes in characteristics observed for the BOMA, Hilliard and S-77 waters over a period of just a few weeks in September suggest temporal changes in water chemistry at these sites can be dramatic, a factor that in turn would necessitate temporal (likely real-time) adjustments to target alum doses.

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[1] US Patents 7,014,776 B1 and US 7,510,660 B1

Table 1. Jar test results for the BOMA site. Raw site water was subjected to a “range-finding” trail, and a separate, replicated “target dose” trial.

Event	Date	Component	Rep	mg Al/L Dose	µg/L TP	µg/L TDP	µg/L SRP	µg/L DOP	µg/L PP	mg/L TN	mg/L TKN	mg/L Diss TKN	mg/L NOx-N	mg/L NHx-N	mg/L TOC	mg/L DOC	mg/L Sulfate	µg/L Diss Al	units pH	mg/L Alkalinity	NTU Turbidity
1	9/10/20	Raw Water		0	176	150	130	20	26	1.76	1.50	1.40	0.260	0.026	24	23	25	14	7.66	163	1.94
1	9/10/20	Range Finding		8	43						1.00				15				6.56	122	2.97
1	9/10/20	Range Finding		10	16						0.92				12				6.50	113	1.16
1	9/10/20	Range Finding		12	10						0.83				11				6.40	99	0.81
1	9/10/20	Range Finding		14	8						0.75				10				6.34	94	0.71
1	9/10/20	Target dose	1	12	12	4	<2	3	8	1.03	0.74	0.78	0.290	0.033	11	11	90	90	6.44	103	0.89
1	9/10/20	Target dose	2	12	11	4	<2	3	7	1.04	0.76	0.78	0.280	0.032	11	10	90	123	6.49	104	0.80
2	9/17/20	Raw Water		0	131	112	95	17	19	1.76	1.30	1.20	0.460	<0.0098	21	20	33	10	7.59	180	1.45
2	9/17/20	Range Finding		6	40						0.94				15				6.78	146	2.93
2	9/17/20	Range Finding		8	20						0.84				12				6.69	136	1.54
2	9/17/20	Range Finding		10	12						0.72				11				6.59	124	1.04
2	9/17/20	Range Finding		12	12						0.66				10				6.52	115	1.02
2	9/18/20	Target dose	1	10	13	4	<2	3	9	1.20	0.73	0.72	0.470	<0.0098	11	10	87	144	6.82	128	1.12
2	9/18/20	Target dose	2	10	12	5	<2	4	7	1.24	0.77	0.81	0.470	<0.0098	11	11	88	129	6.83	127	0.93
3	9/24/20	Raw Water		0	181	162	144	18	19	1.74	1.30	1.30	0.440	<0.0098	22	21	35	9	7.74	211	1.95
3	9/24/20	Range Finding		8	41						0.96				15				6.73	173	2.42
3	9/24/20	Range Finding		10	28						0.88				14				6.67	160	2.01
3	9/24/20	Range Finding		12	22						0.82				12				6.58	151	1.86
3	9/24/20	Range Finding		14	18						0.73				11				6.51	140	1.78
3	9/25/20	Target dose	1	14	11	4	<2	3	7	1.18	0.72	0.68	0.460	<0.0098	10	10	120	109	6.89	140	0.84
3	9/25/20	Target dose	2	14	10	4	<2	3	6	1.15	0.69	0.73	0.460	<0.0098	11	10	120	<6.8	6.94	139	0.75

Table 2. Jar test results for the Hilliard canal site. Raw site water was subjected to a "range-finding" trail, and a separate, replicated "target dose" trial.

				mg Al/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	units	mg/L	NTU
Event	Date	Component	Rep	Dose	TP	TDP	SRP	DOP	PP	TN	TKN	Diss TKN	NOx-N	NHx-N	TOC	DOC	Sulfate	Diss Al	pH	Alkalinity	Turbidity
1	9/10/20	Raw Water		0	56	31	16	15	25	1.11	1.10	1.10	<0.016	<0.0098	20	19	16	<6.8	7.68	195	1.19
1	9/10/20	Range Finding		10	10						0.77				12				6.57	149	0.85
1	9/10/20	Range Finding		12	8						0.64				10				6.55	138	0.75
1	9/10/20	Range Finding		14	9						0.63				10				6.45	127	0.71
1	9/10/20	Range Finding		16	6						0.59				9				6.39	119	0.64
1	9/10/20	Target dose	1	14	31	3	<2	2	28	0.63	0.62	0.60	<0.016	<0.0098	10	9	95	80	6.49	129	0.65
1	9/10/20	Target dose	2	14	6	<3	<2	1	5	0.65	0.64	0.65	<0.016	<0.0098	10	10	92	106	6.68	129	0.66
2	9/17/20	Raw Water		0	74	48	32	16	26	1.47	1.30	1.20	0.170	0.047	20	19	20	<6.8	7.59	182	1.33
2	9/17/20	Range Finding		8	16						0.90				12				6.69	139	1.32
2	9/17/20	Range Finding		10	10						0.88				11				6.59	132	0.91
2	9/17/20	Range Finding		12	8						0.78				10				6.47	123	0.82
2	9/17/20	Range Finding		14	7						0.70				9				6.43	113	0.88
2	9/18/20	Target dose	1	12	7	<3	<2	1	6	0.92	0.74	0.78	0.180	0.070	10	10	86	88	6.74	122	0.68
2	9/18/20	Target dose	2	12	6	<3	<2	1	5	0.94	0.76	0.72	0.180	0.079	10	9	87	92	6.75	122	0.61
3	9/24/20	Raw Water		0	76	56	45	11	20	1.62	1.30	1.20	0.320	0.110	20	19	28	11	7.63	196	0.98
3	9/24/20	Range Finding		8	13						0.94				12				6.68	151	1.17
3	9/24/20	Range Finding		10	9						0.87				11				6.61	144	0.97
3	9/24/20	Range Finding		12	6						0.83				10				6.54	136	0.78
3	9/24/20	Range Finding		14	5						0.82				9				6.46	124	0.72
3	9/25/20	Target dose	1	12	6	<3	<2	1	5	1.18	0.84	0.81	0.340	0.120	10	10	93	119	6.93	133	0.61
3	9/25/20	Target dose	2	12	6	6	<2	5	0	1.18	0.84	0.80	0.340	0.130	10	10	94	106	6.97	132	0.55

Table 3. Jar test results for the S-77 site. Raw site water was subjected to a “range-finding” trail, and a separate, replicated “target dose” trial.

Event	Date	Component	Rep	mg Al/L Dose	µg/L TP	µg/L TDP	µg/L SRP	µg/L DOP	µg/L PP	mg/L TN	mg/L TKN	mg/L Diss TKN	mg/L NOx-N	mg/L NHx-N	mg/L TOC	mg/L DOC	mg/L Sulfate	µg/L Diss Al	units pH	mg/L Alkalinity	NTU Turbidity
1	9/10/20	Raw Water		0	149	115	87	28	34	1.93	1.90	1.60	0.030	0.180	32	30	16	32	7.15	55	2.57
1	9/10/20	Range Finding		8	59						1.30				21				5.74	20	11.00
1	9/10/20	Range Finding		10	12						0.94				11				5.46	12	2.58
1	9/10/20	Range Finding		12	9						0.80				9				5.04	5	2.66
1	9/10/20	Range Finding		14	10						0.80				9				4.43	1	3.61
1	9/10/20	Target dose	1	12	8	<3	<2	1	7	0.82	0.78	0.75	0.037	0.200	9	8	81	251	5.17	5	1.79
1	9/10/20	Target dose	2	12	7	<3	<2	1	6	0.86	0.82	0.75	0.037	0.200	9	8	80	246	5.13	5	1.64
2	9/17/20	Raw Water		0	70	29	12	17	41	1.66	1.60	1.20	0.056	0.086	21	21	22	17	7.36	71	4.14
2	9/17/20	Range Finding		6	34						1.20				19				6.33	37	8.49
2	9/17/20	Range Finding		8	15						0.75				11				6.10	36	2.18
2	9/17/20	Range Finding		10	8						0.68				8				5.86	26	1.18
2	9/17/20	Range Finding		12	7						0.62				7				5.62	16	1.40
2	9/18/20	Target dose	1	12	8	<3	<2	1	7	0.66	0.60	0.63	0.062	0.110	7	7	86	54	5.82	16	1.18
2	9/18/20	Target dose	2	12	6	<3	<2	1	5	0.63	0.57	0.60	0.062	0.095	7	6	92	47	5.80	16	1.09
3	9/24/20	Raw Water		0	106	83	64	19	23	1.79	1.70	1.30	0.088	0.087	25	26	17	17	7.29	74	1.26
3	9/24/20	Range Finding		6	95						1.30				25				6.27	47	10.90
3	9/24/20	Range Finding		8	21						0.88				13				6.07	41	3.57
3	9/24/20	Range Finding		10	8						0.71				10				5.88	29	1.49
3	9/24/20	Range Finding		12	5						0.63				8				5.96	18	1.26
3	9/25/20	Target dose	1	12	7	<3	<2	1	6	0.77	0.66	0.62	0.110	0.100	8	7	84	50	6.08	19	1.03
3	9/25/20	Target dose	2	12	6	<3	<2	1	5	0.76	0.65	0.60	0.110	0.097	8	8	83	48	6.10	19	0.96

Table 4. Results of floc recycle tests during Events 2 and 3.

