Chapter 5C: Restoration Strategies Science Plan

Edited by R. Thomas James, Cassondra Armstrong, Jill King,
Kim O'Dell, Tracey Piccone, and Odi Villapando

SUMMARY

The *Restoration Strategies Regional Water Quality Plan* (Restoration Strategies; SFWMD 2012a) was established by the South Florida Water Management District (SFWMD or District) to achieve a stringent water quality based effluent limit (WQBEL) for total phosphorus (TP) concentration in discharge flow from the Everglades Stormwater Treatment Areas (STAs) to the Everglades Protection Area (EPA; FDEP 2012a, b, SFWMD 2012b). Consent orders associated with Florida Department of Environmental Protection (FDEP) permits for these STAs required SFWMD to develop and implement a science plan as part of Restoration Strategies to improve the understanding of mechanisms and factors that affect phosphorus (P) reduction and treatment performance in STAs, particularly those mechanisms and factors that are key drivers to performance in low TP environments (e.g., within the outflow region where TP concentration are at or below 20 micrograms per liter [µg/L]).

To meet the requirements of these consent orders, the *Science Plan for the Everglades Stormwater Treatment Areas* (Science Plan) was developed in 2013 (SFWMD 2013) and updated in 2018 (SFWMD 2018). The Science Plan is a framework to develop and coordinate scientific research to identify critical factors that influence P reduction treatment performance in the STAs. The ultimate purpose of scientific research is to support the design, operation, and management of STAs to achieve and sustain TP discharge concentrations that meet the WQBEL. The research focus is specific to the Everglades STAs and does not encompass science related to source control technologies upstream of the STAs, which falls under a separate program (see Chapter 4 of this volume).

The Science Plan includes key questions regarding STA physical, chemical, and biological processes, as well as STA optimization of management. These questions are used to develop research studies. Nine studies were initiated as part of the 2013 Science Plan and three others were started in Fiscal Year 2018 (FY2018; October 1, 2017–September 30, 2018) while the 2018 Science Plan update was under development (**Table 5C-1**). Note that the studies are not presented in a strict temporal sequence. Two additional studies were added in FY2019. Of these 14 studies, eight are ongoing and six are complete.

The status, update of progress, and key findings of ongoing or nearly completed studies are summarized in **Table 5C-2** and discussed further in this report. Monitoring of the inflow and outflow structures continues for the completed PSTA Study (see **Table 5C-1** for full study names) and an update of its P budget is included in this chapter. A detailed update of the Faunal Study is presented in Appendix 5C-1. Detailed findings from studies can be found in the *2019 South Florida Environmental Report* (SFER) – *Volume I*. P Flux, Cattail, Soil Management, Faunal, and Water and P Budget studies (see **Table 5C-1** for the full names or the studies) were provided in Appendices 5C-1, 5C-2, 5C-3, 5C-4, and 5C-5, respectively, of the 2019 SFER (Villapando and King 2019, Diaz and Vaughan 2019, Josan et al. 2019, Evans et al. 2019,

and Zhao and Piccone 2019, respectively). The current five-year (2018–2023) work plan, including the development of new studies, is included in the 2018 Science Plan (SFWMD 2018).

Table 5C-1. List of all studies initiated under the Science Plan.

Study Title	Initiation and Status
Evaluation of P Sources, Forms, Flux and Transformation Processes in the STAs (P Flux Study) – improve understanding of the mechanisms and factors that affect P reduction in the STAs, particularly in the lower reaches of the treatment flow-ways.	2013 Completed in 2019
Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability (Cattail Study) – assess cattail health under different inundation depths and durations to identify thresholds for cattail sustainability in the Everglades STAs.	2013 Ongoing
Use of Soil Amendments and/or Management to Control P Flux (Soil Management Study) – investigate the benefits of soil amendment applications and/or soil management techniques to reduce internal loading of P in the STAs.	2013 Ongoing
Investigation of STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Technology Performance, Design, and Operational Factors (PSTA Study) – assess the chemical, biological, design, and operational factors of the PSTA Cell that contribute to the superior performance of this technology.	2013 Completed in 2018
Evaluation of the Role of Rooted Floating Aquatic Vegetation (rFAV) in STAs (rFAV Study) – assess the ability of rFAV to further enhance low-level P reduction performance of submerged aquatic vegetation (SAV) communities.	2013 Completed in 2018
Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs (Tussock Study) – determine key factors that cause cattail plant floating and tussock formation in STAs.	2018 Ongoing
Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs (**Faunal Study**) – evaluate faunal processes and factors that affect the P treatment performance of STAs at low TP concentrations.	2018 Ongoing
Improving Resilience of SAV in the STAs (**SAV Resilience Study**)– investigate the effects of operational and natural environmental conditions on SAV health in the STAs	2018 Ongoing
STA Water and P Budget Improvements (Water and P Budget Study) – improve annual estimations of STA water and P budgets of treatment cells to better understand and assess treatment performance of STAs.	2013 Ongoing
Development of Operational Guidance for Flow Equalization Basin (FEB) and STA Regional Operation (Operation Study) – create tools and methodologies to provide operational guidance for FEBs and STAs.	2013 Completed in 2017
Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow P Concentrations (**Canal Study**) – determine if and how conveyance through STA inflow or outflow canals alters TP concentrations or loads.	2013 Completed in 2017
Evaluation of Sampling Methods for TP (Sampling Study) – identify factors that may bias water quality monitoring results in order to improve sampling procedures for the STAs.	2013 Completed in 2017
Periphyton and Phytoplankton P Uptake and Release (Periphyton Study) – estimate P uptake and release rates from periphyton and phytoplankton in downstream STA treatment flow-ways to determine their influence on the P cycle and TP discharge from STAs	2019 Ongoing
L-8 FEB Operational Guidance (L8-FEBOG) – provide guidance for FEB operations to moderate TP in discharge as affected by stage, flow, and groundwater.	2019 Ongoing

Table 5C-2. Status and key findings summary of the Science Plan's ongoing or recently completed studies.

