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

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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.

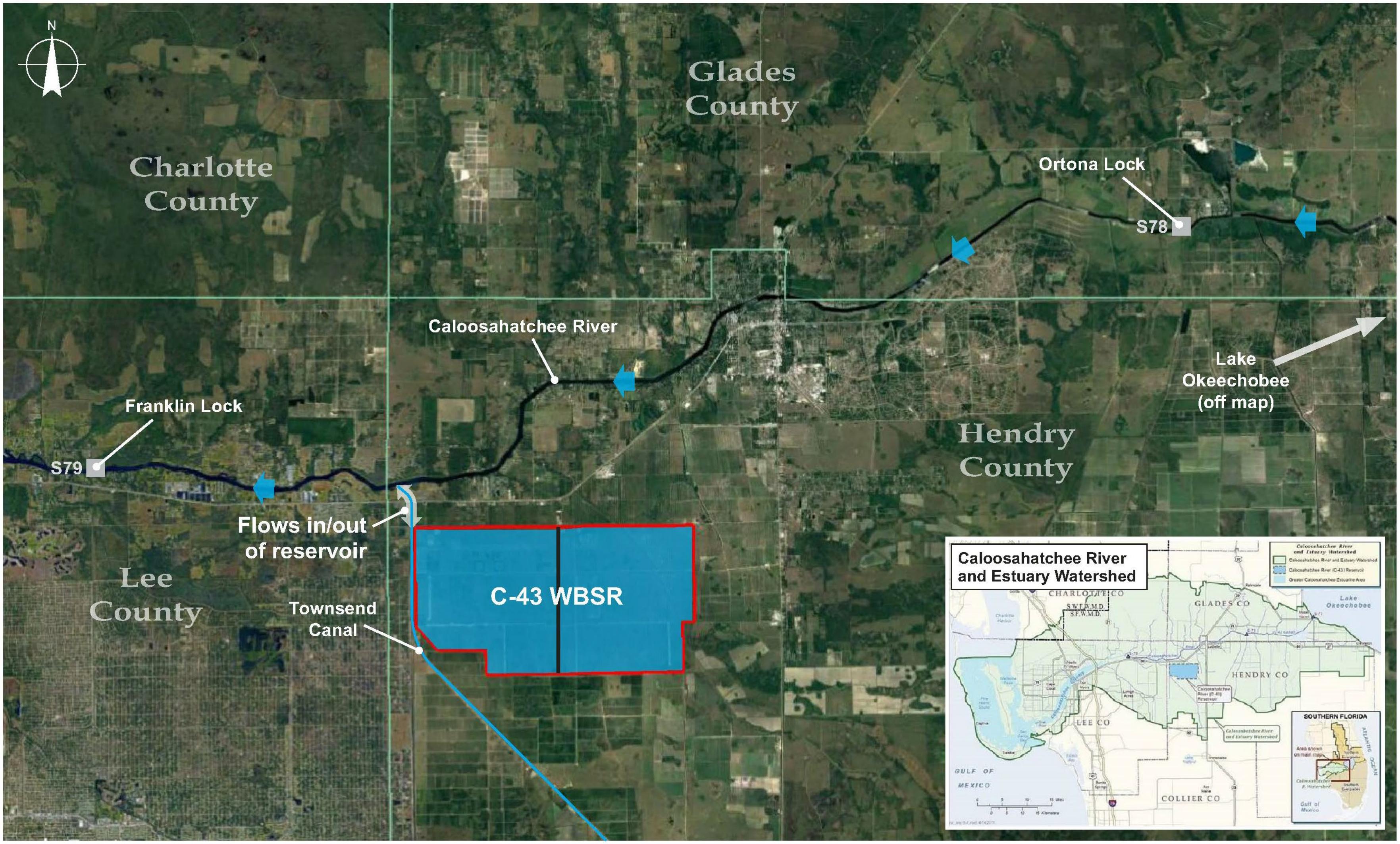


Figure 1-1. Location Map of C-43 West Basin Reservoir

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.

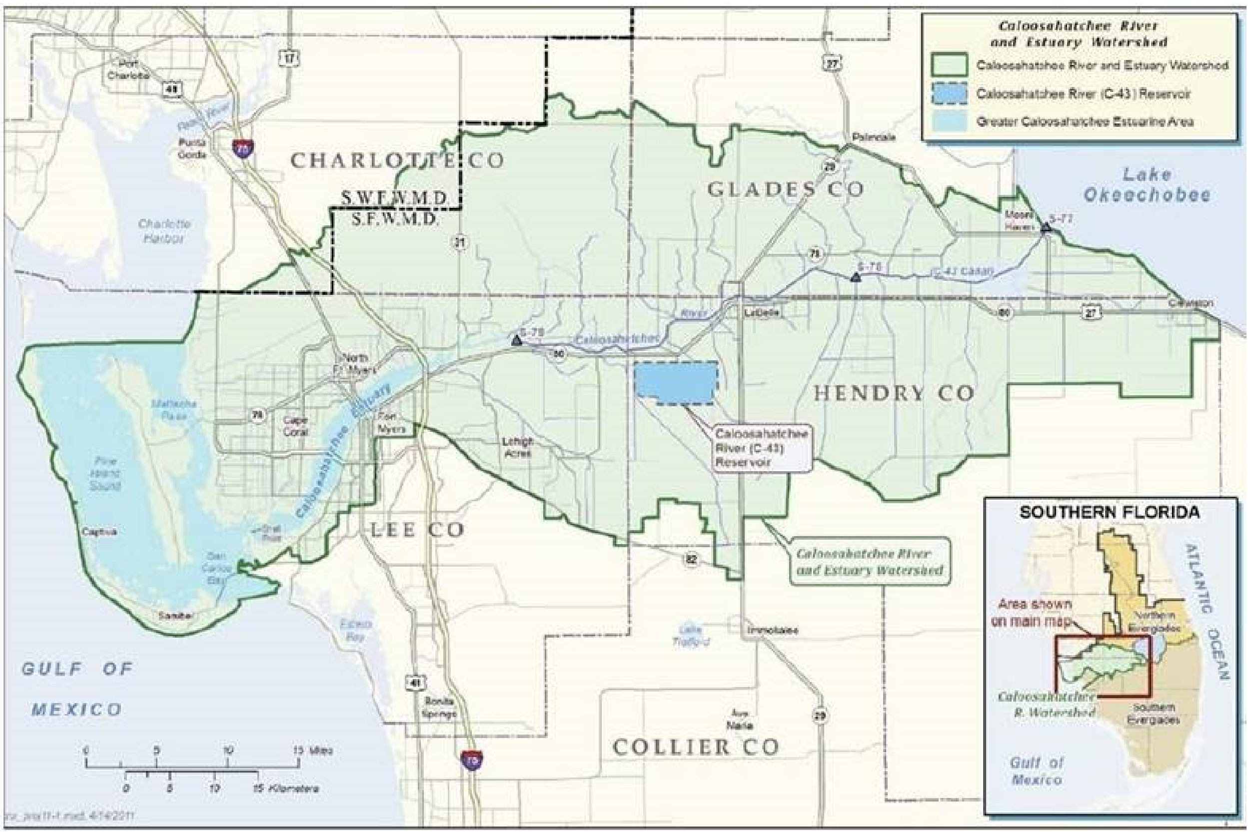


Figure 3-1. Caloosahatchee River and Estuary Watershed

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.