Station	Event	Date	Component	Rep	mg Al/L Dose	µg/L TP	units pH	mg/L TKN	mg/L TOC
BOMA	2	9/17/20	Raw Water		0	131	7.59	---	---
BOMA	2	9/17/20	Range Finding		6	40	6.78	---	---
BOMA	2	9/17/20	Range Finding		8	20	6.69	---	---
BOMA	2	9/17/20	Range Finding		10	12	6.59	---	---
BOMA	2	9/17/20	Range Finding		12	12	6.52	---	---
BOMA	2	9/18/20	Target dose	1	10	13	6.82	---	---
BOMA	2	9/17/20	Target dose	2	10	12	6.83	---	---
BOMA	**2**	**9/18/20**	**Recycle**	**1**	**0**	**89**	**6.56**	**---**	**---**
BOMA	**2**	**9/17/20**	**Recycle**	**2**	**0**	**89**	**7.50**	**---**	**---**
Hilliard	2	9/17/20	Raw Water		0	74	7.59	---	---
Hilliard	2	9/17/20	Range Finding		8	16	6.69	---	---
Hilliard	2	9/17/20	Range Finding		10	10	6.59	---	---
Hilliard	2	9/17/20	Range Finding		12	8	6.47	---	---
Hilliard	2	9/17/20	Range Finding		14	7	6.43	---	---
Hilliard	2	9/18/20	Target dose	1	12	7	6.74	---	---
Hilliard	2	9/18/20	Target dose	2	12	6	6.75	---	---
Hilliard	**2**	**9/18/20**	**Recycle**	**1**	**0**	**39**	**7.43**	**---**	**---**
Hilliard	**2**	**9/18/20**	**Recycle**	**2**	**0**	**38**	**7.43**	**---**	**---**
S-77	2	9/17/20	Raw Water		0	70	7.36	---	---
S-77	2	9/17/20	Range Finding		6	34	6.33	---	---
S-77	2	9/17/20	Range Finding		8	15	6.10	---	---
S-77	2	9/17/20	Range Finding		10	8	5.86	---	---
S-77	2	9/17/20	Range Finding		12	7	5.62	---	---
S-77	2	9/18/20	Target dose	1	12	8	5.82	---	---
S-77	2	9/18/20	Target dose	2	12	6	5.80	---	---
S-77	**2**	**9/18/20**	**Recycle**	**1**	**0**	**44**	**7.05**	**---**	**---**
S-77	**2**	**9/18/20**	**Recycle**	**2**	**0**	**42**	**7.06**	**---**	**---**
S-77	3	9/24/20	Raw Water		0	106	7.29	1.70	25
S-77	3	9/24/20	Range Finding		6	95	6.27	1.30	25
S-77	3	9/24/20	Range Finding		8	21	6.07	0.88	13
S-77	3	9/24/20	Range Finding		10	8	5.88	0.71	10
S-77	3	9/24/20	Range Finding		12	5	5.96	0.63	8
S-77	3	9/25/20	Target dose	1	12	7	6.08	0.66	8
S-77	3	9/25/20	Target dose	2	12	6	6.10	0.65	8
S-77	**3**	**9/25/20**	**Recycle**	**1**	**0**	**43**	**7.48**	**1.40**	**24**
S-77	**3**	**9/25/20**	**Recycle**	**2**	**0**	**42**	**7.49**	**1.40**	**24**

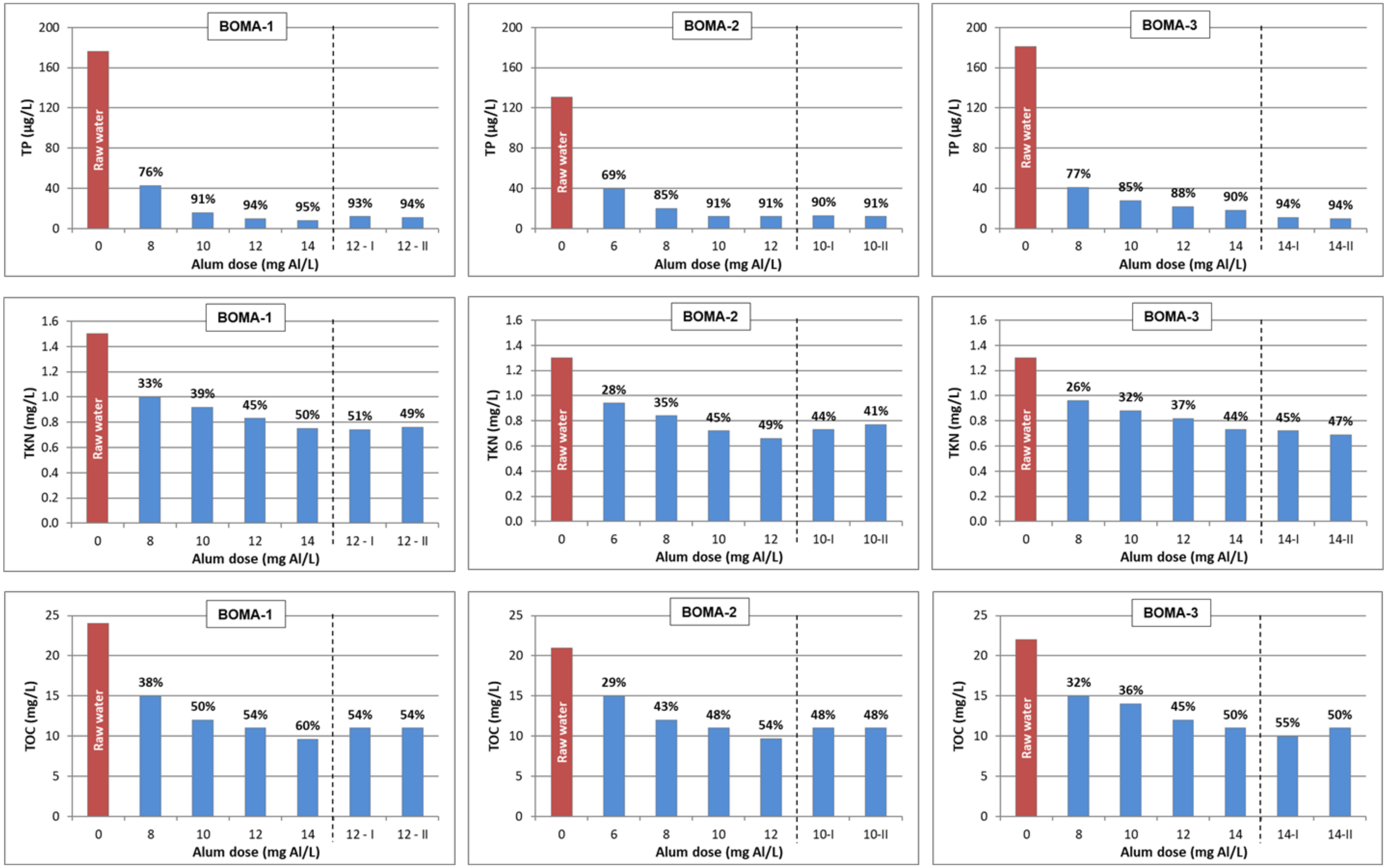

Figure 1. Response of BOMA water TP, TKN and TOC concentrations to four alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. BOMA 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the "target dose" using duplicate vessels (right of vertical dotted line). Numbers above each bar represent the % reduction from the raw water conc.

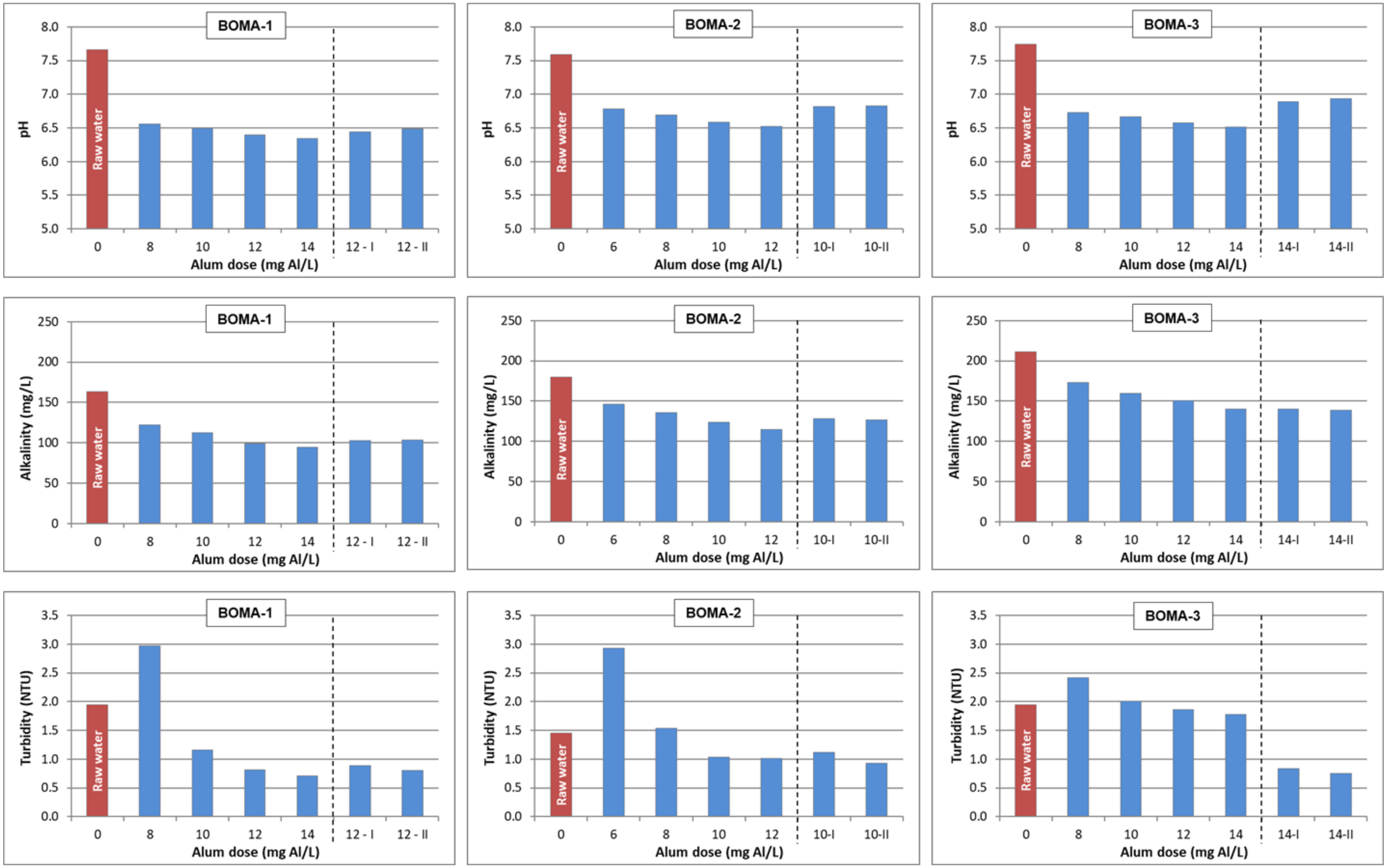

Figure 2. Response of BOMA water pH, alkalinity and turbidity to four alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. BOMA 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the “target dose” using duplicate vessels (right of vertical dotted line).