Study	Status & Summary of Key Findings to Date
Evaluation of P Sources, Forms, Flux and Transformation Processes in the STAs (P Flux Study)	This multi-component study evaluates the mechanisms and factors that affect P treatment performance in the STAs. The components include flow-way (FW) water quality assessment, flux measurements, soil characterization, microbial enzymatic patterns, vegetation assessments, particulate transport and settling, and data synthesis and integration. The overall study has been completed and data evaluation and report writing will conclude in the coming months. Details on the latest key findings are provided later in this report and several of the various study findings were highlighted in Appendix 5C-1 of the 2019 SFER (Villapando and King 2019).
Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability (Cattail Study)	This study evaluates cattail (*Typha domingensis*) health under different inundation depths and durations to identify thresholds for sustainability in the STAs through field monitoring and evaluation of growth in test cells. Field monitoring of STA-1 West (STA-1W) Cell 2A and STA-3/4 Cell 2A was completed in 2018 and presented in Appendix 5C-5 of the 2018 SFER (Diaz 2018) and Appendix 5C-2 of the 2019 SFER (Diaz and Vaughan 2019). Deep water cattail stress (greater than 91 centimeters for over one-hundred consecutive days) was inferred from various measurements including cattail density, shoot elongation rate, and below ground biomass:leaf ratio. To study water depth effects on cattail in a more controlled environment, the 15 STA-1W northern test cells, which are 0.2 hectare in size, were refurbished. Cattail populations were established in these test cells and allowed to mature. Treatments, which include a range of water depth regimes and inundation durations, are to begin in July 2019.
Use of Soil Amendments and/or Management to Control P Flux (Soil Management Study)	This study investigates methods to reduce internal P loading in the STAs. This includes soil management techniques that can remove or bury P, and applications of soil amendments (e.g., chemical or biological materials typically rich in metal cations, primarily aluminum, calcium, iron or magnesium) that readily bond with dissolved P. A literature review found many technologies and amendments that may lower water column P concentration in constructed wetlands (Chimney 2015, 2017). For soil amendments, a decision was made to postpone indefinitely evaluations due to potential effects on STA operations and the downstream marsh, uncertainties in treatment efficacy, and high estimated costs. For management techniques, a burial method to reduce internal P loading was investigated. This technique, soil inversion or deep tilling, was used to remediate for high copper concentrations in surface soils as a requirement for construction and pre-operation of the STA-1W Expansion Area #1. The technique buried copper-enriched (and coincidentally P-enriched) surficial soils under low copper (and P) subsurface soils. An evaluation of the effects of the soil inversion on P in surface soils and flux of P from soil cores was reported in Appendix 5C-3 of the 2019 SFER (Josan et al. 2019). All cells in the STA-1W Expansion Area #1 were flooded in 2019. Start-up criteria have not been passed and the facility is not in operation as of this report. Weekly monitoring of water quality at the inflow and outflow structures of Cells 7 (tilled) and 8 (untilled) will commence once operations begin.
Investigation of STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Technology Performance, Design, and Operational Factors (PSTA Study)	This study evaluated the ability of periphyton-assisted treatment to remove P as a final polishing step. The science study was completed in Water Year 2018 (WY2018; May 1, 2017–April 30, 2018) and results were published in Chapter 5C of the 2019 SFER (James et al. 2019) and Appendix 5C-2 of the 2018 SFER (Zamorano et al. 2018). The PSTA Cell remains in operation and water quality (TP) and flow are monitored at inflow and outflow structures. The PSTA Cell performance data included in this chapter document the continued ability of the PSTA Cell to meet the WQBEL.

Table 5C-2. Continued.

Study	Status & Key Findings to Date
Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs (Tussock Study)	This study evaluates factors that may contribute to floating wetland community formation in STAs. Areas with healthy cattail populations are compared to areas that are prone to the formation of floating wetland communities. The study also assesses the effects of floating wetlands on STA treatment performance and evaluates factors contributing to their formation in the STAs. A nomenclature of floating wetland communities was developed from a literature review to describe these communities, which vary based on species, size, and floating matter. Multispectral imaging sensors carried on unmanned aircraft systems were used to find floating wetland communities in the STAs. This study is ongoing through September 2020.
Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs (Fauna Study)	This project continues an effort that was part of the P Flux Study to evaluate the effect of faunal communities on P cycling and reduction in the STAs through measurements of storage, excretion, and bioturbation. As part of this project, fish abundance surveys, bioturbation experiments, and excretion rate studies were conducted in 2018–2019 but only the excretion work is reported here. Excretion rate estimates by small fish species (e.g., eastern mosquitofish [*Gambusia holbrooki*]) were higher per kilogram (kg) of weight than those of larger species (e.g., sailfin catfish [*Pterygoplichthys multiradiatus*]) for P and nitrogen (N). Combining fish abundance and excretion measurements in the STAs suggests that fish have a substantial effect on water column nutrient concentrations. The six dominant fish species are estimated to excrete 228 kg of N and 52 kg of P per day in STA-2 Cells 3, 4, 5, and 6 combined. These amounts are equivalent to 6% of the average annual N load and 53% of the average P load entering STA-2. More detailed information is presented in Appendix 5C-1. The excretion study is completed. The fish surveys and bioturbation work are ongoing through 2019.
Improving Resilience of Submerged Aquatic Vegetation (SAV) in the STAs (SAV Resilience Study)	This study investigates the effects of operational and environmental conditions on the health of SAV in the STAs. A literature review and an analysis of the 18 years of semi-quantitative STA surveys of SAV are complete. The literature review and analysis indicate that chemical, physical, and biological conditions as well as nutrients in the water column and soils can affect SAV resilience. The most influential factors were P loading, soil type, and water depth. Two mesocosm experiments are now ongoing to evaluate soil substrate (farm muck, aged muck, and marl) and nutrient load on rooted SAV and *Chara*, respectively.
STA Water and P Budget Improvements (Water and P Budget Study)	This effort improves annual estimates of STA water and P budgets for STA treatment cells to more accurately assess STA performance (e.g., P retention) and to identify areas of uncertainty in these calculations. A test case to improve the water budget for STA-3/4 Cells 3A and 3B used better quality structure flow data, which improved budget estimations (Polatel et al. 2014). The method has been applied to the FWs of STA-2 (Zhao and Piccone 2018) and STA-3/4 (Zhao and Piccone 2019). This study is ongoing through 2023.
Periphyton and Phytoplankton P Uptake and Release (Periphyton Study)	This study evaluates nutrient dynamics of periphyton and phytoplankton in downstream STA treatment FWs where TP concentrations are very low (≤ 20 µg/L). This includes nutrient uptake and release, growth, respiration, senescence, and death. In the first phase of this study, a literature review of the methods to measure these various processes was completed. The next phase will include bench top and field studies to measure these various processes. This study is ongoing through 2022.
L-8 FEB Operational Guidance Study (L-8 FEBOG)	The objective of this study is to evaluate the relationships of internal L-8 FEB water quality to stage, surrounding groundwater, and the inflow and outflow structures of the FEB. This study will provide guidance for FEB operations to support management of STA-1 East and STA-1 West. Phase I of this study is a data collection effort to evaluate water quality (nutrients, ions, temperature, dissolved oxygen, and conductivity) monthly, from January through August 2019, and groundwater quality quarterly, from January to July 2019.

INTRODUCTION

The STAs are freshwater treatment wetlands constructed to reduce TP concentration in surface water runoff before being discharged to the EPA (**Figure 5C-1**). The STAs, which are operated by SFWMD, are a major component of the *Restoration Strategies Regional Water Quality Plan* (SFWMD 2012a). There are five STAs: STA-1 East (STA-1E), STA-1 West (STA-1W), STA-2, STA-3/4, and STA-5/6; with an approximate effective treatment area of 57,000 acres [23,067 ha]. In addition, two flow equalization basins (FEBs), A-1 FEB and L-8 FEB, have been constructed as components of Restoration Strategies and are operated to attenuate peak stormwater flows and improve inflow delivery rates to downstream STAs.