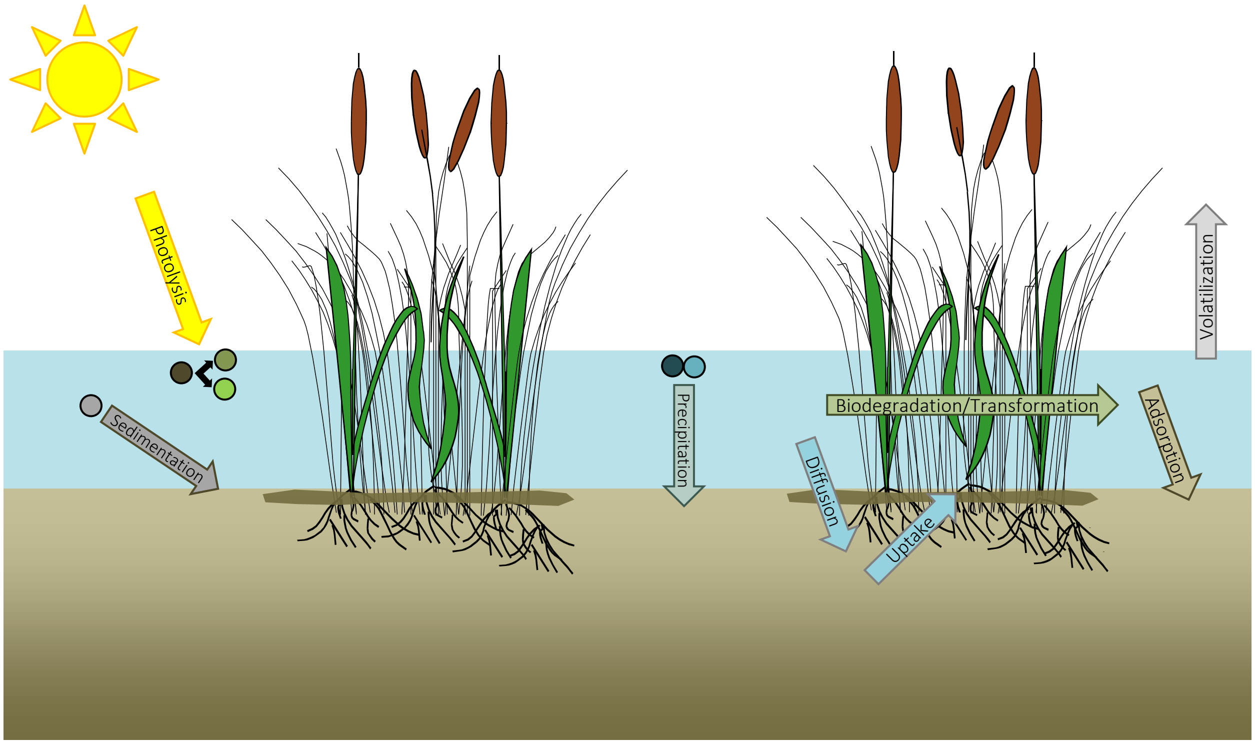


Figure 3-2. Generalized Wetland Water Quality Improvement Processes

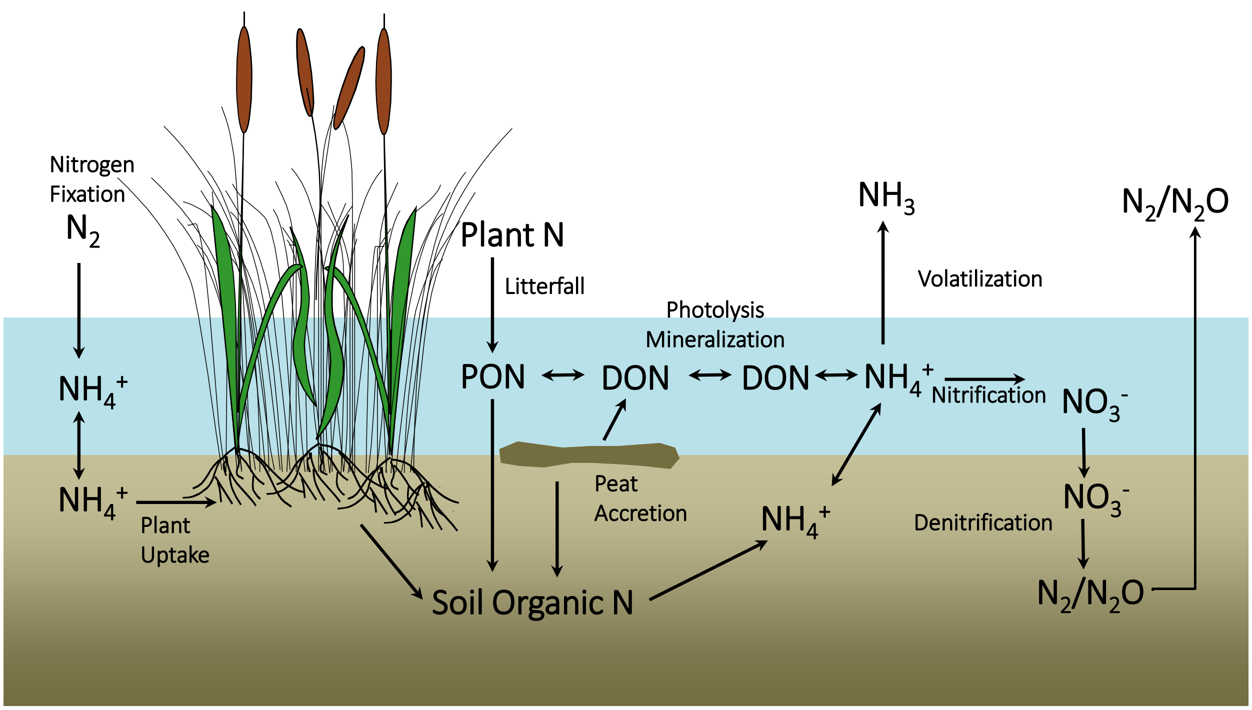


Figure 3-3. Aquatic Nitrogen Cycle

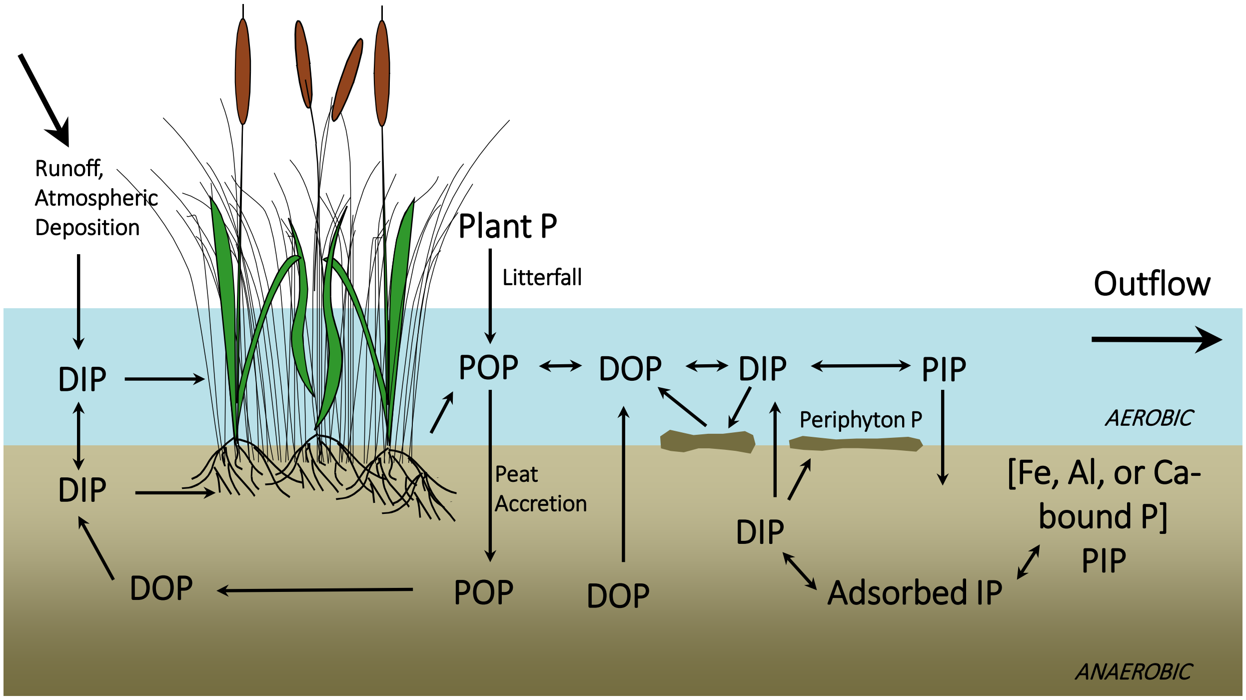


Figure 3-4. Aquatic Phosphorus Cycle

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).

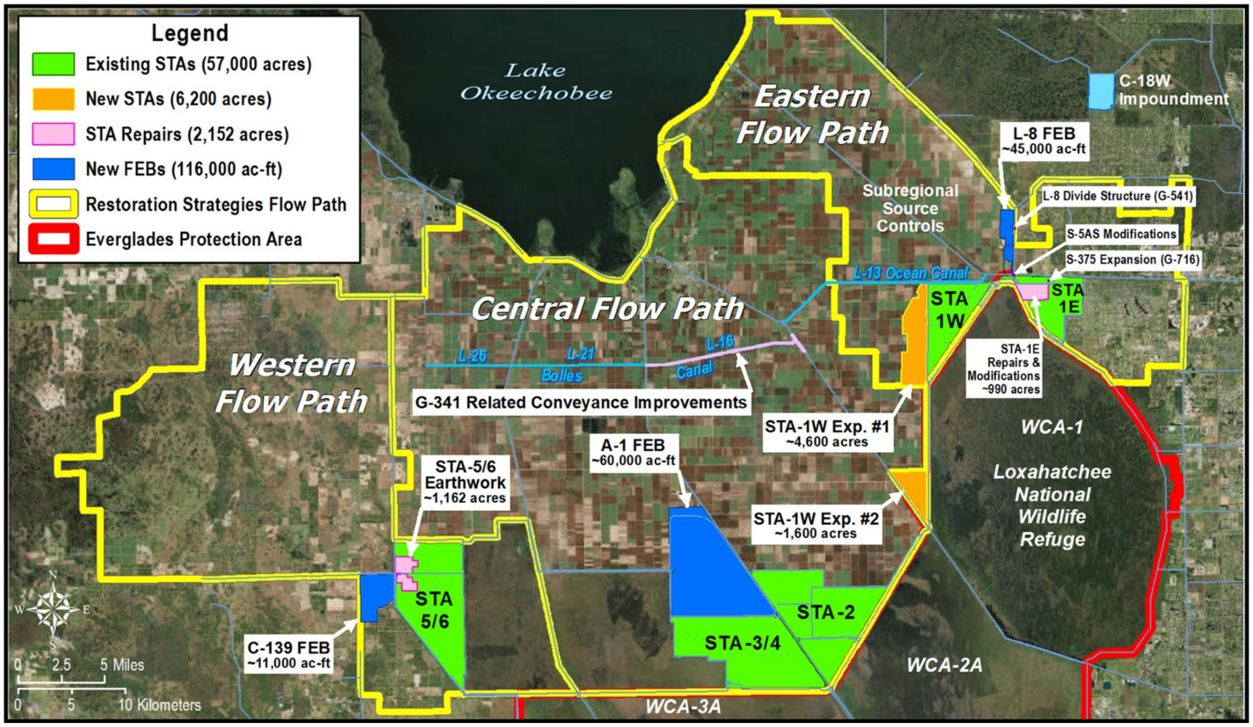


Figure 3-6. **Location of SFWMD Stormwater Treatment Areas (SFWMD, 2019a)**

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

	TN (mg/L)			TN (mt)				
STA	Inflow	Outflow	% Removal	Inflow	Outflow	% Removal	Period of Record	
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).