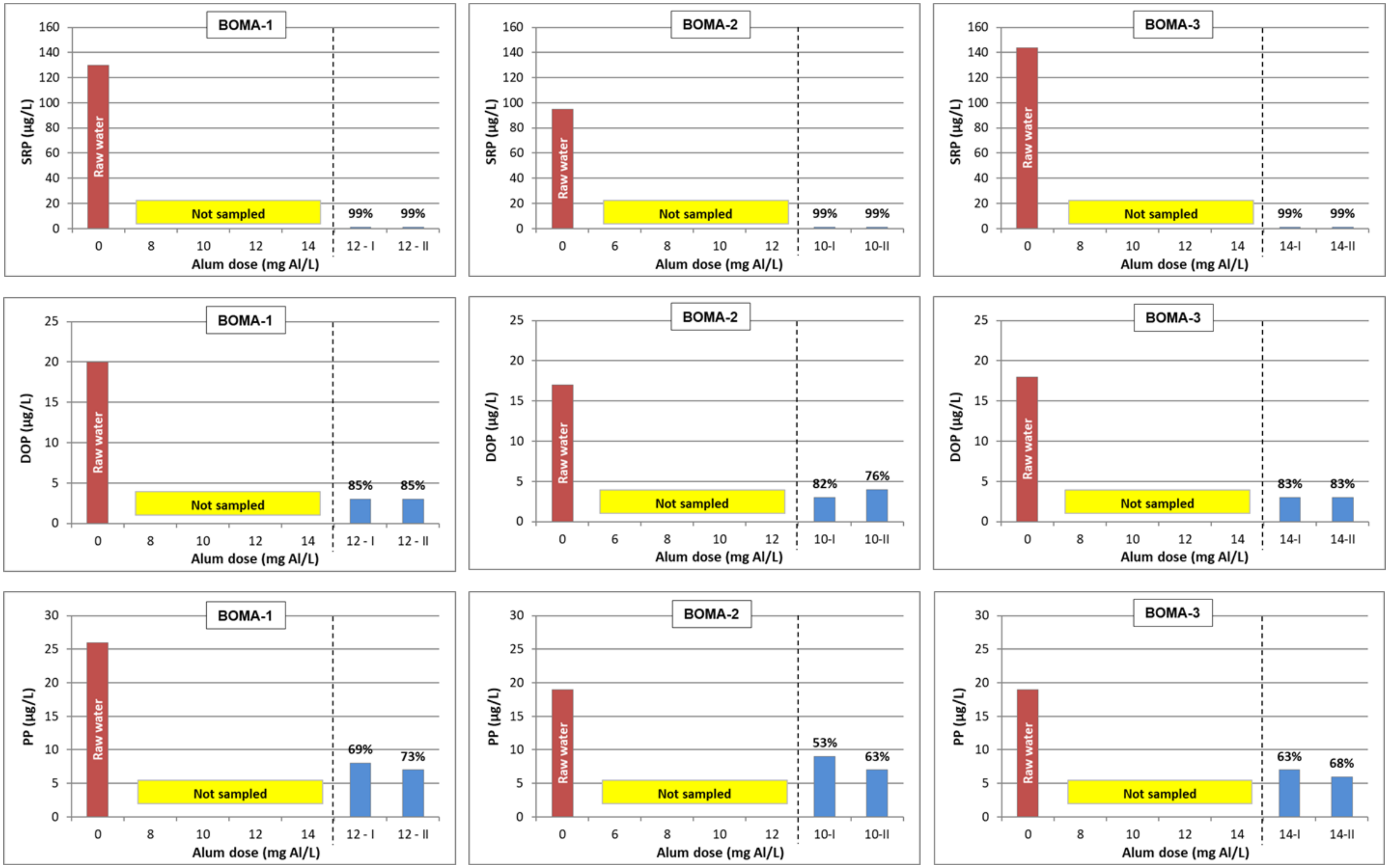

Figure 3. Response of BOMA water SRP, DOP and PP concentrations to the "target alum dose" using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. BOMA 1) represent the event number (see methods for collection date). Numbers above each bar represent the % reduction from the raw water conc.

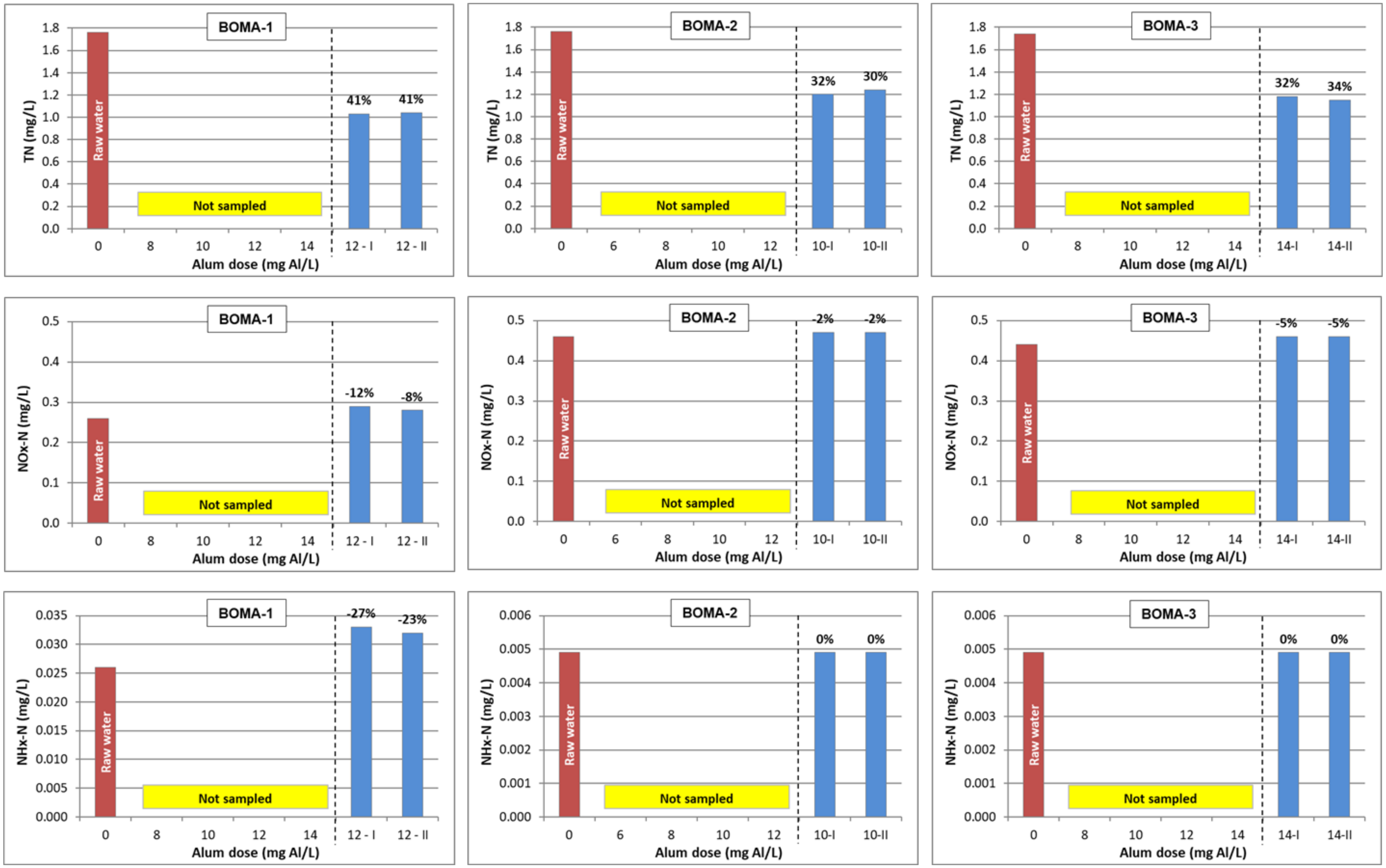

Figure 4. Response of BOMA water TN, NOx-N and NHx-N concentrations to the "target alum dose" using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. BOMA 1) represent the event number (see methods for collection date). Numbers above each bar represent the % reduction from the raw water conc.