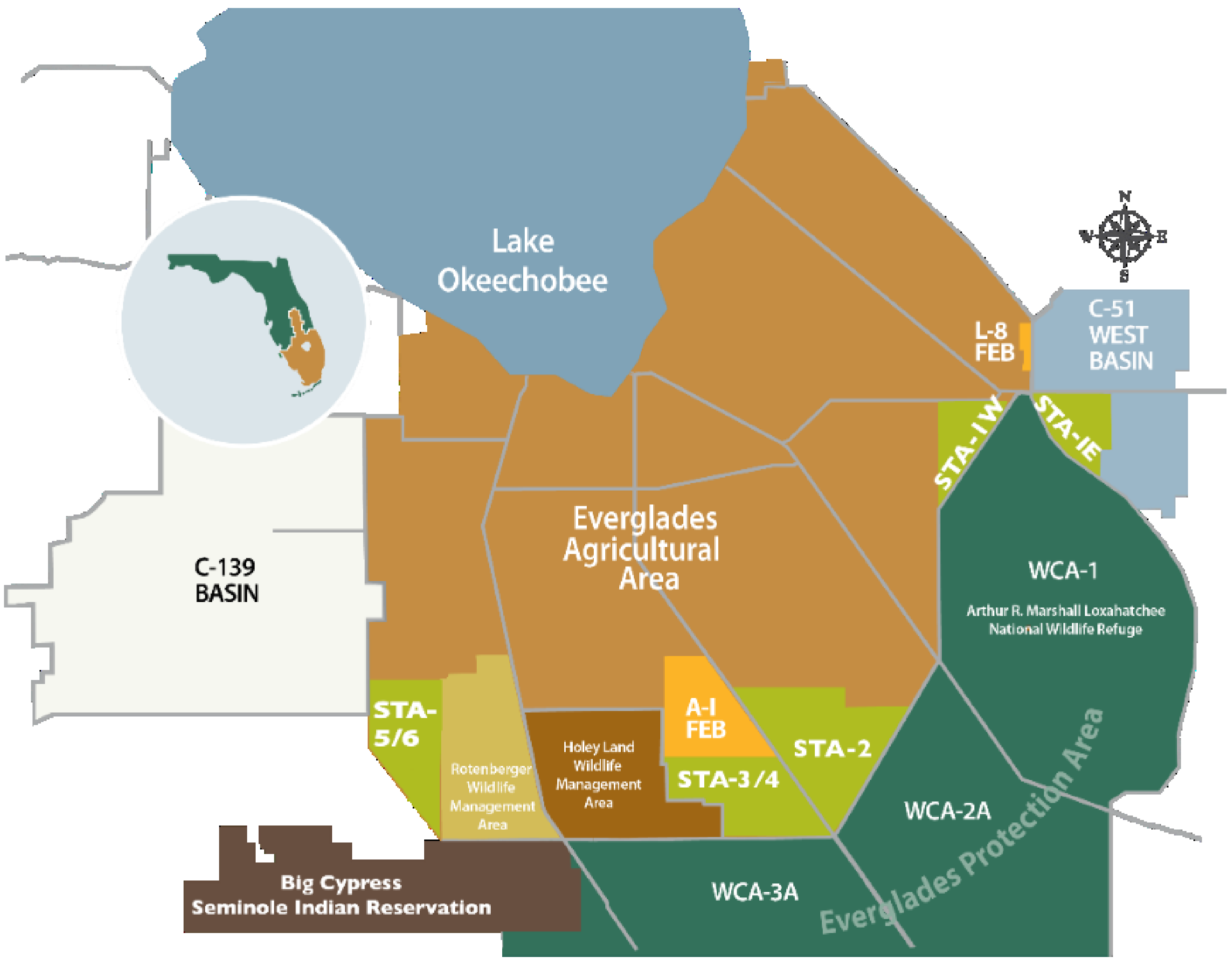

Figure 5C-1. Location of the STAs (STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6) and the FEBs (A-1 and L-8) in relation to the Everglades Agricultural Area, C-139 Basin, EPA, and other landscape features of South Florida. Maps of individual cells and flow-ways for all STAs can be found in Appendix 5B-1 of this volume.

The STAs, located primarily on former agricultural lands, retain nutrients through plant and microbial uptake, particulate settling, chemical sorption, and ultimately accretion of this material to the soil layer. Over the period of record, which started in 1994, all STAs combined have reduced TP loads by 77% and achieved an average outflow TP concentration of 31 µg/L (see Chapter 5B, Table 5B-1 of this volume). Treatment performance was affected in Water Year 2018 (WY2018; May 1, 2017–April 30, 2018) by two major storms, and the system is recovering with TP discharge concentrations approaching pre-WY2018 levels (see 2019 SFER Chapter 5B; Chimney 2019). Work initiated through the Science Plan, and reported in this SFER chapter, supports the development of strategies to meet the WQBEL criteria at the STA outflows.

The WQBEL was established in two permits for operating the STAs: (1) a National Pollution Discharge Elimination System (NPDES) watershed permit, and (2) an Everglades Forever Act (EFA) watershed permit. These permits defined a stringent limit for TP in discharges from the Everglades STAs. The WQBEL is a numeric discharge limit to assure that TP discharges from the STAs do not cause or contribute to exceedances of the 10-µg/L TP criterion (long-term geometric mean) within the EPA. The WQBEL includes two parts: (1) TP as an annual flow-weighted mean concentration (FWMC) discharged from each STA shall not exceed 13 µg/L in more than 3 out of 5 water years on a rolling basis; and (2) the annual FWMC from each STA shall not exceed 19 µg/L in any water year. The WQBEL is separate from the 4-part test for the Everglades TP criterion (62-302.540(4)(d)1, Florida Administrative Code).

Consent orders associated with the two permits for STA operation required SFWMD, in consultation with Restoration Strategies Technical Representatives from the United States Environmental Protection Agency, Florida Department of Environmental Protection (FDEP), United States Army Corps of Engineers, and United States Department of the Interior (Everglades National Park and United States Fish and Wildlife Service), to develop and carry out the Restoration Strategies Science Plan. The consent orders specify that the Science Plan must evaluate mechanisms and factors that affect P reduction and treatment performance, particularly those that are key drivers to performance at low TP concentrations (i.e. < 20 µg/L), with the goal of attaining the WQBEL. In 2013, the Science Plan was developed and defined nine studies that were implemented from 2013 to 2017 (SFWMD 2013). The Science Plan was updated in 2018 and this update included three additional studies that began in 2018. An additional eight studies have been proposed for the next five-year period (2018–2023; SFWMD 2018). In WY2019, two additional studies were initiated. Results from these studies will be used to inform the design and management of the STAs to further improve STA performance. Related data and information gathered from these studies will also be incorporated into the development and refinement of SFWMD's operational guidance tools.

RESEARCH QUESTIONS

To increase our understanding of mechanisms and factors that affect P treatment performance, the original Science Plan included six key questions and 39 subquestions formulated through workshops and meetings that reviewed existing knowledge and information gaps (SFWMD 2013). The nine original studies were developed from a subset of these questions. The 2018 Science Plan reviewed these key questions and subquestions to assess their continued relevance to achieving the WQBEL, to determine if they had been fully addressed in the initial five years of Science Plan implementation, and to reevaluate if a meaningful and cost-effective study could be designed to address them (SFWMD 2018). In addition, several questions were revised for clarity and to make them more general to encompass multiple variables. Ongoing studies (**Tables 5C-1** and **5C-2**) are addressing nine research subquestions:

1. What key factors affect and what management strategies could improve system resilience of submerged aquatic vegetation (SAV) communities?
2. What key factors affect and what management strategies could improve system resilience of emergent aquatic vegetation (EAV) communities?
3. What is the role of vegetation in modifying P availability to low-P environments, including the transformation of refractory forms of P?
4. What are the key physicochemical factors influencing P cycling in very low P environments?
5. Are there design or operational changes that can be implemented in the STAs to reduce particulate phosphorus (PP) and dissolved organic phosphorus (DOP) in the water column?

6. What is the treatment efficacy, long-term stability, and potential impacts of soil amendment management?
7. What are the sources, forms, and transformation mechanisms controlling the residual P pools within the different STAs, and how do they compare to the natural system?
8. What are direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (e.g., are they net sinks or sources)?
9. How should storage in the FEBs be managed throughout the year so water can be delivered to the STAs in a manner that allows them to achieve desired low outflow TP concentrations?