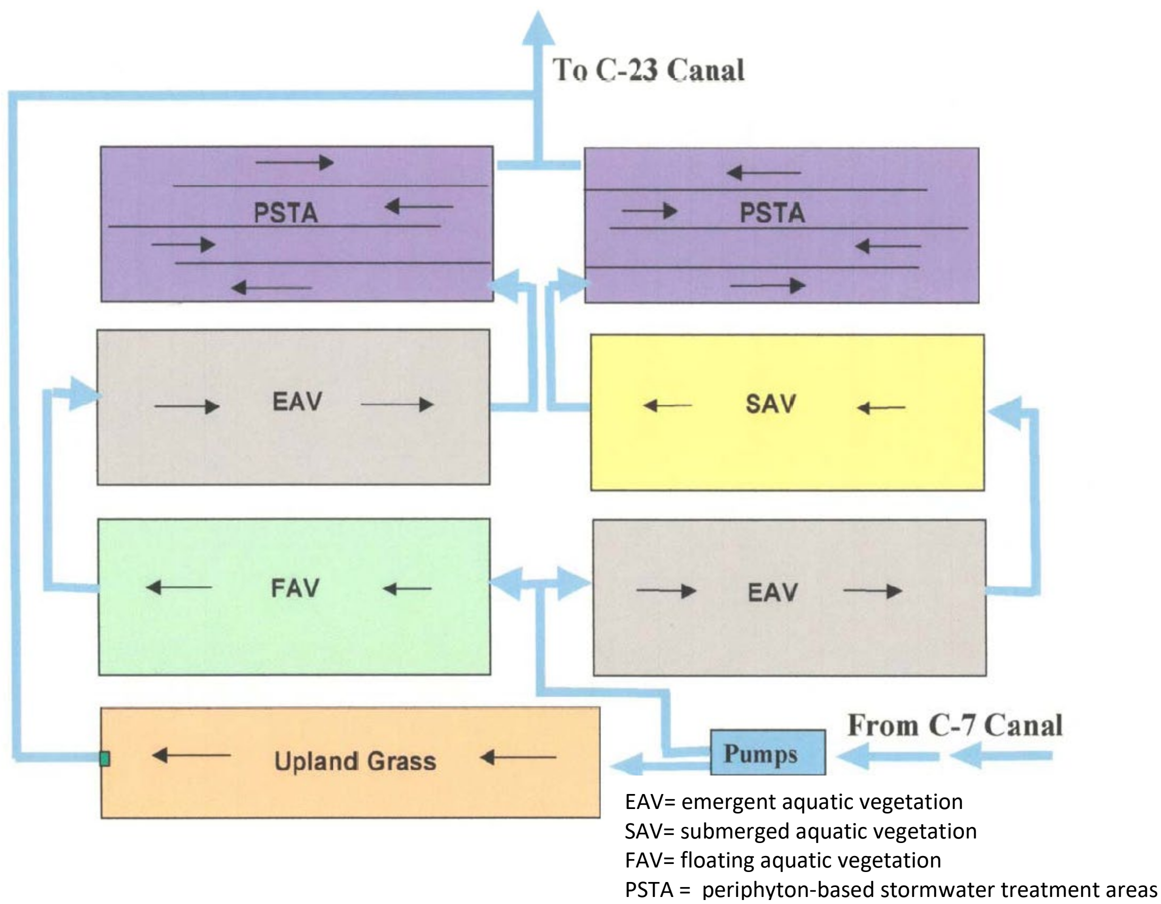
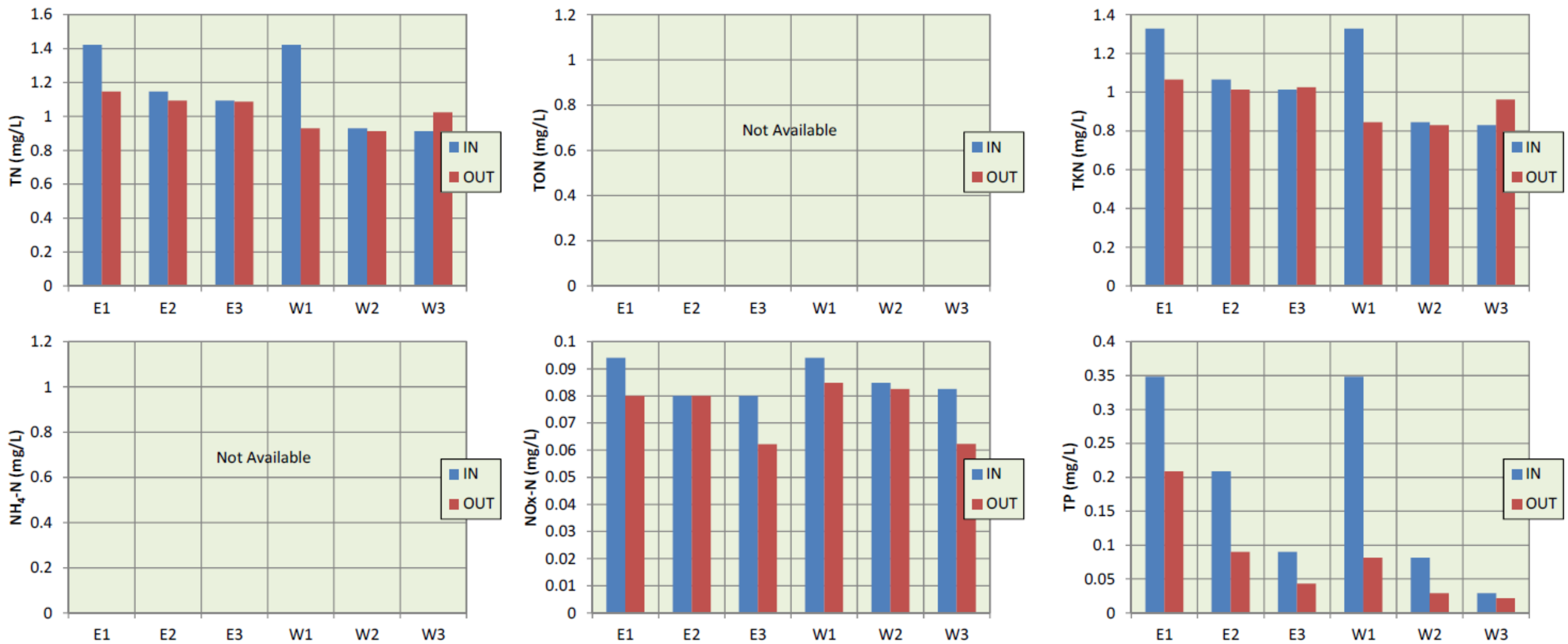
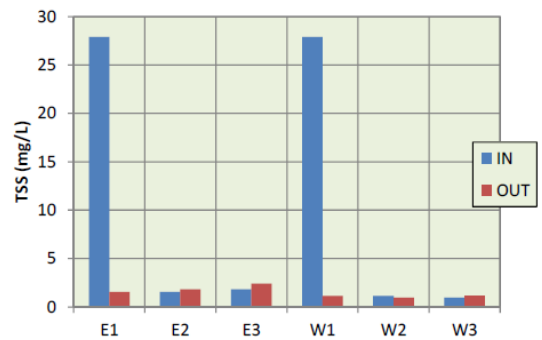


Figure 3-7. Village of Wellington Aquatics Pilot Facility Layout (WSI, 2012a)





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).

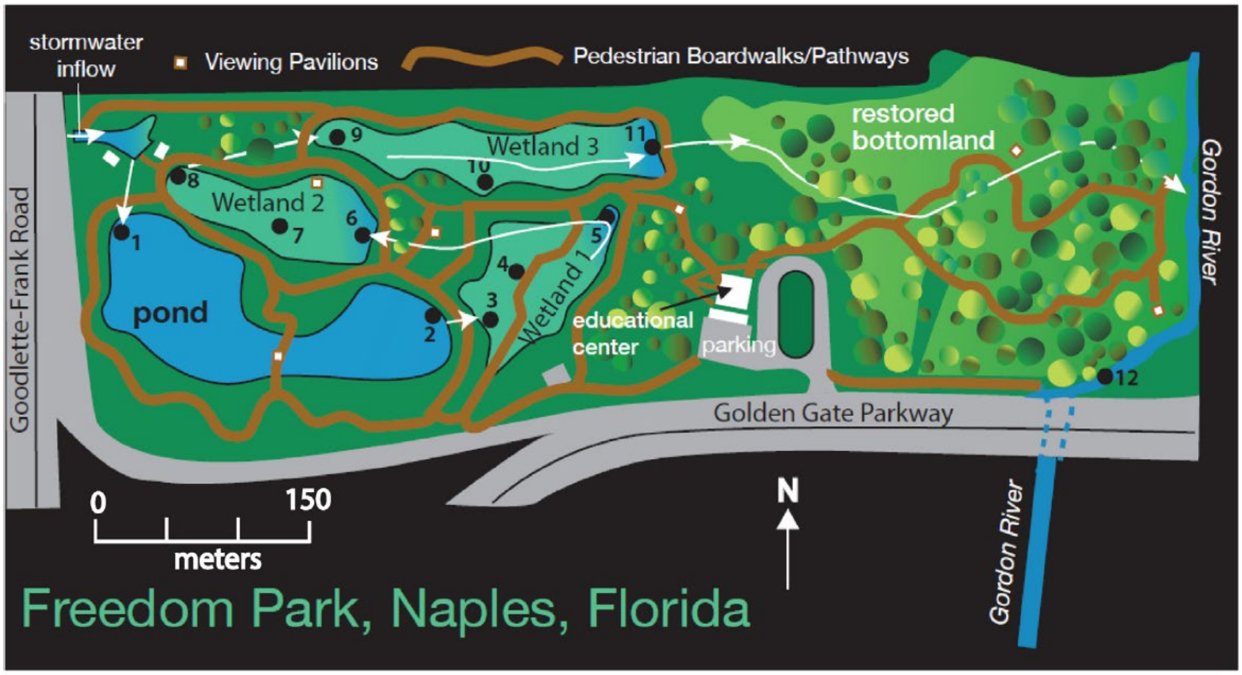


Figure 3-14. Freedom Park (Griffiths and Mitsch, 2017)

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).