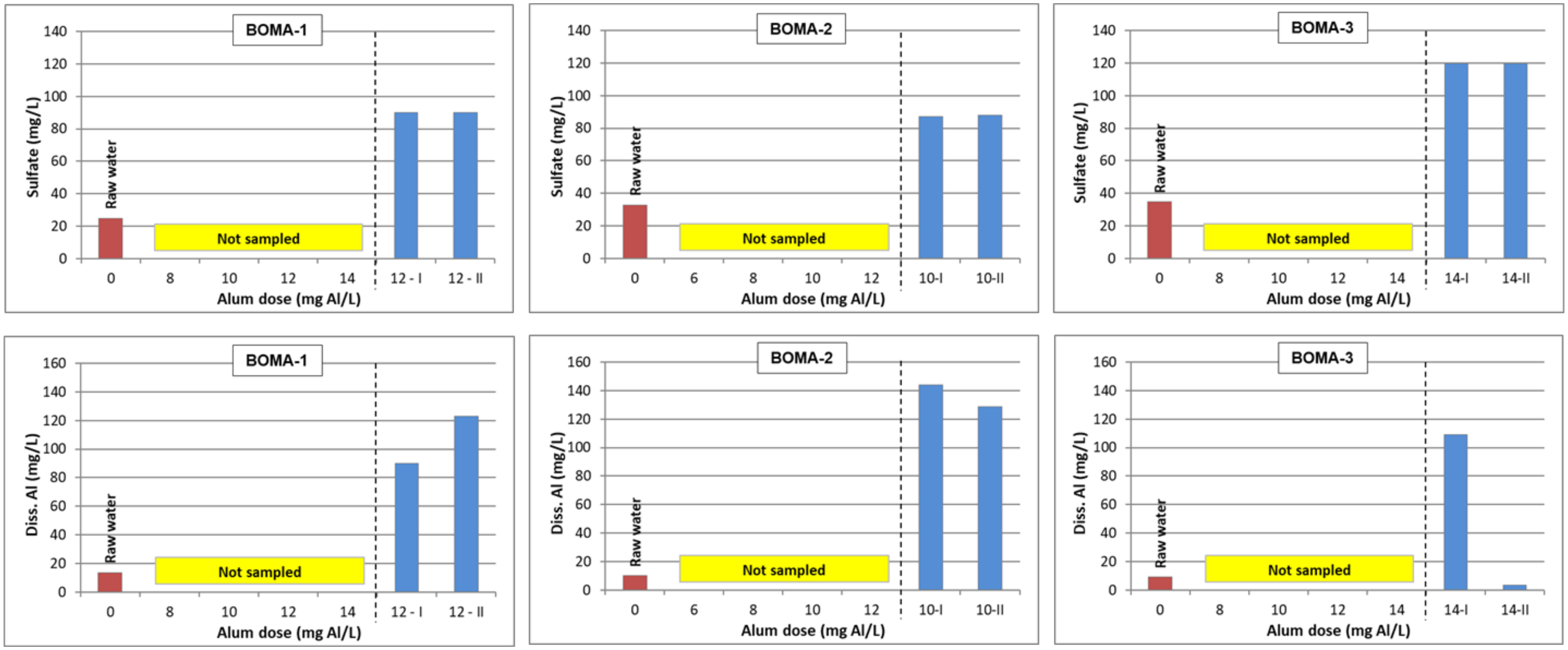

Figure 5. Response of BOMA water sulfate and dissolved Al concentrations to the “target alum dose” using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. BOMA 1) represent the event number (see methods for collection date).

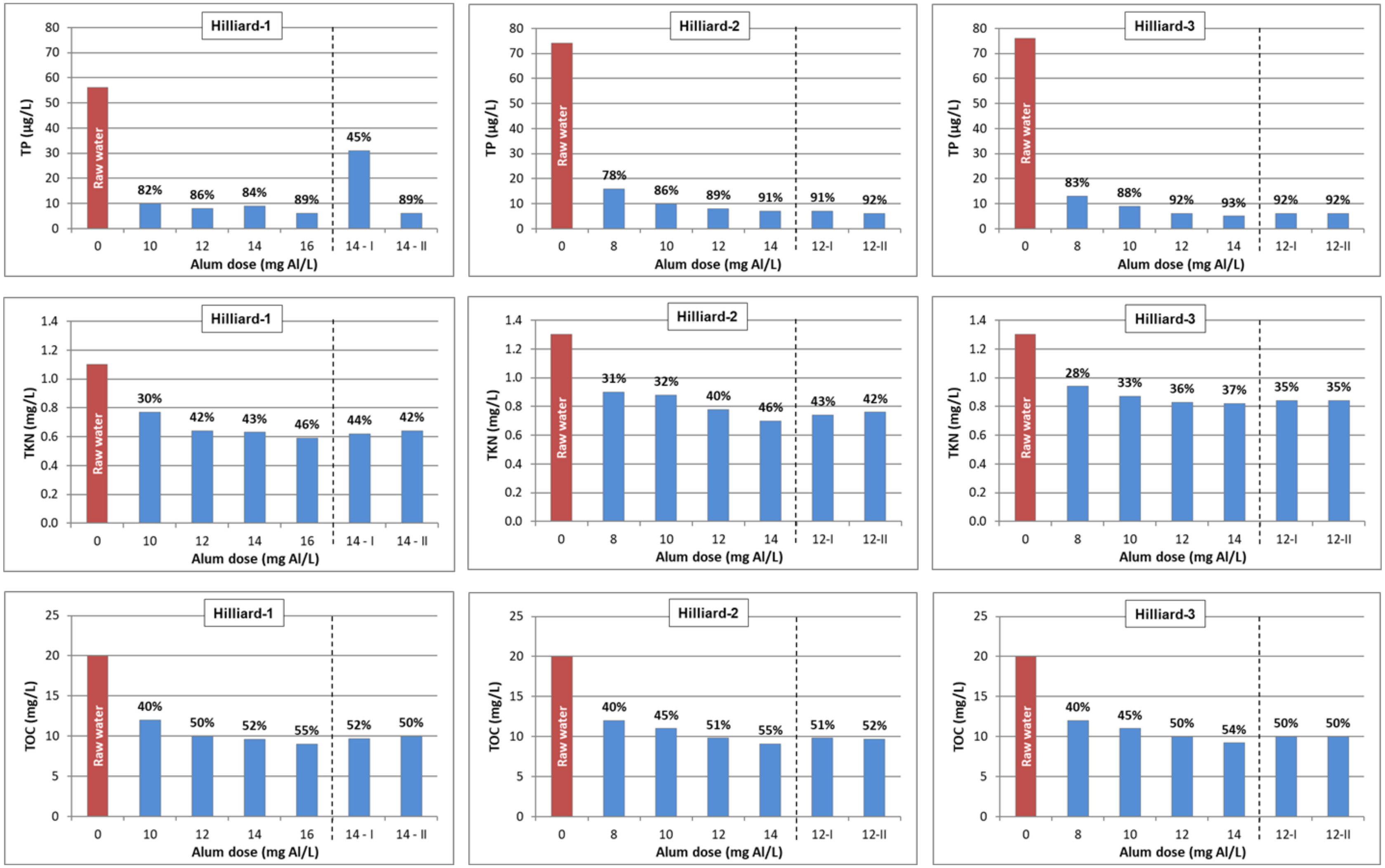

Figure 6. Response of Hilliard canal water TP, TKN and TOC concentrations to four alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. Hilliard 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the "target dose" using duplicate vessels (right of vertical dotted line). Numbers above each bar represent the % reduction from the raw water conc.

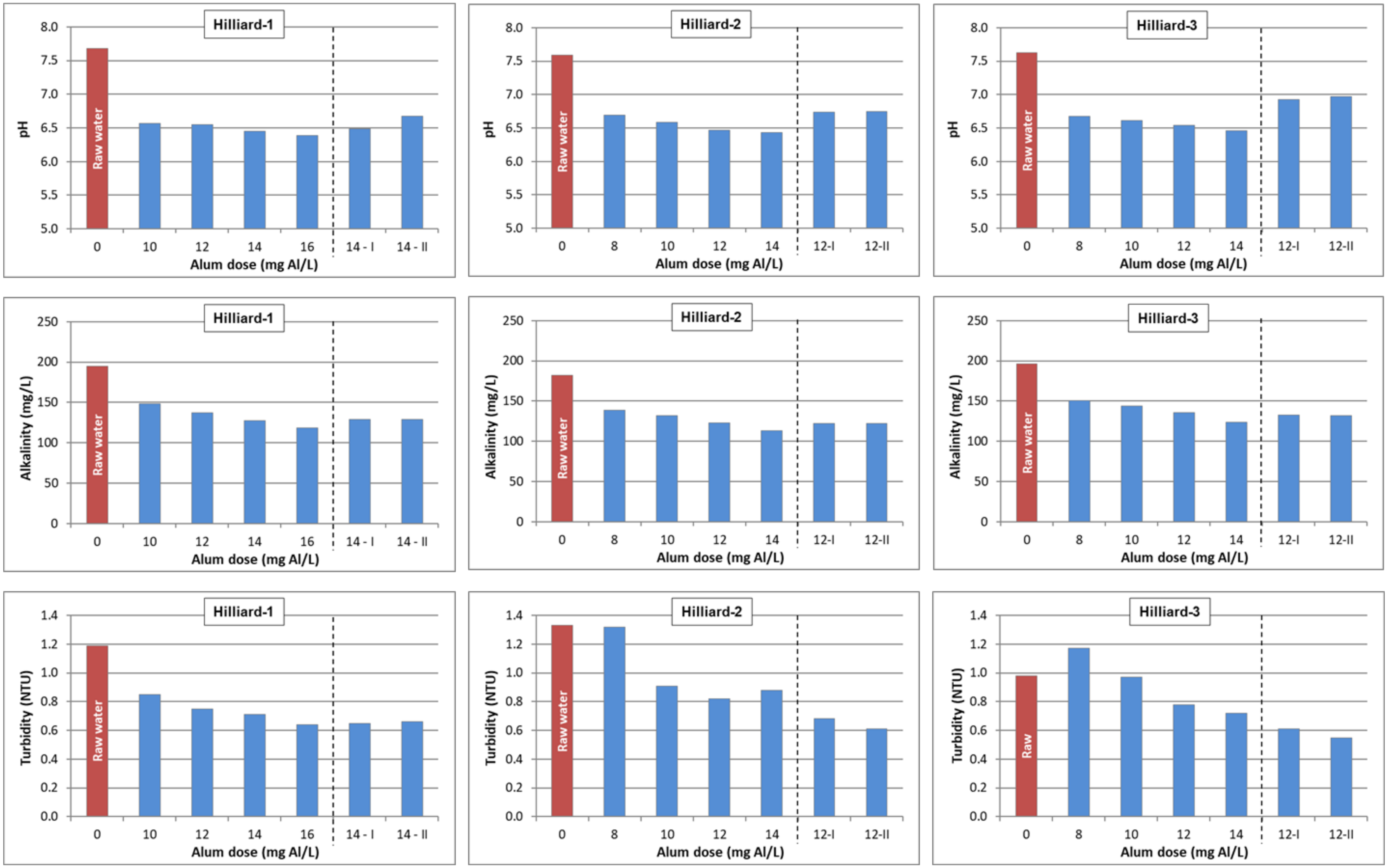

Figure 7. Response of Hilliard canal water pH, alkalinity and turbidity to four alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. Hilliard 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the “target dose” using duplicate vessels (right of vertical dotted line).