RESEARCH STUDIES

Because of the extensive number of questions and subquestions developed in the 2013 Science Plan, key questions and subquestions were prioritized and nine studies were initiated in 2013 (**Table 5C-1**). Of these nine studies, three were completed in 2017, two in 2018 and one will be completed in 2019. Three additional studies were implemented in FY2018 during the development of the 2018 Science Plan. Two studies proposed in the 2018 Science Plan were initiated in FY2019. Six additional studies have been proposed in the updated Science Plan (SFWMD 2018; **Table 5C-3**). Further synthesis and integration of data are planned in the future as more data are gathered to better understand the intricacies of STA performance, develop management actions, and identify uncertainties and information gaps that could direct future studies.

Table 5C-3. New studies proposed in the 2018 five-year workplan (Appendix A, SFWMD 2018).

Study Name	Subquestion(s) Addressed	Associated Key Questions
Sustainable Landscape and Treatment in an STA (Landscape Study)	What are the effects of topography on STA performance? What key factors affect and what management strategies could improve system resilience of EAV communities? What are the key physicochemical factors influencing P cycling in very low P environments? Are there design or operational changes that can be implemented in the STAs to reduce PP and DOP in the water column?	What operational or design refinements could be implemented at existing STAs and future features, including the STA expansions and FEBs/reservoirs, to improve and sustain STA treatment performance? What measures can be taken to enhance vegetation-based treatment in the STAs?
Quantifying the Recalcitrance and Lability of P to Optimize P Retention within STAs (Biomarker Study)	What are the key physicochemical factors influencing P cycling in very low P environments? Are there design or operational changes that can be implemented in the STAs to reduce PP and DOP in the water column? What are the sources, forms, and transformation mechanisms controlling the residual P pools within the STAs, and how do they compare to the natural system? What is the role of vegetation in modifying P availability in low P environments, including the transformation of refractory forms of P?	How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the STAs? How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce soluble reactive phosphorus (SRP), PP, and DOP concentrations at the outflow of the STAs?
The Effect of Vertical Advective Transport on TP Concentrations in the STAs (Advective Transport Study)	Will reduced advective loading from the soil to the water column reduce P concentrations out of the STAs?	What operational or design refinements could be implemented at existing STAs and future features, including the STA expansions and FEBs/reservoirs, to improve and sustain STA treatment performance?
P Reduction Dynamics in STA-1E, STA-1W, STA-2, and STA-5/6 (P Dynamics Study)	What are the key physicochemical factors influencing P cycling in very low P environments?	What operational or design refinements could be implemented at existing STAs and future features, including the STA expansions and FEBs/reservoirs, to improve and sustain STA treatment performance? How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the STAs? How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce SRP, PP, and DOP concentrations at the outflow of the STAs?
Prescribed Burn Effects on Cattail Communities (Burn Study)	What key factors affect and what management strategies could improve system resilience of EAV communities?	What measures can be taken to enhance vegetation-based treatment in the STAs?
Assess Benefits and Feasibility of Consolidating Accrued Marl in the STAs' SAV Cells (Marl Study)	Are there design or operational changes that can be implemented in the STAs to reduce PP and DOP in the water column? What is the treatment efficacy, long-term stability, and potential impact of soil amendment management?	How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the STAs? How can the biogeochemical or physical mechanisms, including internal P flux, be managed to further reduce SRP, PP, and DOP concentrations at the outflow of the STAs?

EVALUATION OF PHOSPHORUS SOURCES, FORMS, FLUX AND TRANSFORMATION PROCESSES IN THE STORMWATER TREATMENT AREAS

Jill King and Odi Villapando

The purpose of this study, referred to as the P Flux Study, is to evaluate mechanisms and factors that affect P treatment performance of the STAs, with a focus on the outflow regions of the treatment flow-ways (FWs). Results from this study will assist in the development of management strategies to improve the overall function and operation of STAs to achieve permit compliance with the WQBEL. Six study components: FW water quality assessments, internal P load measurements, soil P forms, microbial enzymatic patterns, vegetation assessments, and settling and entrainment of STA particulates, were highlighted in the 2019 SFER Appendix 5C-1 (Villapando and King 2019). The latest updates and findings from the studies are included in this section and **Table 5C-4**.

All laboratory and field work associated with all study components are now complete. Data evaluation and reporting will be complete by September 2019. A total of ten controlled flow events and associated measurements were carried out in STA-2 FWs 1 and 3 and STA-3/4 Western FW (Cells 3A and 3B). There was a distinct decreasing gradient in TP concentrations from inflow to outflow of all study FWs, with PP and DOP dominating the residual P pool at the outflow region. Similar decreasing trends of nutrients were observed in the vegetation, particulates, and soils from inflow to outflow of STA-2 FWs 1 and 3 and STA-3/4 Western FW. Data integration efforts are substantially complete with two key approaches to address study questions using many STA data sets and newly acquired data from this study. The two different modeling approaches show promise for integrating the various data sets collected from all study components and explaining the internal processes that affect outflow P concentrations.

Table 5C-4. P Flux Study summary of progress to date.

Substudy	Status and Comments	Publications and Reports
Data Integration	This effort has been substantially completed using a numerical version of a conceptual model that allows the assimilation of different (yet connected) data streams. This bottom up model approach identifies the various fluxes and transformation among the major P reservoirs within a wetland shown on a 1-dimensional grid where the spatial dimension is the direction of water flow. When integrated with existing data, key processes (settling, resuspension, etc.) were captured well with a better model-data match for EAV than for SAV. The top down approach focused on two major controlling variables, internal load and flow. The resultant Low-P Wetland Event Model (LPWEM) was developed through evaluation of transect data and the effects of varying flows to determine outflow P concentrations (see Flux Substudy below). Model results suggest that internal loading was primarily responsible for outflow P concentrations. The current version of LPWEM was evaluated by SFWMD modelers. There were some concerns about model results and they suggested that LPWEM could be improved by simulating STA flow-ways with good treatment performance and flow-ways with poor treatment performance.	University of Florida 2019 Jerauld et al. 2019 Juston and Kadlec 2019 SFWMD 2019b
Organic P Speciation	A suite of biomarkers (lignin phenols, amino acids, and pigments) was used to evaluate the quality of organic matter (OM) in sites within STA-3/4 and WCA-2A and assess linkages between carbon (C) and P cycling within these two systems, with a particular emphasis on particulate OM and P dynamics. five components of the system, water column, sediment collected from vertical sediment traps, flocculent material, periphyton, and 0- to 5-centimeter soil, were sampled to determine OM transformations both down-profile (i.e., water column to soil) and among sites dominated by EAV and SAV. More vascular plant-based OM was found in EAV areas, and more algal-based OM was in SAV areas. Treatment SAV areas have fresher and more degradable OM than the reference wetland sites. Other than dense cattail areas, water column particulate organic C in SAV areas was derived from microbial/cryptomonad sources, rather than macroscopic sources (vascular plants and algal mats) as was found in the EAV areas. Amino acid degradation indices and organic P, were positively correlated with bacterial amino acid biomarkers, suggesting microbial abundance was associated with “fresher” OM. These results highlight how this type of multi-biomarker approach may evaluate the relative “freshness” of OM pools, identify sources of OM, and highlight the importance of water column processes in P cycling in STAs.	University of Florida 2019 Morrison et al. in review
Flow-way Assessment	This is a field evaluation of biogeochemical response of three well performing STA FWs to different flow conditions: high, moderate, low, and no flow. A total of 10 controlled flow events were conducted in STA-2 FWs 1 and 3 and in the Western FW of STA-3/4 (Cells 3A and 3B) between August 2015 and July 2017. There was a distinct TP concentration gradient from inflow to outflow at all phases of the flow events for both STAs. The magnitude at which P is removed from the water column per unit increase in distance from the inflow was greater for EAV-dominated systems (STA-2 FW 1 and STA-3/4 Cell 3A) than SAV-based systems (STA-2 FW 3 and STA-3/4 Cell 3B). When data were pooled from all flow events and grouped into flow (combining data from low, moderate, and high flow periods) and no flow, a significant increase in TP concentrations in SAV-dominated systems was observed under the no flow condition. The increase was attributed to in-situ production of PP through several processes that include phytoplankton growth, periphyton sloughing, litter fragmentation, resuspension via entrainment or bioturbation, and horizontal transport. soluble reactive phosphorus (SRP) was the dominant P species in the inflow water and accounted for the majority of the reduction in TP concentration along the FW under flow and no flow conditions. PP and DOP comprised the residual P pool at the back end of the FW with concentrations being slightly higher in SAV-based systems than in EAV systems under no flow condition. The increase in TP concentrations under no flow condition has important implications for STA operation and performance.	University of Florida 2019
Flux Measurement	This substudy evaluated the gradual increases of water TP concentrations that reached an equilibrium during no flow phases of many flow events. The most likely explanation for this increase is internal loading of P from the underlying soils of the STAs. Through P flux research and a compilation of additional STA data sets, LPWEM was developed and used to estimate these internal P loading rate magnitudes successfully for STA-2 FW 1 and FW 3. LPWEM has been reviewed by SFWMD modelers.	Jerauld et al. 2019 SFWMD 2019b