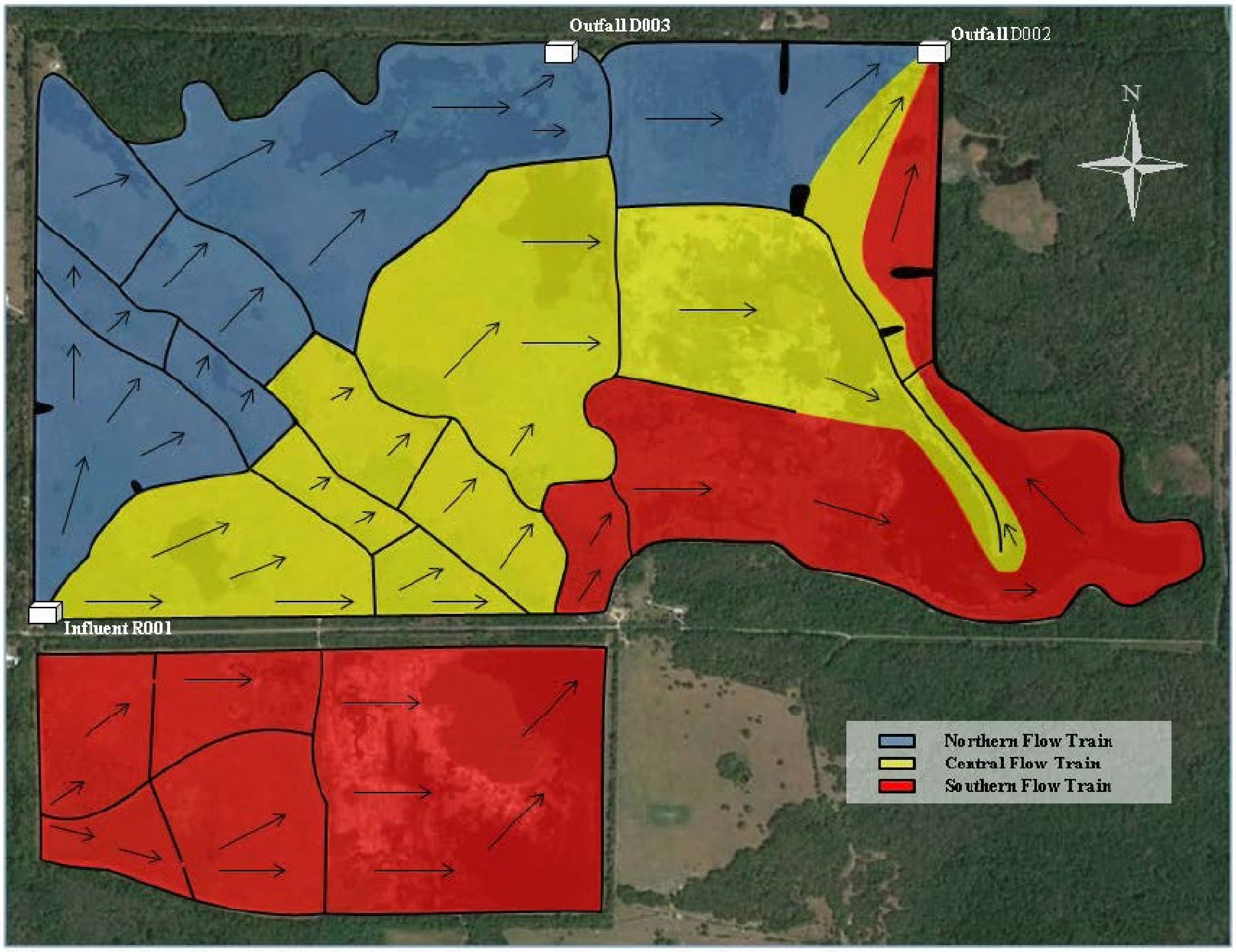


Figure 3-15. Orlando Easterly Wetlands Layout (City of Orlando, 2019)

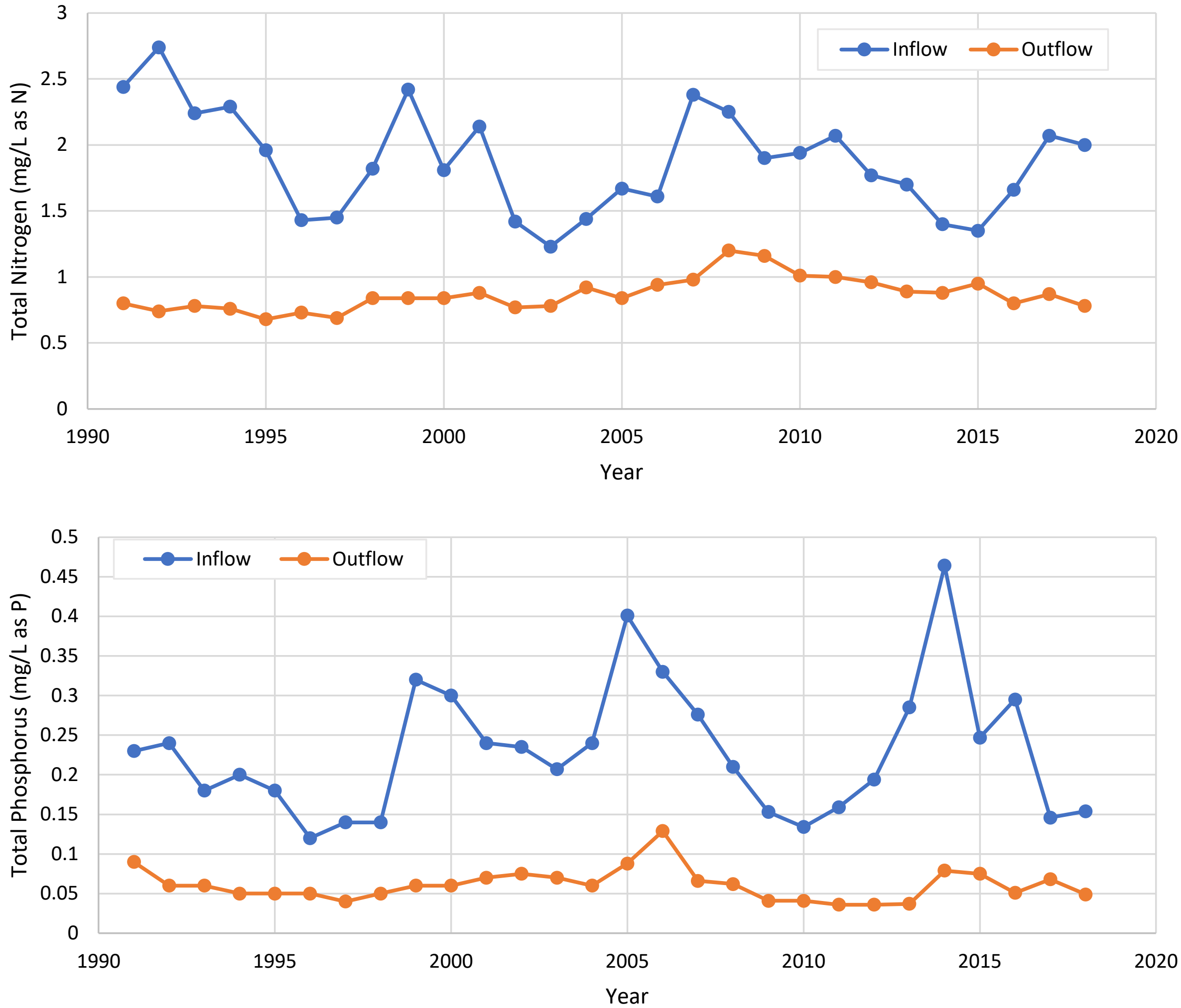


Figure 3-16. Orlando Easterly Wetlands Performance 1991-2018 (City of Orlando, 2019)

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.