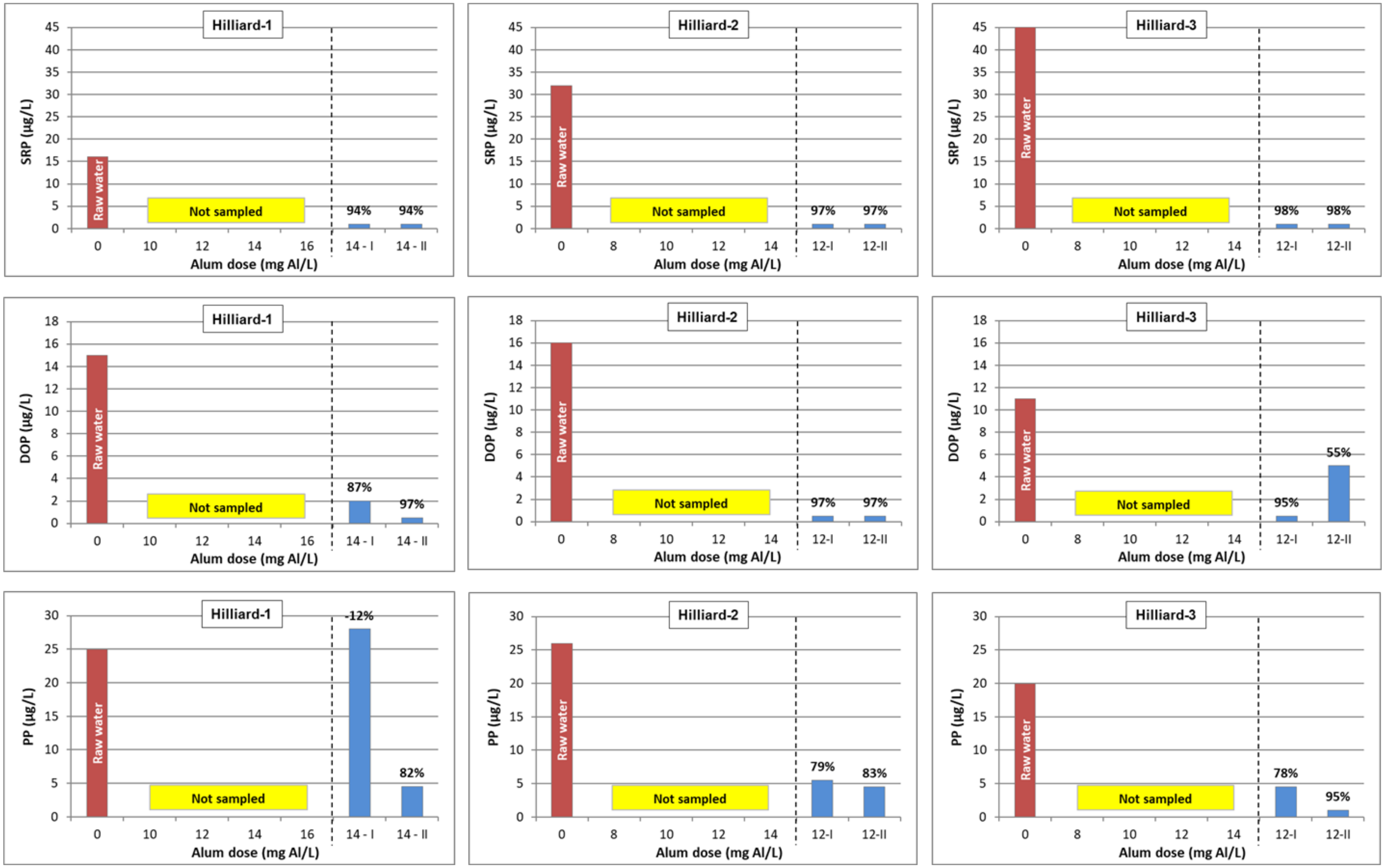

Figure 8. Response of Hilliard canal water SRP, DOP and PP concentrations to the “target alum dose” using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. Hilliard 1) represent the event number (see methods for collection date). Numbers above each bar represent the % reduction from the raw water conc.

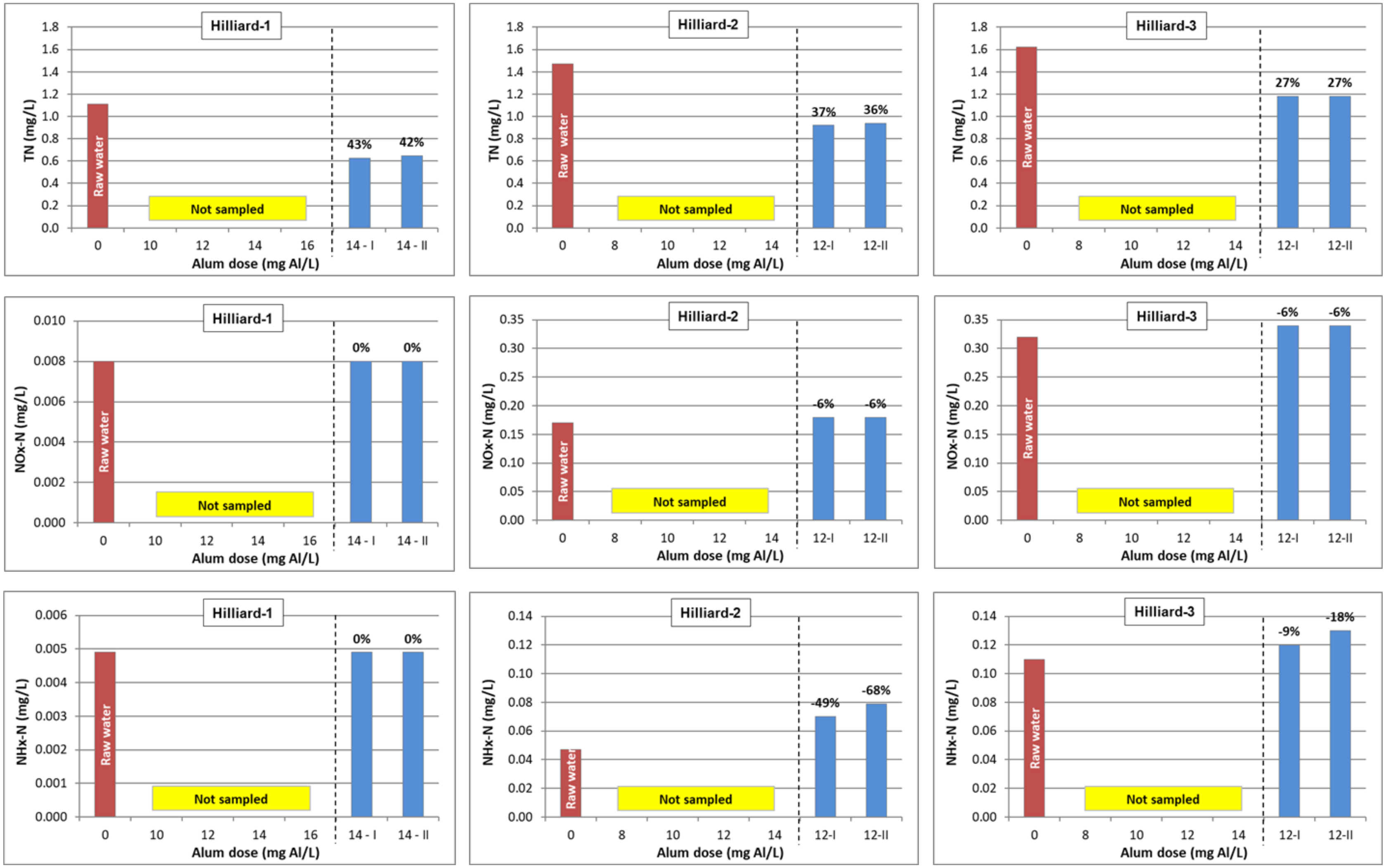

Figure 9. Response of Hilliard canal water TN, NOx-N and NHx-N concentrations to the “target alum dose” using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. Hilliard 1) represent the event number (see methods for collection date). Numbers above each bar represent the % reduction from the raw water conc.