Table 5C-4. Continued.

Substudy	Status and Comments	Publications and Reports
Particle Dynamics	This substudy is complete. A major finding was that primary drivers of velocity in the STAs are gate operations, wind, and distance to remnant agricultural canals and ditches. The highest velocities were found near inflow and outflow structures and remnant canals/ditches. For all flow events, inflow regions of both STA-2 and STA-3/4 Cell 3B had the highest observed sediment settling/resuspension and net accumulation rates. Net sediment P accumulation rates into floc were similar in magnitude to cell-specific (i.e., inflow, mid-flow, and outflow) net P storage inferred from water-derived (velocity x water TP) mass balances for STA-2 FW 3; however, the lower storage rate in STA-3/4 Cell 3B suggested either lower accumulation, higher erosion, or more spatial variability (not yet quantified) at the inflow region of this cell. While this work highlights the importance of P accumulation into (or loss from) floc in driving P retention, refining the relationships between P accumulations and hydrologic conditions (e.g., flow velocities, depth, vegetation, or topography management), will improve our ability to optimize retention in the future. From the tests on sheer stress of the benthic sediments in cells dominated by SAV at relatively low and stable water velocities (< 0.5 centimeter/second [cm/s]), water column particulates are most likely coming from sloughed SAV biomass, rather than benthic sediments, and driven by wind-wave shear stress rather than velocity-driven shear stress. However, localized high flows (> 5 to 20 cm/s) in remnant farm ditches in the outflow cell of STA-2 FW 3 suggest future efforts relating resuspension of benthic sediments to flow deserve further attention. In STA-2 FW 3, rates of PP resuspension and settling (gross and net), derived from a synthesis of sediment trap data and lab- and field-measured resuspension, are approximately 10 times higher than total P loading and accumulation rates derived from cell-specific, water-derived mass balance. Therefore, the potential for large swings in P storage or loss may be expected depending on the factors that drive these fluxes.	Florida International University 2019
Soil Characterization	All substudies included in this soil characterization work are complete. The litter decomposition substudy found that in P-enriched inflow region of the FW, SAV decomposed more quickly than EAV and leached more P during initial decomposition. At the outflow region, P limitation regulated decomposition in both EAV and SAV. Results from the abiotic degradation study indicated that the decomposition of dissolved organic matter (DOM) was catalyzed by ultra-violet photodegradation and hydrogen peroxide, which is a significant pathway to the mineralization of organic P and C. DOM was processed to a greater degree in STA-2 FW 3 (SAV) than in STA-2 FW 1 (EAV) due to the extent of open water in FW 3. FW 1 experienced greater DOM production and increased concentration of aromatic structures in discharge waters. The spatial and temporal patterns of P and related elements in soils resulted in high P enrichment of floc at the inflow regions of the FWs but was much higher and more spatially expansive in EAV than SAV areas of the STAs. Through steady nutrient loading to the STAs, the accumulation of P along the upper regions of the FWs resulted in lower nitrogen (N):P ratios in both floc and recently accreted soil, suggesting a shift from P limitation to N limitation. All forms of soil P in the STAs increased as a result of P loading, with a large proportion of P stored in an inorganic form in SAV and organic form in EAV sites. These soil layer results provide further insight into how the different components of the STAs process nutrients and the associated biogeochemical processes. The ability of soils to retain and release P was influenced by vegetation type, depth in the profile, and distance from the inflow. The floc and recently accreted soil were more bioreactive than underlying sediments. SAV-dominated sites generally exhibited lower equilibrium P concentration, indicating a greater potential to retain P at lower floodwater P concentrations. The higher equilibrium P concentration of EAV-dominated sites indicates that P is less likely to be retained at lower floodwater P concentrations. Distance along the flow gradient exhibited inconsistent results with respect to P sorption. P desorption potential was generally not affected by distance from inflow but tended to be higher under EAV- than SAV-dominated sites. Controlling factors of P sorption parameters included extractable and total iron and aluminum for EAV-dominated FWs while calcium and magnesium exerted more of an effect for SAV-dominated FWs P exchange between floc/soil and the overlying water column indicated a significant influence of vegetation community regulation of internal P load as SAV soils exhibited a greater P retention capacity than EAV. P flux from floc to overlying water was higher in upstream areas of the flow path as compared to downstream areas.	University of Florida 2019

Table 5C-4. Continued.

Substudy	Status and Comments	Publications and Reports
Vegetation Assessment	The pilot study of Worldview satellite imagery has been completed. Satellite data acquired during the wet and dry seasons provided spectral signatures for vegetation classes at different stages of the phenological cycle. These data were then ground-truthed to verify the imagery. Differences in SAV and EAV spectral signatures could be detected for SAV areas dominated by a single species, specifically *Chara*. Mixed SAV species beds were more difficult to distinguish. When cross-validated with ground-truthing, the spectral analysis found 96% of reference samples were classified correctly. Phase II will proceed with recommendations to acquire imagery under conditions of shallow water depths, conduct ground-truthing as close to imagery acquisition as possible, and to simplify the classification scheme with no more than six classes. The vegetation nutrient study analysis was completed for STA-2 FW 1 and FW 3. Two harvesting events were completed in STA-3/4, however results were not available at time of this report. Nutrient analysis results for STA-2 showed higher nutrient storages (P, N, and C) for EAV compared to SAV. Of the SAV species, *Chara* had the highest nutrient storages of all species. EAV biomass and performance were consistent throughout the study in FW 1 while FW 3 experienced a decline in performance following the significant loss of SAV.	Gann et al. 2019
Enzyme Activity	Enzyme assay analyses have been completed for all 10 planned flow events in STA-2 and STA-3/4. The study was designed to look for trends and patterns along the nutrient gradients within the FWs and within the dominant vegetation communities (EAV and SAV). Enzyme activities related to C, N, and P cycling in four different wetland components (surface water, periphyton, floc, and litter) were measured. Overall enzyme activities were highly variable along the FWs under differing flow conditions, as demonstrated in the surface water analyses, where no obvious trends were observed due to high variation. Litter was not found in sufficient quantities at all study sites to provide conclusive results. Flow had a major influence on nutrient limitation in the floc with more N-limited conditions found in EAV areas and more P-limited conditions in SAV areas. Higher phosphatase activity was found in floc from the outflow region of SAV areas under flow conditions. In periphyton, enzyme activities were variable along the nutrient gradient and among the different vegetation communities. Periphyton biomass generally increased during flow with the greatest accumulation at inflow locations. Periphyton in EAV areas had approximately 10% more organic matter (60 to 65%) than SAV areas. Periphyton enzyme activity varied among vegetation types and flow regimes. For EAV areas, C-acquiring enzyme activity was highest during flow. For SAV areas, enzyme activity was lowest during flow. P-acquiring enzyme activity increased along the nutrient gradient of both EAV and SAV areas, indicating greater P-limiting conditions at the outflow. P enzyme activity was not affected by flow for EAV sites and increased at SAV outflow locations. N enzyme activity increased during no flow conditions for both vegetation communities. A new periphyton study will focus on the transformations of P uptake and release in the periphyton/phytoplankton community along with determining the rates of periphyton growth, productivity, and senescence, especially at the outflow regions of the STAs.	University of Florida 2019