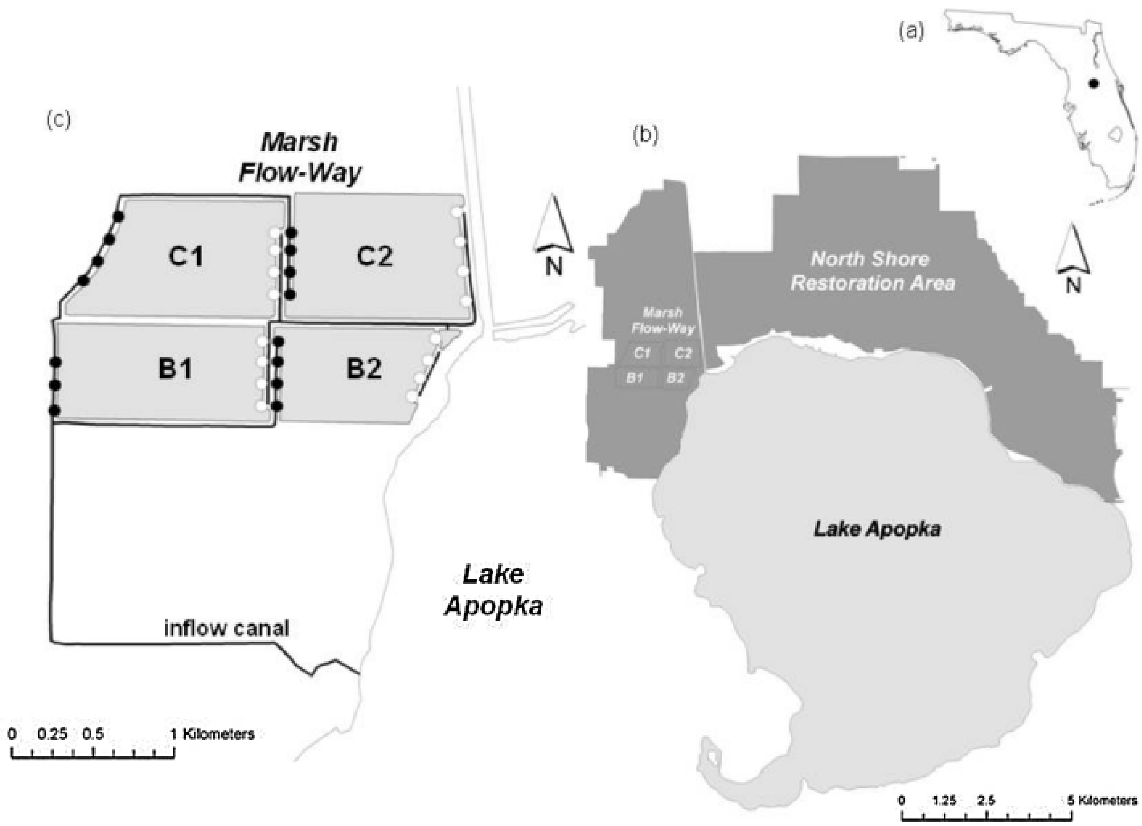


Figure 3-17. Apopka Marsh Flow-Way (Dunne et al., 2015)

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).

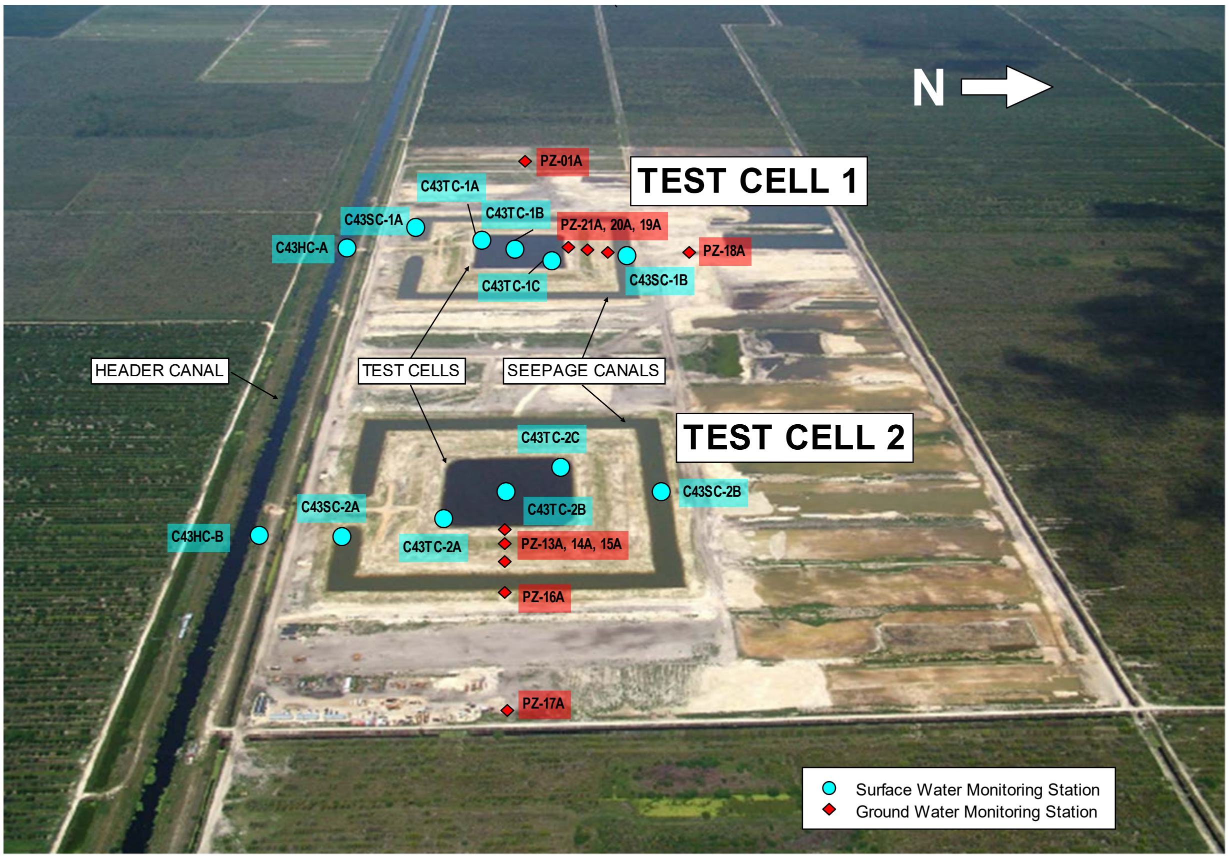
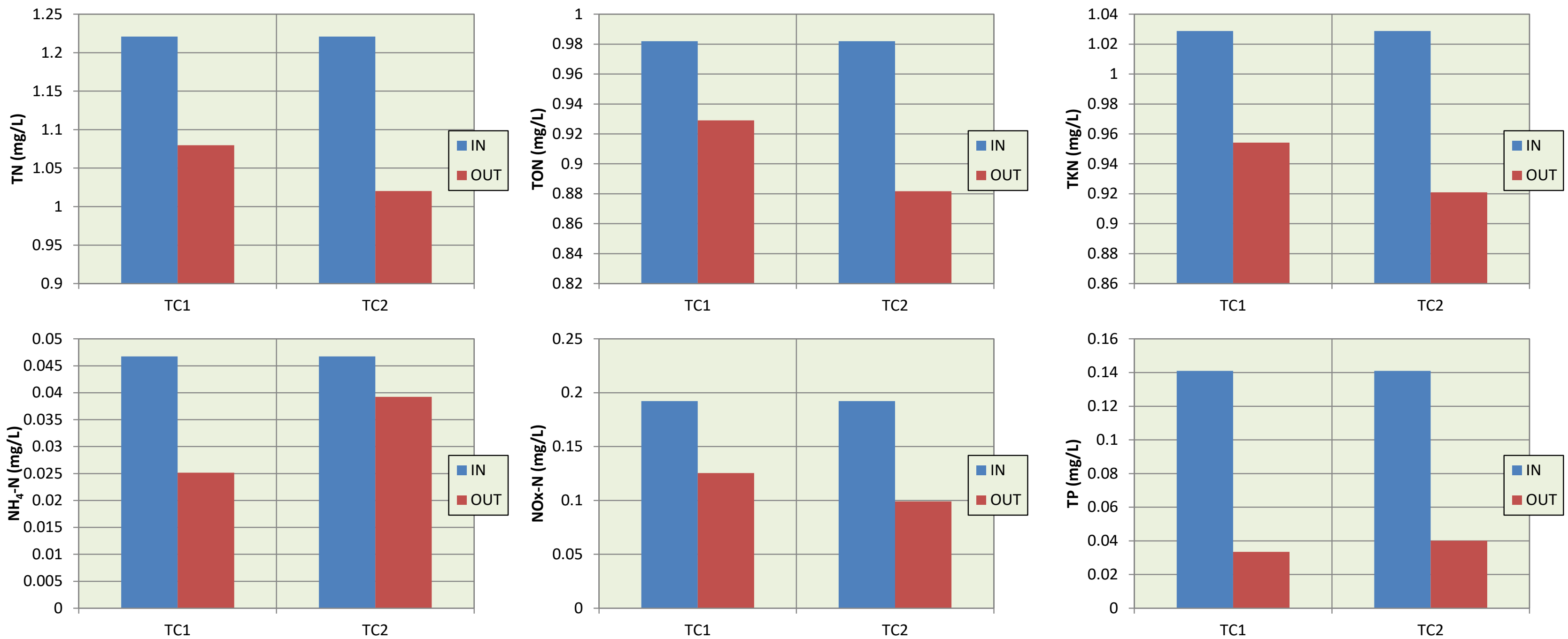
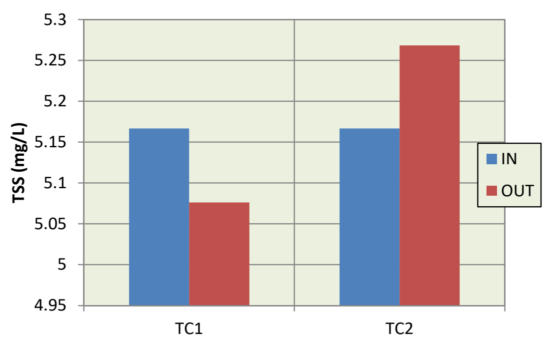


Figure 3-18. C-43 West Basin Storage Reservoir Test Cells (WSI, 2007a)

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 (m^3/d) In	Avg Flow (m^3/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).