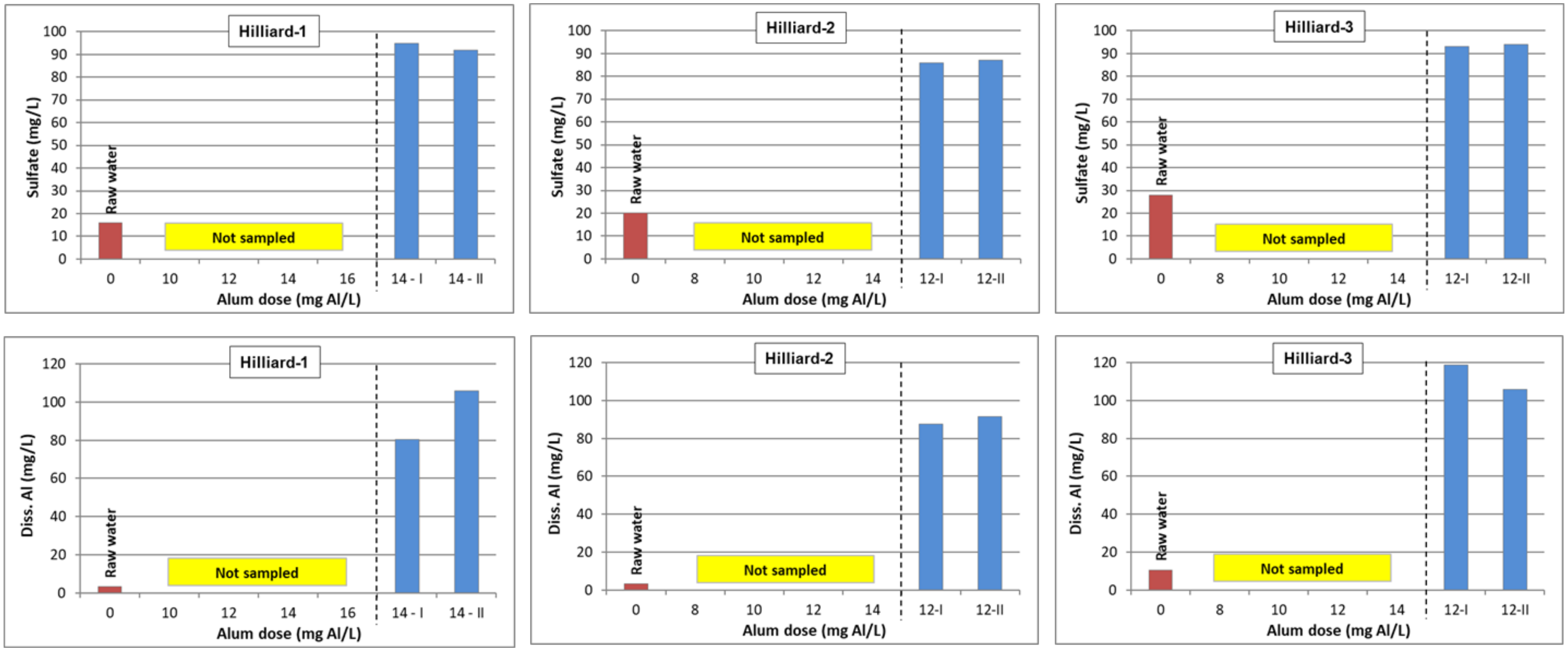

Figure 10. Response of Hilliard canal water sulfate and dissolved Al concentrations to the “target alum dose” using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. Hilliard 1) represent the event number (see methods for collection date).

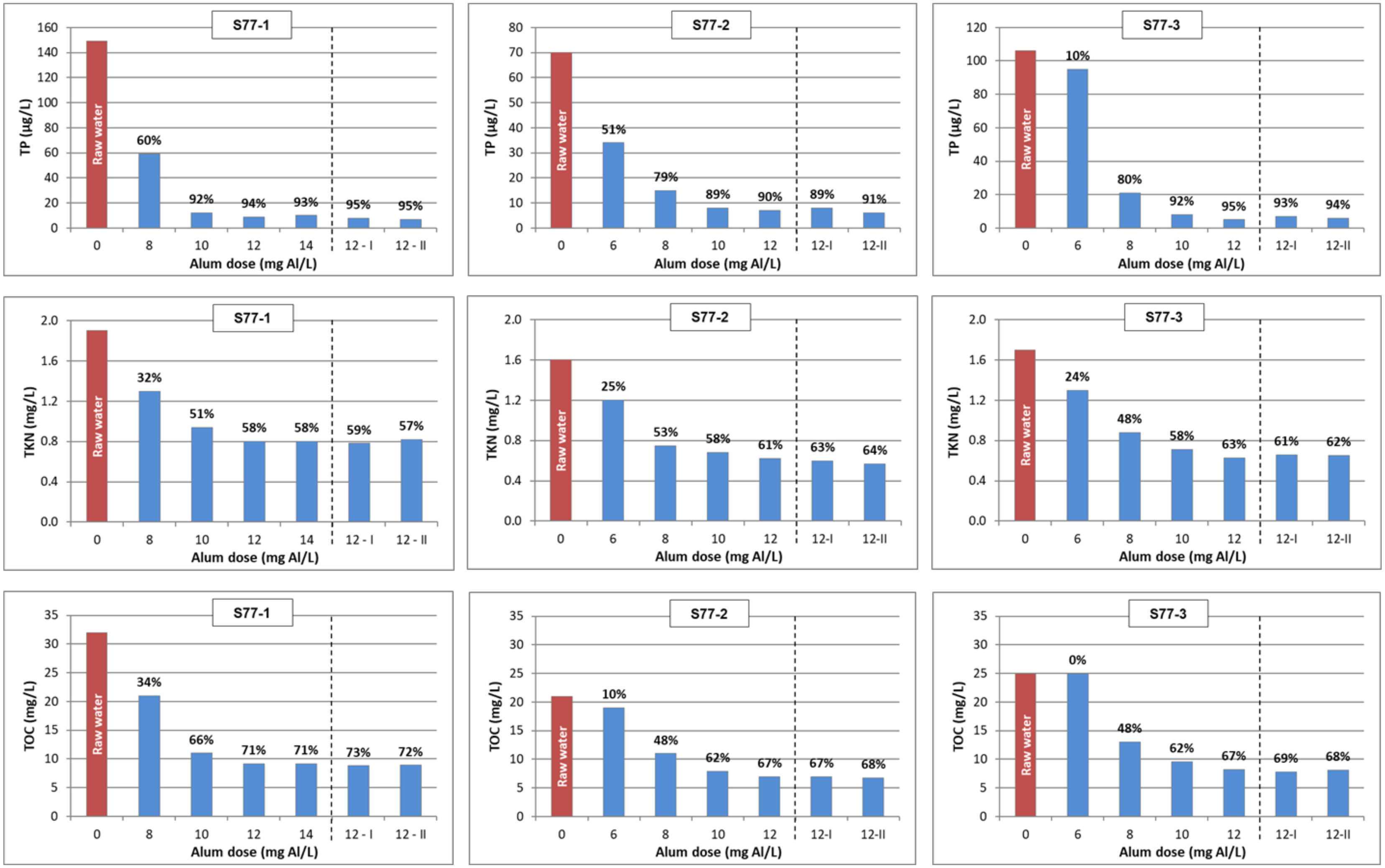

Figure 11. Response of S-77 water TP, TKN and TOC concentrations to four alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. S-77 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the "target dose" using duplicate vessels (right of vertical dotted line). Numbers above each bar represent the % reduction from the raw water conc.

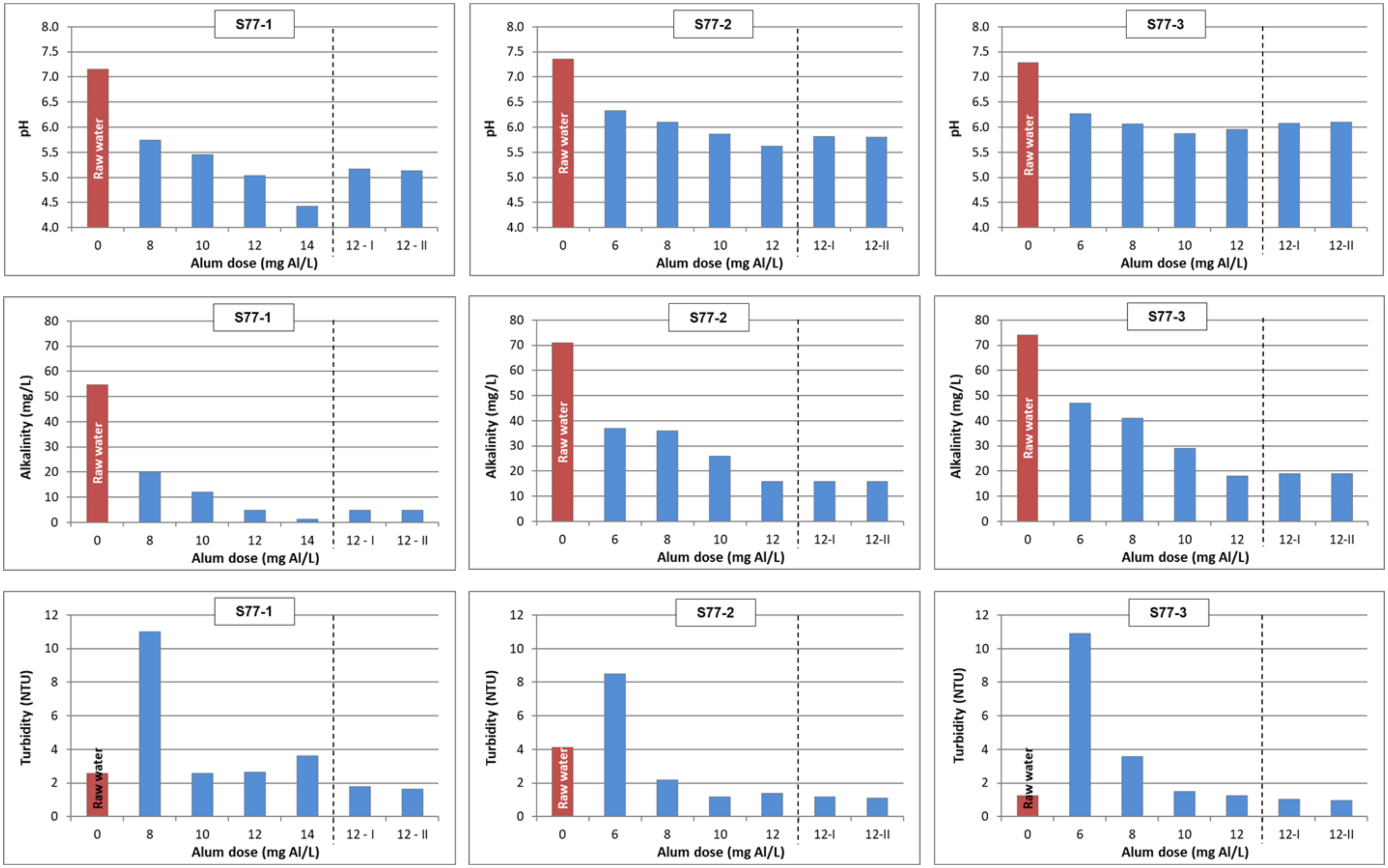

Figure 12. Response of S-77 water pH, alkalinity and turbidity to four alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. S-77 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the “target dose” using duplicate vessels (right of vertical dotted line).