EVALUATION OF INUNDATION DEPTH AND DURATION THRESHOLD FOR CATTAIL SUSTAINABILITY

Orlando Diaz

The purpose of this study, referred to as the Cattail Study, is to identify the inundation depth and duration threshold to sustain cattail (*Typha domingensis*) communities in the STAs. Dense cattail communities in the upper region of a treatment FW reduce particulates in the water column and facilitate microbial P cycling through production of litter. Previous field observations and studies have indicated that water depths exceeding certain criteria and maintained over long periods cause increased physiological stress to cattail plants, reducing growth, biomass, density, and anchorage capacity in EAV treatment cells. The study has two main components: (1) in situ surveys, and (2) a test cell study (controlled depth study).

The in situ component of this study was completed in 2018, and results are reported in Appendix 5C-5 of the 2018 SFER (Diaz 2018) and Appendix 5C-2 of the 2019 SFER (Diaz and Vaughan 2019). Results indicated that prolonged water depths above 91 centimeters (cm) for over 100 consecutive days resulted in a decline of both cattail density and total belowground biomass, as well as increased leaf elongation in response to the high water.

The test cell study is in its initial phase of implementation. Cattail were planted in 2018 and allowed to grow in the 15 STA-1W northern test cells (0.2 hectare in size). As of June 2019, healthy cattail populations have been established and matured to a condition appropriate to begin the experiments (**Figure 5C-2**). The cells will be flooded with a range of water depth regimes and inundation durations over the next year (**Table 5C-5**).

Figure 5C-2 Aerial view of STA-1W Northern Test Cells showing cattail communities prior to initiation of experiments

Table 5C-5. Status and highlights for the Cattail Study.

Task	Status and Comments	Publications and Reports
In Situ Surveys – STA-1W Cell 2A	Year 1 wet season cattail monitoring was completed in October 2015. Evaluation of this cell was discontinued due to widespread decline of cattail conditions, including the presence of floating cattails.	Diaz 2018
In Situ Surveys – STA-3/4 Cell 2A	Cattail monitoring began in 2015 and was completed in early 2018. Results from the three monitoring seasons indicate significant stress to cattail when water depth was greater than 36 inches (91 cm) for more than 100 consecutive days.	Diaz and Vaughan 2019
Test Cell Study	STA-1W Northern Test Cells were refurbished in 2016. Weed control and inflow pump testing continued through 2017. Cattail seeds were applied to test cells the first week of May 2018. Young cattail seedlings of 5 to 6 inches (12 to15 cm) in height (50 to 55 days old) were planted at a density of approximately 140 cattail plants per cell from mid-May 2018 through mid-June 2018. Water levels were maintained between 4 to 6 inches (10.2 to 15.2 cm) above the soil surface for 2 to 3 months to encourage seedling growth. Water levels were maintained at about 40 cm from January to June of 2019 to encourage and maintain the establishment and growth of cattail while minimizing terrestrial weed growth. Test cells are to be flooded in July 2019 with a range of water depths to start the experimental treatments.	

USE OF SOIL AMENDMENTS AND/OR MANAGEMENT TO CONTROL PHOSPHORUS FLUX

Michael Chimney and Manohardeep Josan

The purpose of this study, referred to as the Soil Management Study, is to investigate techniques that reduce the flux of soluble reactive phosphorus (SRP) from the soil to the water column of STAs. Reduction of this internal flux should result in lower outflow TP concentrations. These techniques include soil amendments (e.g., chemical or biological materials typically rich in metal cations, primarily aluminum, calcium, iron or magnesium, that readily bond with SRP) and soil management (e.g., soil inversion to bury high P soils). Phase I of the study proposed two options for conducting large-scale field trials within the STAs: option one was to leverage a remediation project that used soil inversion (deep tilling) to bury copper-enriched agricultural soils in STA-1W Expansion area (Chimney 2015; **Table 5C 6**), and option two was to build sub-cells in four STAs to test various technologies. Considering the uncertainties in treatment efficacy, potential effects to STA operations, the estimated cost of large-scale field trials, and the practicality to implement these technologies at full-scale in the STAs, a decision was made to leverage option one, the copper soil remediation effort, to determine the effects on P flux from soils after flooding. The remediation effort inverted the soil column through deep tilling so that oxidized, P-rich surface soil (along with copper) was deeply buried and lower-P soil at depth was brought to the surface. Work on Phases II and III for a variety of soil amendments and management techniques outlined in Chimney (2015) has been postponed indefinitely due to the uncertainties described above. More detailed information was reported in Appendix 5C-1 of the 2017 SFER Volume 1 (Chimney 2017).

STA-1W Expansion Area #1 adds three new cells to STA-1W (Cells 6, 7, and 8). Soils were tilled to a depth of at least 60 cm in Cell 7 and part of Cell 6 to remediate for high copper levels in the surface soils (AECOM Technical Services, Inc. 2016). A preliminary soil study assessed the effectiveness of deep tilling. It is hypothesized that—compared to untilled soils—deep tilling will reduce the TP content of surface soil, reduce the flux of P from the soil to the water column, and result in lower TP concentration in the overlying water (Josan et al. 2019). The soil brought to the surface through tilling included peat (inverted-peat) and marl (inverted-marl). The median TP contents of the inverted peat and marl soils (527 and 160 milligrams per kilogram [mg/kg], respectively) were significantly lower than the median TP content of the untilled soils (830 mg/kg). P flux was measured from inverted and untilled soils, soil cores were flooded with STA-1W outflow water in the laboratory and incubated under dark, aerobic conditions. After 42 days of incubation, the average water column TP concentration for untilled, inverted peat and inverted marl soils was 156, 68, and 13 µg/L, respectively. The mean SRP flux rate in these cores after 42 days of incubation was 3.3, 1.6, and 0.1 milligrams P per square meter per day (mg P/m^2/d), respectively.

The STA-1W Expansion #1 was flooded in 2019. Samples of water and sediments were collected in April 2019. Average surface soil TP concentration concentrations were similar in the tilled and no-tilled cells: 963 ± 154 mg/kg and 821 ± 31 mg/kg, respectively. Surface water TP concentrations varied considerably within both cells, with TP concentrations ranging between 40 and 636 µg/L in Cell 7 and 43 to 155 µg/L in Cell 8 (DBE 2019b). Once operational criteria are met and flow-through begins, the treatment performance of Cell 7 (tilled) will be compared to Cell 8 (untilled) through comparison of inflow and outflow TP concentrations. Flow-through operation is anticipated to begin in WY2020.

Table 5C-6. Progress to date of the Soil Management Study.