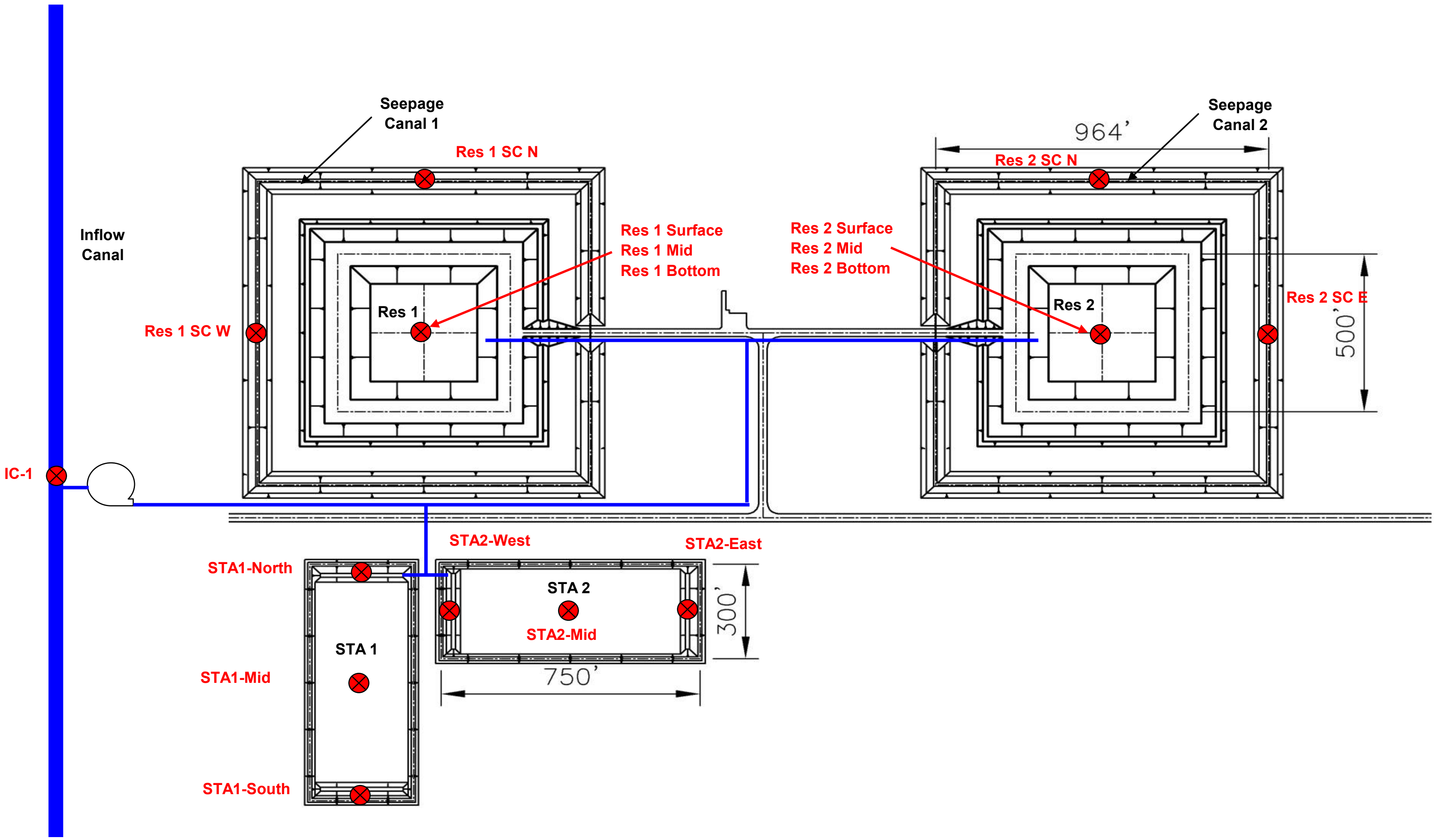
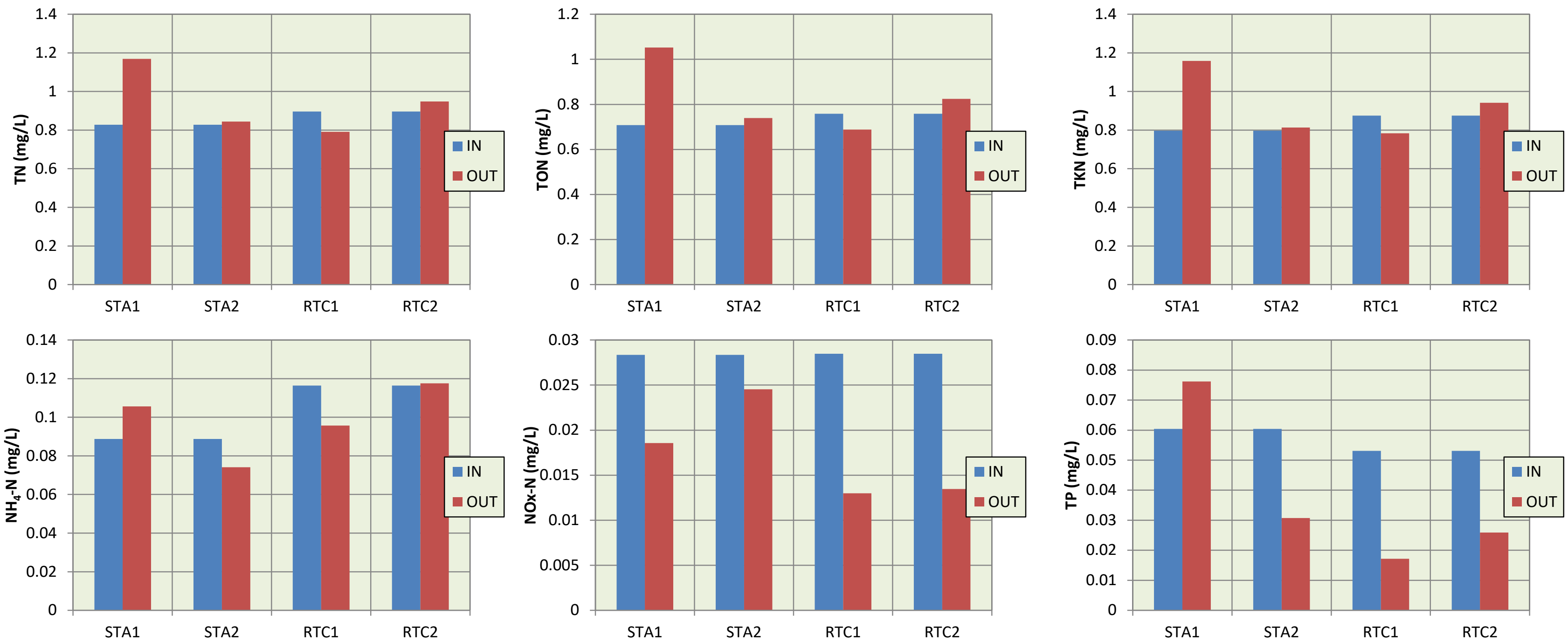
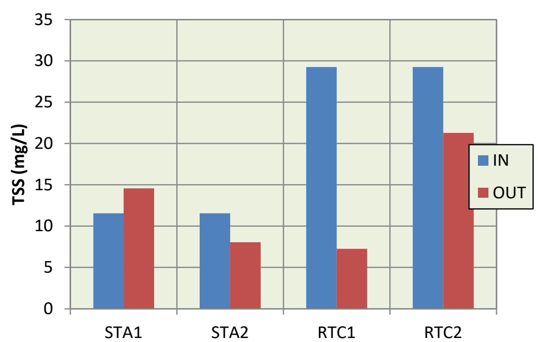


Figure 3-20. C-44 West Basin Storage Reservoir Test Cells (WSI, 2007b)





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.

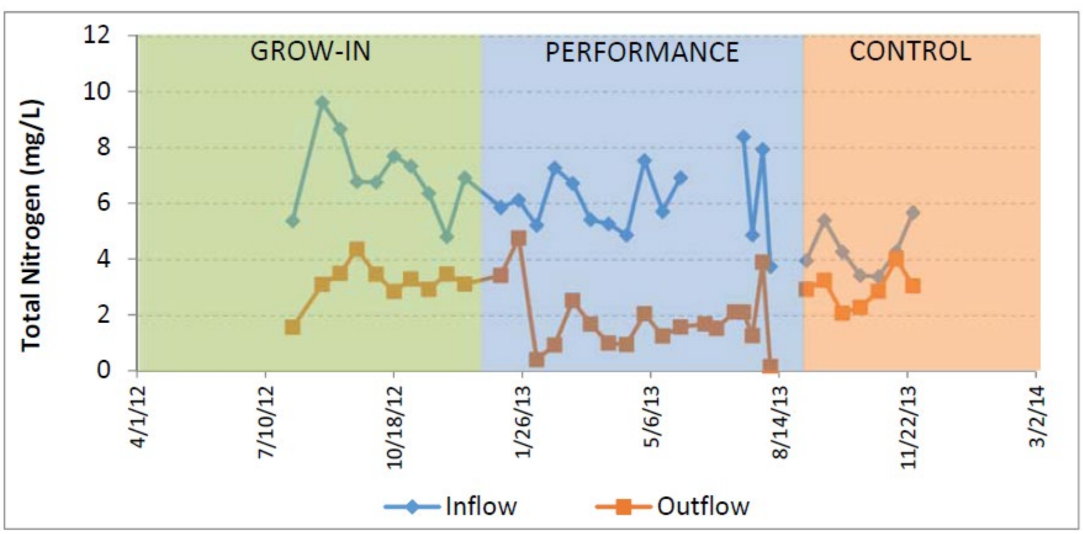


Figure 3-22. Pasco County FTW Nitrogen Performance (Vazquez-Burney et al., 2014)

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.