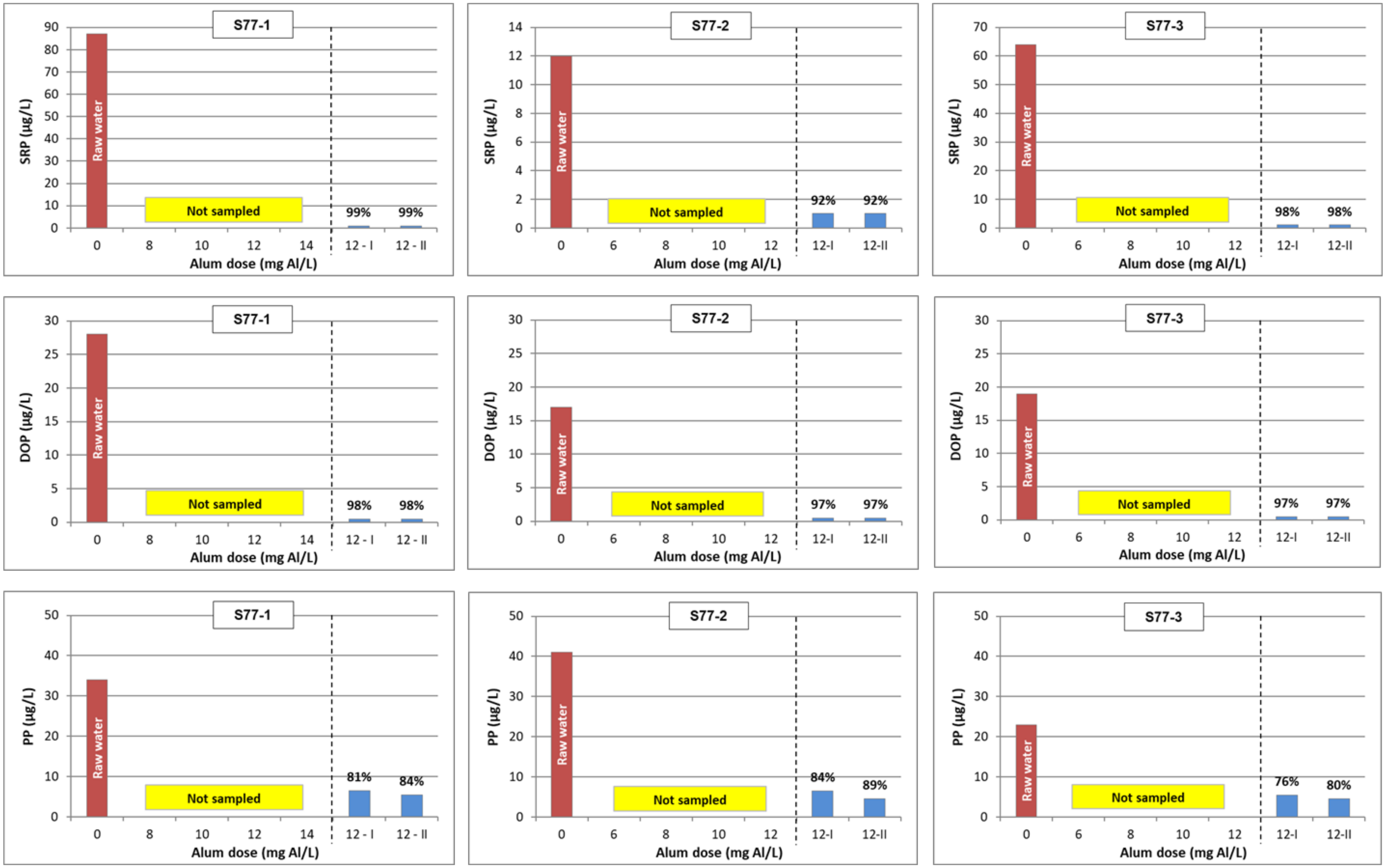

Figure 13. Response of S77 water SRP, DOP and PP concentrations to the "target alum dose" using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. S77- 1) represent the event number (see methods for collection date). Numbers above each bar represent the % reduction from the raw water conc.

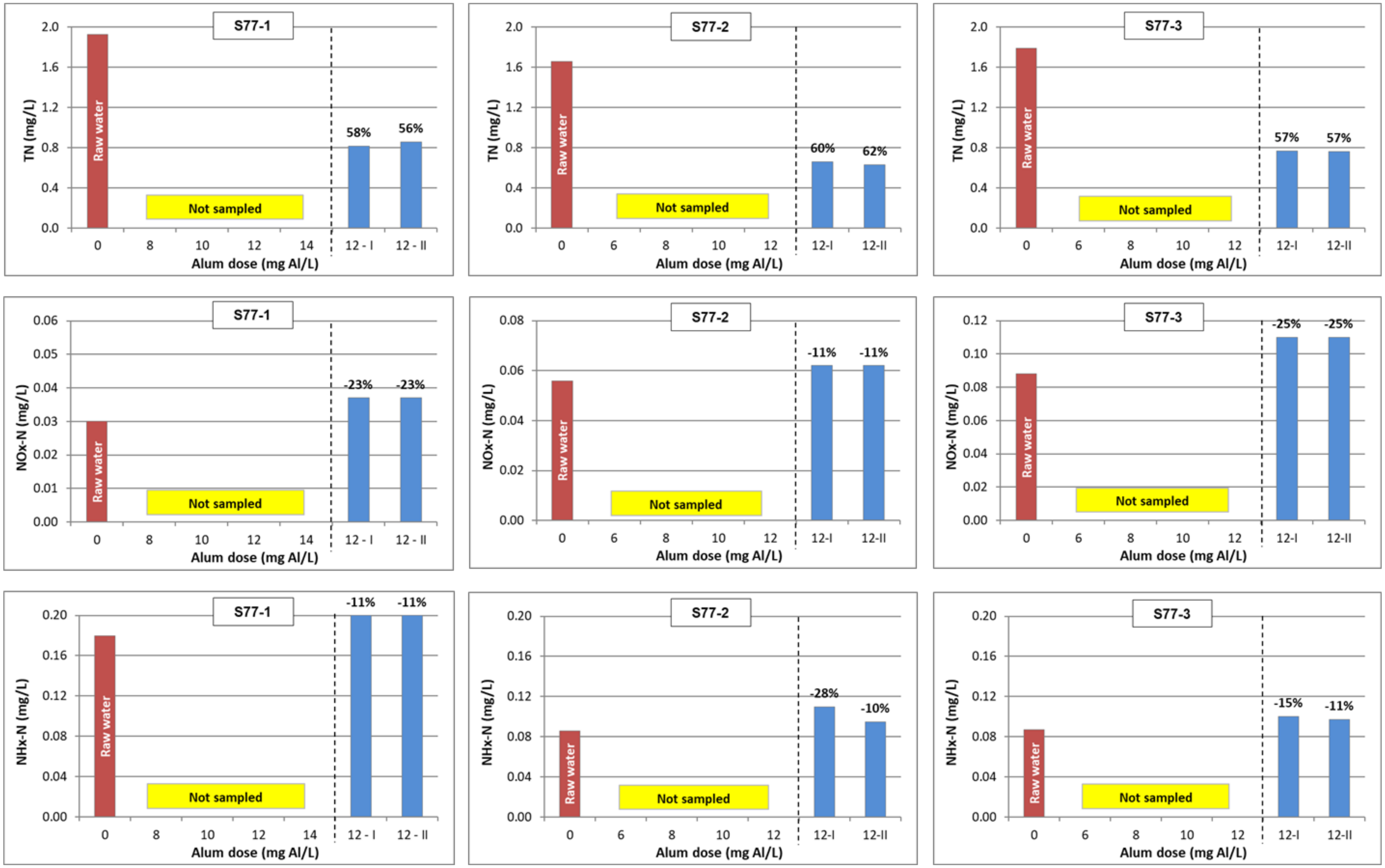

Figure 14. Response of S77 water TN, NOx-N and NHx-N concentrations to the "target alum dose" using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. S77- 1) represent the event number (see methods for collection date). Numbers above each bar represent the % reduction from the raw water conc.