Task	Status and Key Findings	Publication or Report
Phase I: (1) literature review of technologies, (2) synthesize relevant SFWMD supported projects, and (3) assess the feasibility of implementing at full-scale in the STAs.	Completed in October 2015. Many soil amendments and technologies sequester P in aquatic environments. Application can be very costly and there are several uncertainties regarding potential effects on ecosystems and STA operations, and the frequency of application to maintain benefits of treatment.	Chimney 2015
Phase II: Small-scale experiments to screen a variety of soil amendments/management techniques identified in Phase I	A decision was made not to proceed with Phase II.	
Phase III: large-scale field trials – soil P evaluations	A field-scale treatment of soil inversion for copper remediation in the STA-1 W Expansion Area #1 was carried out in 2017. The inverted soils were tested for P concentrations and P flux from intact soil cores. The STA-1W expansion areas have been flooded and waters have been sampled in regions of inverted and non-inverted soils to compare P flux from these soils.	Josan et al. 2019

INVESTIGATION OF STORMWATER TREATMENT AREA 3/4 PERIPHYTON-BASED STORMWATER TREATMENT AREA TECHNOLOGY PERFORMANCE, DESIGN, AND OPERATIONAL FACTORS

Tracey Piccone and Hongying Zhao

The purpose of this completed study, referred to as the Periphyton-based (PSTA) Study, was to assess the chemical and biological characteristics and the design and operational factors of the PSTA Cell in STA-3/4 that contribute to the superior treatment performance of this technology (**Table 5C-7**). Monitoring of the PSTA Cell inflow and outflow flows and TP concentrations have continued beyond the study completion, and the P budget is updated through WY2019 in the *Annual Performance* subsection below. For the twelve years of operation, outflow TP FWMCs ranged from 8 to 13 µg/L compared to inflow TP FWMCs that ranged from 10 to 27 µg/L. More detailed information on this study was presented in Appendix 5C-2 of the 2018 SFER (Zamorano et al. 2018).

Table 5C-7. Status and highlights for the PSTA Study.

Task	Status and Key Findings	Publications and Reports
Effects of pulse flows	Task was completed in 2015. Pulse flow events and associated higher P loads had no adverse effect on the PSTA Cell's P treatment performance.	Zamorano 2015
Effects of sustained moderate flows	Task was completed in 2017. Moderate flow levels for extended periods of time did not negatively affect the performance.	James and Zamorano 2017
Effects of season, time of day, water depth, and inflow concentration	Task was completed in 2015. There were no significant differences of outflow TP concentration for two operational depths (0.40 and 0.55 meter) or time of day. Generally, lower outflow TP was observed during the wet season. Data also indicate that outflow TP concentrations of 13 µg/L or lower occur when inflow concentrations to the PSTA Cell were 22 µg/L or less. This confirms the suitability of PSTA treatment as a final polishing step, i.e., in the downstream region of a treatment cell where the water has already been treated in upstream EAV and SAV areas.	James 2015 Zamorano 2015
Effects of seepage	Task was completed in 2016. Stage differences between the PSTA Cell and adjacent Lower SAV Cell and canal were the driving force for seepage flow. Compared to the total annual inflow to the PSTA Cell, the percent of net seepage to the PSTA Cell varied from 5 to 37% depending on the hydrologic conditions. Increasing the target stage for the PSTA Cell by 0.15 meter reduced seepage into the cell. Lateral seepage through the levee between the Lower SAV Cell and the PSTA Cell had greater influence on seepage than upward movement of groundwater into the PSTA Cell.	Zhao et al. 2015 Zamorano 2016 Polatel and Zamorano 2016
Evaluation of limerock cap as an alternative to scraping of muck	Task was completed in 2018. Limerock-capped mesocosms produced outflow concentrations similar to the PSTA Cell where the muck was scraped during construction. Results show that muck soil with low P content that is chemically stable can produce ultra-low outflow water P concentrations, with or without a calcareous substrate. In contrast, P-enriched muck substrates did not reduce water column P from low inflow levels (18 µg/L) without a limerock cap. A separate evaluation of soil amendments, including limerock capping, and associated cost estimates was summarized in Chimney (2015).	DBE 2015a DBE 2016 DBE 2018a DBE 2018c
Influence of soil accrual and vegetation nutrient contents	Task was completed in 2018. No significant difference was found in soil accrual depth or soil P content between inflow and outflow regions of the PSTA Cell. Macrophyte tissues and periphyton showed decreasing P content with distance from inflow through the PSTA Cell, reflecting the influence of external P loading to the inflow region. The PSTA Cell SAV communities generally had lower tissue P content than SAV in the outflow region of P-enriched muck-based STA cells. These data suggest that PSTA soils do not contain enough P to enrich the P content of macrophyte tissues, unlike many STA SAV cells with enriched muck, which could contribute to elevated water column P concentrations.	DBE 2015a DBE 2015b DBE 2018a

ANNUAL PERFORMANCE

Annual treatment performance of the PSTA Cell was evaluated from measured and calculated values for WY2008–WY2019. Using measured inflow, outflow, inflow TP load, and outflow TP load, the cell's inflow and outflow FWMC, annual hydraulic loading rate (HLR), P loading rate (PLR), hydraulic residence time (HRT), and TP settling rate (k) were calculated (**Table 5C-8**). These calculations accounted for the duration of the PSTA Cell's operational period for each water year. The operational period was defined as the span of time over which one or both PSTA Cell's inflow structures (G-390A and G-390B) were open. Days when both gates were closed due to protective measures for nesting birds, structure maintenance, or to preserve water during droughts were excluded.

Table 5C-8. Summary of annual hydraulic and treatment performance parameters in the STA-3/4 PSTA Cell during each operational period from WY2008 to WY2019.

Water Year	HLR (cm/d)	HRT (d)	Q_{in} (ha-m)	Q_{out} (ha-m)	FWMC TP_{in} (µg/L)	FWMC TP_{out} (µg/L)	PLR ($g/m^2/yr$)	k (m/yr)	Operational Period	Operational Period (day)
WY2008	5.5	5.8	360	641	27	12	0.24	14.2	06/05/2007–12/12/2017	161
WY2009	6.0	5.9	408	753	14	8	0.14	13.8	07/09/2008–12/23/2008	168
WY2010	6.2	6.2	866	1243	20	10	0.42	27.4	05/26/2009–04/30/2010	341
WY2011	6.1	6.7	394	485	18	11	0.17	7.3	05/01/2010–12/072010	159
WY2012	8.6	4.4	919	1,185	17	12	0.39	12.5	07/19/2011–04/05/2012	262
WY2013	7.7	5.1	1,150	1,377	16	11	0.45	17.8	05/01/2012–04/30/2013	365
WY2014	3.3	16.7	497	468	24	13	0.29	10.0	05/01/2013–04/30/2014	365
WY2015	5.8	9.4	862	911	15	11	0.33	11.9	05/01//2014–04/30/2015	365
WY2016	6.9	7.3	1,023	1,285	11	9	0.27	11.6	05/01/2015–04/30/2016	366
WY2018	5.6	12.9	827	659	10	8	0.20	6.7	05/01/2016–04/30/2017	365
WY2018	5.0	10.5	748	1,102	10	9	0.19	3.7	05/01/2017–04/30/2018	365
WY2019	4.7	19.2	693	325	12	9	0.20	4.2	05/01/2018–04/30/2019	365
Mean	6.0	9.2	729	870	15	10	0.30	11.8		

HLR, PLR, HRT, and k were calculated using the equations below:

(1) $$\mathrm{HLR} = \frac{Q_{in}}{A} \times 100\ \mathrm{cm/m}$$

(2) $$\mathrm{PLR} = \frac{\left[\left(C_{in} \times \frac{10^3 l}{m^3} \times \frac{g}{10^6 ug}\right) \times \left(V_{in(op)}\right)\right]}{A}$$