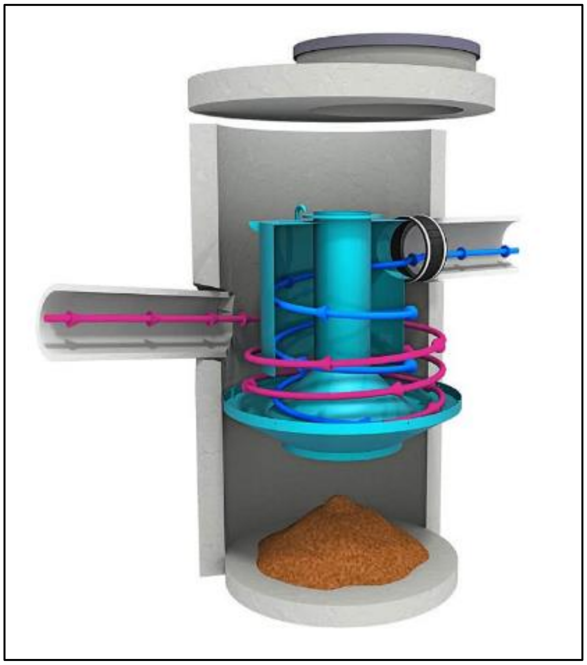


Figure 3-25. Hydro International Downstream Defender Flow Diagram (Hydro International, 2020b)

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.

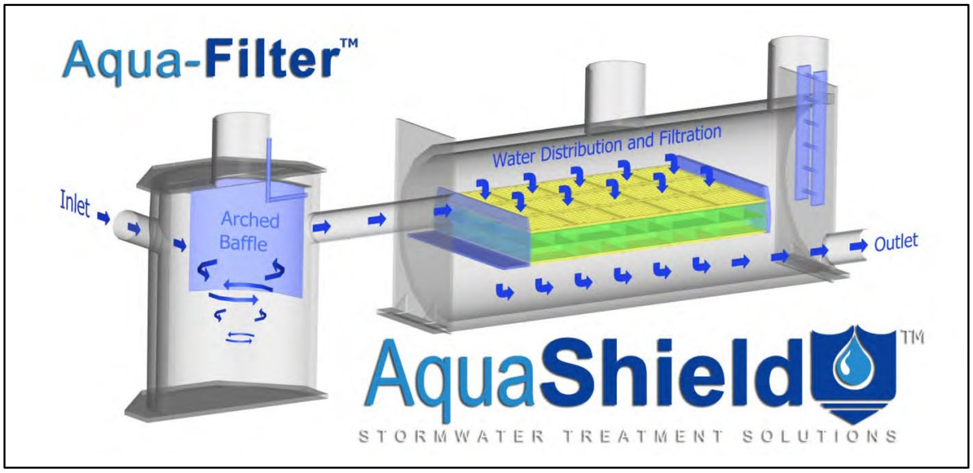


Figure 3-26. Aqua-Filter Water Treatment Process Diagram (AquaShield, Inc., 2013)

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.

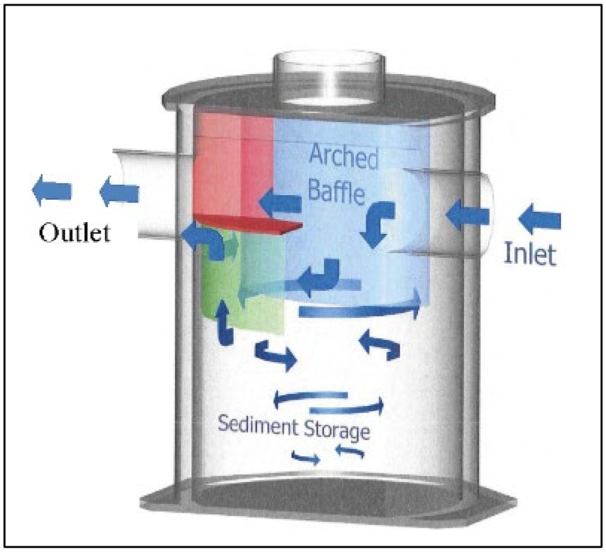


Figure 3-27. Aqua-Swirl Flow Pattern (AquaShield, Inc., 2020a)

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.

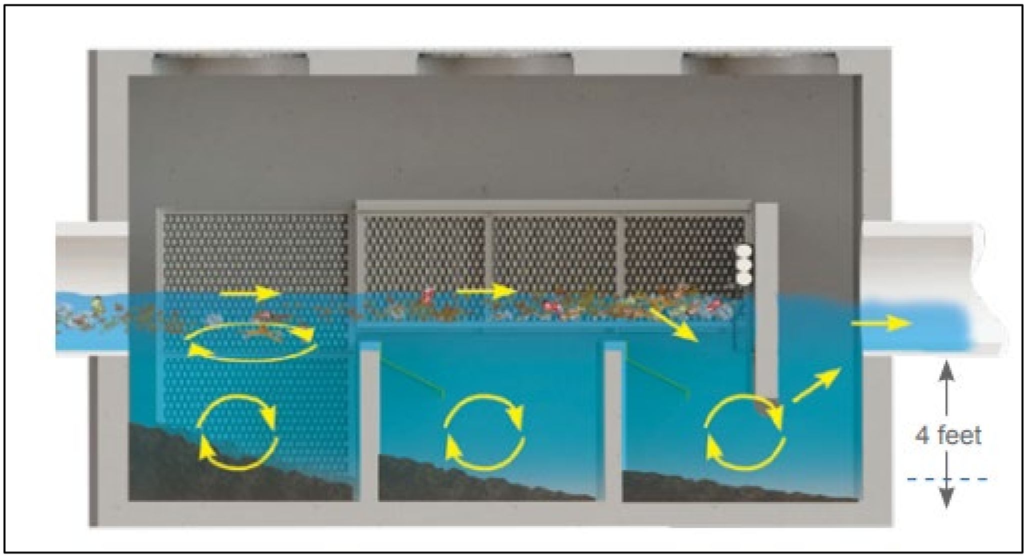


Figure 3-28. Debris Separation Baffle Box Flow Pattern (Kent, 2019b)

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.

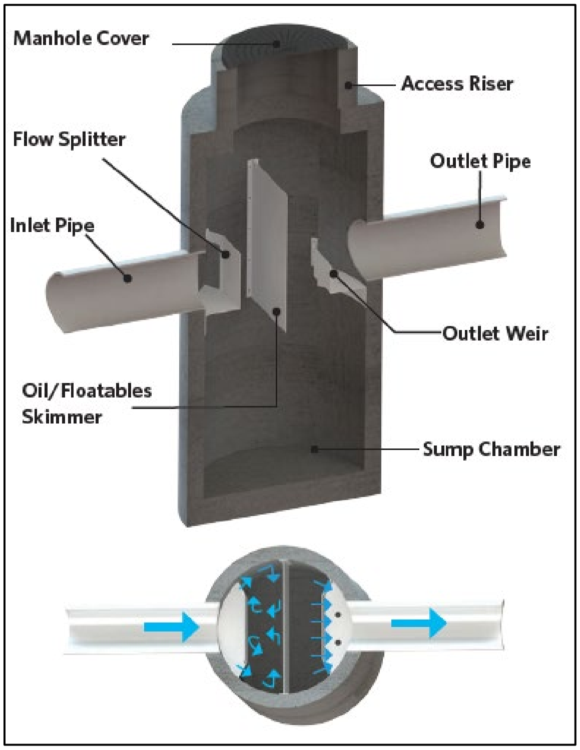


Figure 3-29. SciCLONE Components and Flow Path (Bio Clean, 2020)

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.

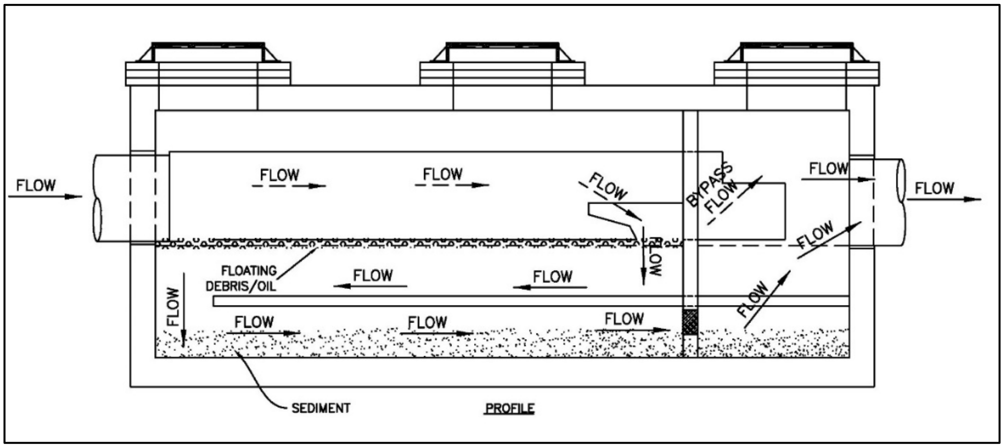


Figure 3-30. StormPro Flow Path (Environment21, 2019)

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.