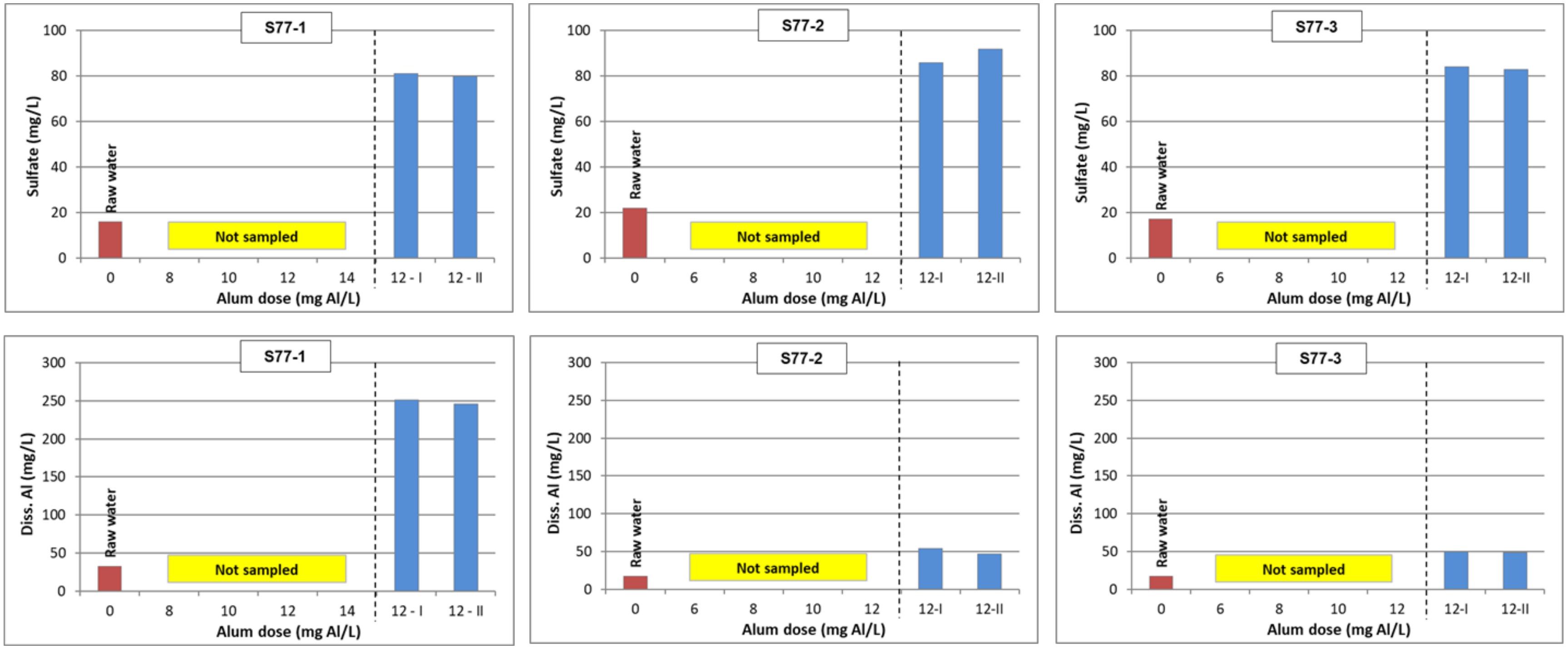

Figure 15. Response of S77 water sulfate and dissolved Al concentrations to the “target alum dose” using duplicate vessels (right of vertical dotted line). Supernatants from the range finding test (left of vertical dotted line) were not analyzed for these constituents. Individual graph labels (e.g. S77- 1) represent the event number (see methods for collection date).

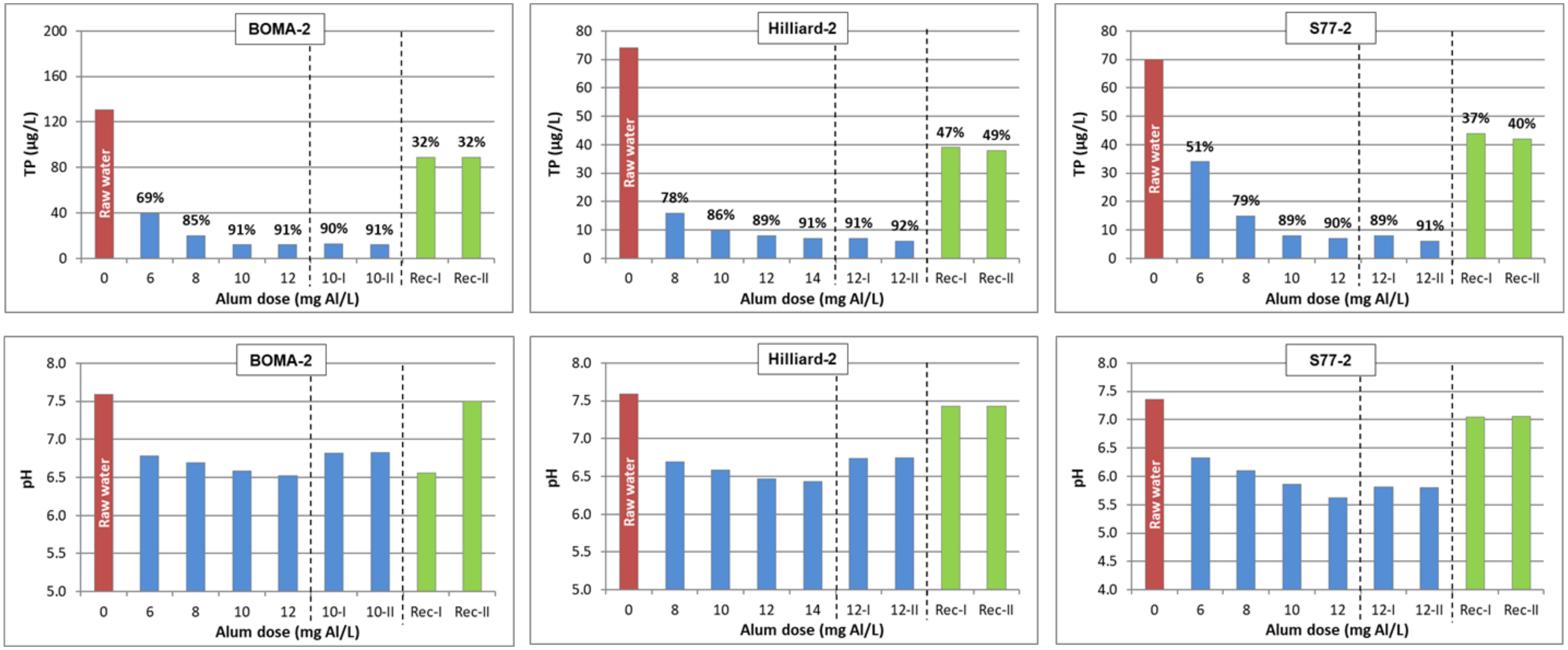

Figure 16. Results of floc recycling tests for all sites, conducted during Event 2. Numbers above each bar represent the % reduction from the raw water conc.

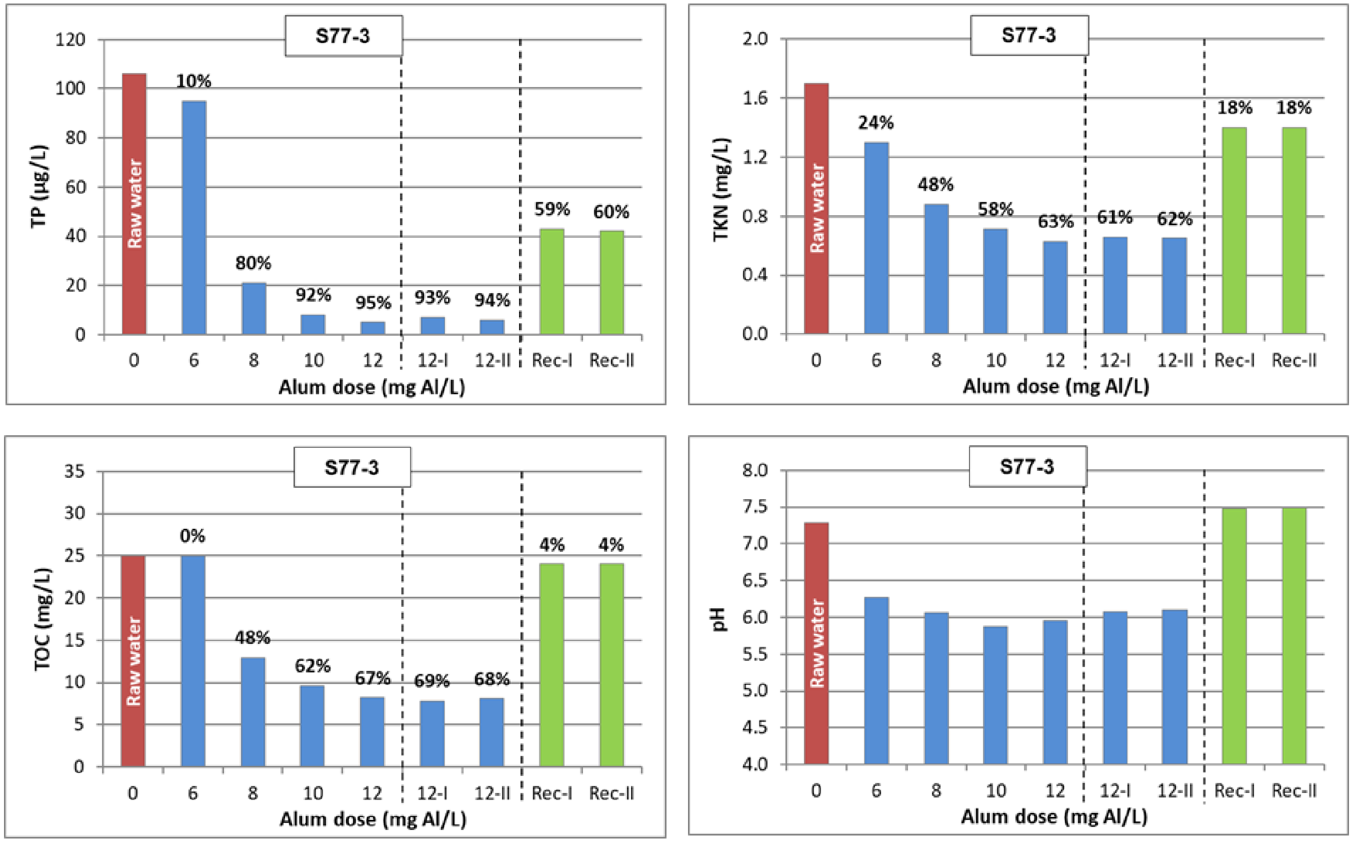

Figure 17. Response of S-77 (Event 3) water pH, TP, TKN and TOC concentrations to exposure to previously-formed floc from the replicated target dose alum doses in a range-finding jar test (left of vertical dotted line). Individual graph labels (e.g. S-77 1) represent the event number (see methods for collection date). Also depicted are results of the separate jar tests at the "target dose" using duplicate vessels (right of vertical dotted line).Results of floc recycling tests for site S-77, conducted during Event 3. Numbers above each bar represent the % reduction from the raw water conc.