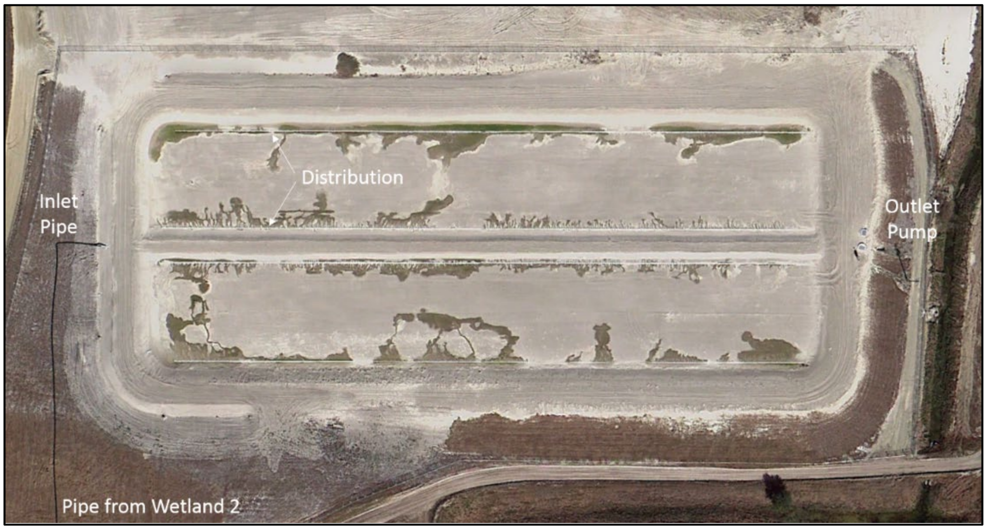


Figure 3-31. Sand Filters for Treatment of Phosphorus Mine Wastewater (Bays et al., 2019)

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.

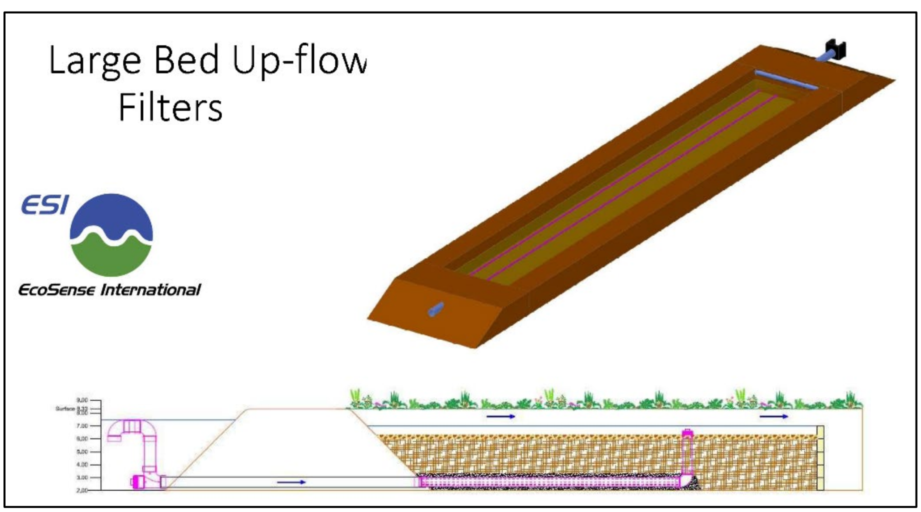


Figure 3-32. Example of NutriGone Large Bed Up-Flow Filters (EcoSense International, 2019)

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.

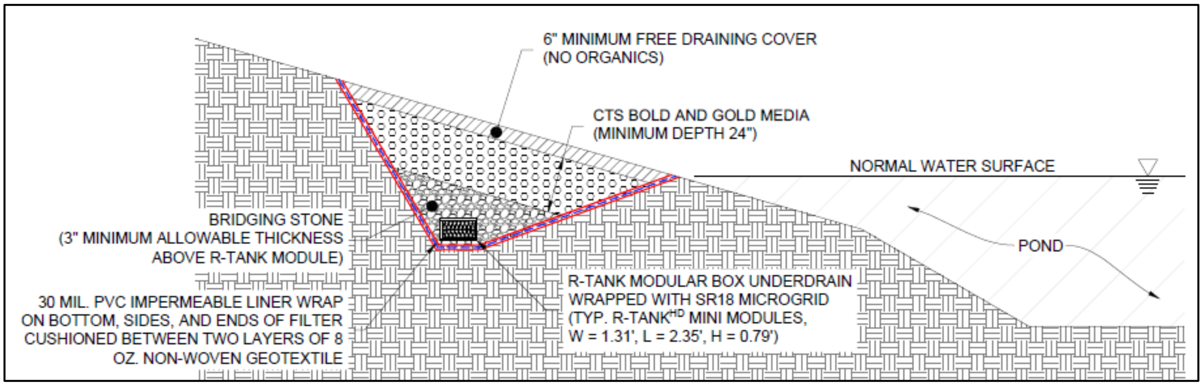


Figure 3-33. Example of Side Bank Filter Constructed by ACF Environmental (Gorneau, 2019)

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.

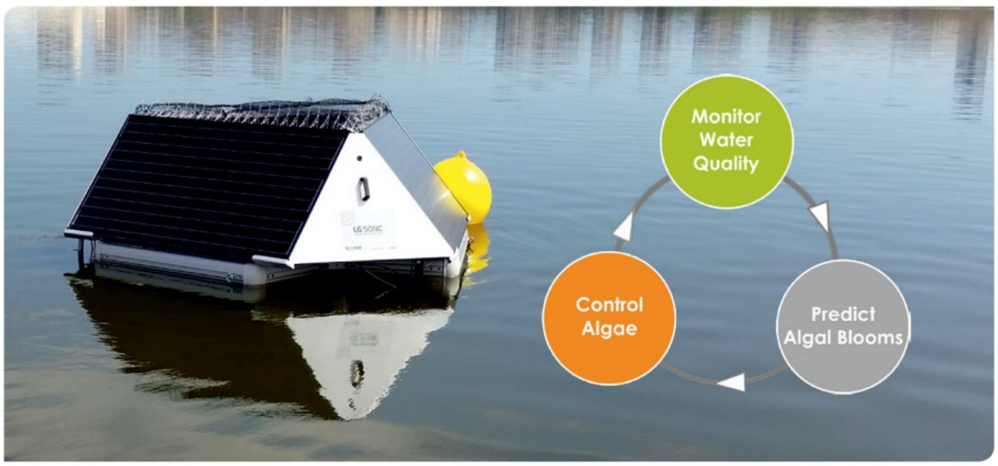


Figure 3-35. MPC-Buoy Technology and Three-Step Process (LG Sonic, 2020)

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.

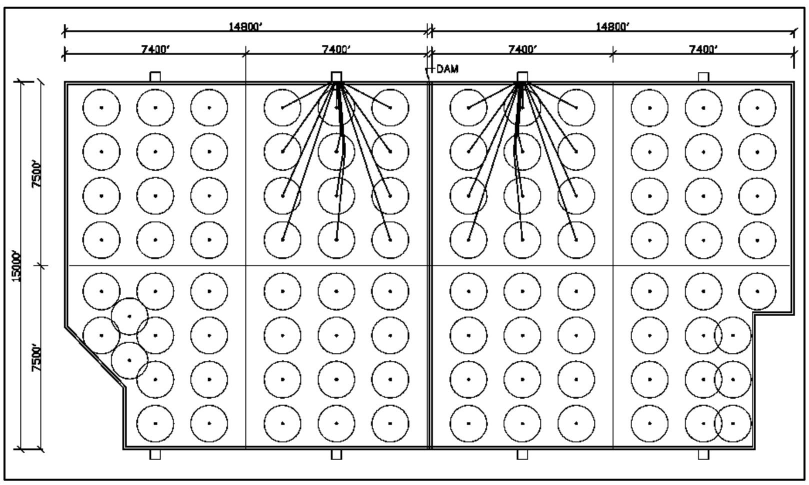


Figure 3-36. ADS Proposed System to Treat C-43 WBSR

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.

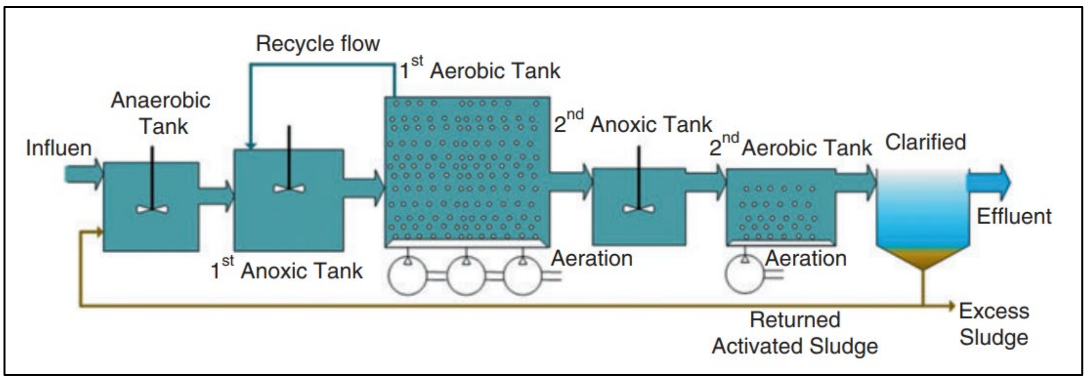


Figure 3-38. Illustration of the Bardenpho Process (Esfahani et al., 2018)

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.

5.0 References

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Appendix A: Technology Vendor Correspondence

If you would like to review Appendix A, please email your request to:
C-43WBSRWQFS@sfwmd.gov