(3) $$\mathrm{HRT} = \frac{V}{(Q_{in} + Q_{out})/2}$$

(4) $$k = \frac{\frac{(V_{in}+V_{out})\times N}{2}}{A} \times \left(\left(\frac{C_{in}-C^*}{C_{out}-C^*}\right)^{\frac{1}{N}} - 1\right)$$

where

V = the PSTA Cell's average storage volume during the operational period (cubic meters [m^3])

V_{in} = the total surface water inflow volume (cubic meters per year [m^3/yr])

V_{out} = the total surface water outflow volume (m^3/yr)

$V_{in(op)}$ = the total surface water inflow water volume during operational period in a water year (m^3/yr)

Q_{in} = the average daily surface water inflow rate during the operational period (cubic meters per day [m^3/d])

Q_{out} = the average daily surface water outflow rate during the operational period (m^3/d)

A = the PSTA Cell effective treatment area (square meter [m^2])

N = the number of continuously stirred tanks-in-series (= 6)

C^* = the background TP concentration (µg/L) (background concentration in STA design)

C_{in} = the surface water inflow TP FWMC during the operational period (µg/L)

C_{out} = the surface water outflow TP FWMC during the operational period (µg/L)

For WY2019, the PSTA Cell produced an annual outflow TP FWMC of 9 µg/L with an inflow TP FWMC of 12 µg/L. For WY2019, the HLR, PLR, and the settling rate *k* of 4.7 centimeters per day (cm/d), 0.20 grams per square meter per year (g/m^2/yr), and 4.2 meters per year (m/yr), respectively, were within the same range as previous water years. Over the period of record, the inflow FWMC was 15 µg/L and the outflow FWMC was 10 µg/L, a reduction of 33%. Based on superior performance, the PSTA technology is included in our adaptive management strategies tool box.

EVALUATION OF FACTORS CONTRIBUTING TO THE FORMATION OF FLOATING TUSSOCKS IN THE STORMWATER TREATMENT AREAS

Mark Clark[1], Katie Glodzik[1], and Manohardeep Josan

The purpose of this study, referred to as the Tussock Study, is to determine key factors that cause the formation of floating mats, islands, and complexes in the STAs. This will be accomplished through an evaluation of the physical, chemical, and biological conditions that occur in areas of healthy cattail coverage and how these conditions differ from areas prone to the occurrence of floating wetland communities (as mat, islands, or complex) in the STAs. Additionally, the effects of these floating wetland communities on STA treatment performance will be assessed. The goal of this study is to provide management and operational guidelines to prevent formation of floating mats, islands, and complexes and reduce their effect on STA performance.

Phase I of this study was to complete a literature review that documents the formation of these floating wetland communities along with the development of a nomenclature scheme to accurately describe various types of floating vegetation and/or floating mats in STAs (**Figures 5C-3** and **5C-4**), and conduct an assessment of current areas that contain floating cattail communities/tussocks in STA EAV cells (**Table 5C-9**).

The literature review used global as well as local terminologies to explain various kinds of floating wetland communities in the STAs. The effort suggested that no universal terminology or classification scheme for floating wetlands had been developed; however, floating substrate (presence/absence), horizontal connectivity, and dominant vegetation are often components of terms used to describe floating wetlands. Therefore, a floating wetland nomenclature was developed to describe emergent plant communities as they develop in the STAs (**Figure 5C-3**; Clark 2019b).

The floating wetland nomenclature uses a hierarchical terminology. “Tussock” and “floating aquatic vegetation (FAV)” are floating vegetation with no associated organic substrate. “Floating island” or “floating mat/complex” describes floating vegetation with associated substrate or unvegetated floating substrate. An “island” is free floating substrate not connected along any side, and a “mat” or “complex” is floating substrate connected along at least one side. The differentiation between “mat” and “complex” is based on size and species richness. For areas less than 10 m^2 and or composed of a single species the term “mat” is used. For contiguous areas greater than 10 m^2 or composed of multiple species, the area is termed a “complex”.

If greater specificity regarding the type of vegetation is associated with the floating substrate, a vegetation modifier can be added in the middle of the terms. For example, floating substrate dominated by *Typha* that is attached to any adjacent vegetation and composed of organic matter would be labeled “*Typha* floating island”. If that same *Typha*-dominated floating substrate were attached to other vegetation, and the area was greater than 10 m^2, the area would be labeled “*Typha* floating complex”. A floating substrate area with mixed herbaceous vegetation that is contiguous and attached to non-floating vegetation would be labeled “marsh floating complex”.

---

[1] Soil and Water Science Department, University of Florida, Gainesville, Florida.

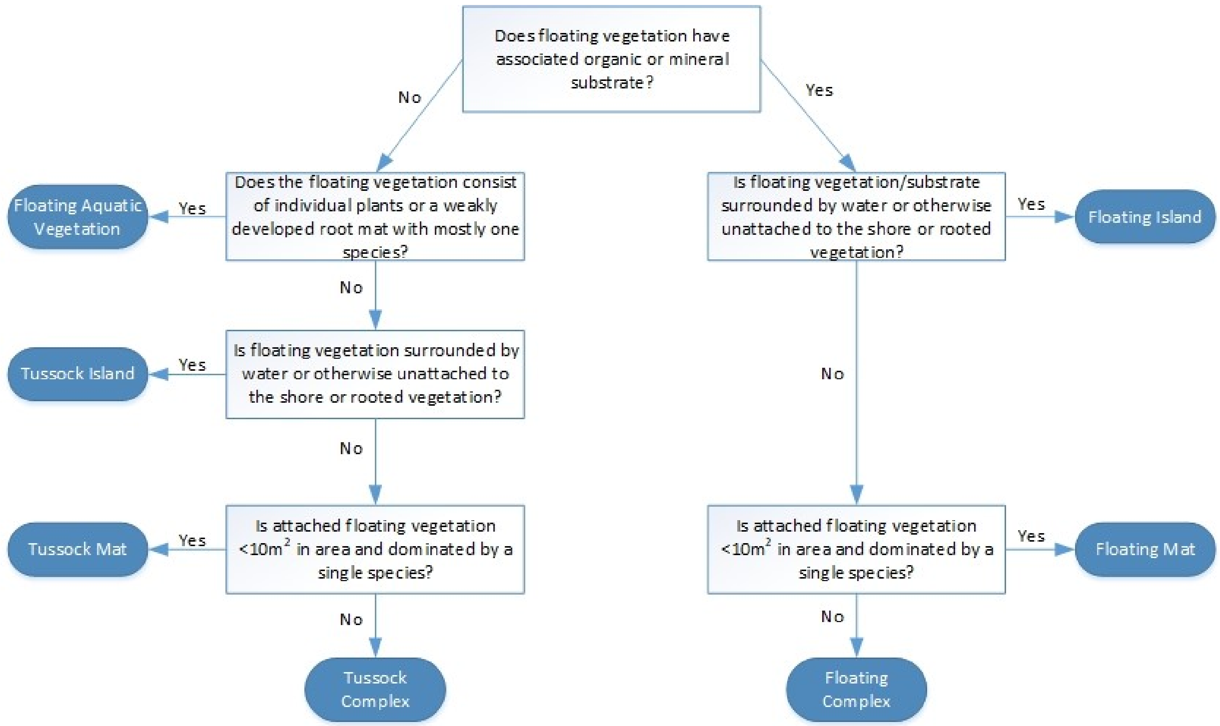

Figure 5C-3. Dichotomous key to the floating wetland nomenclature.

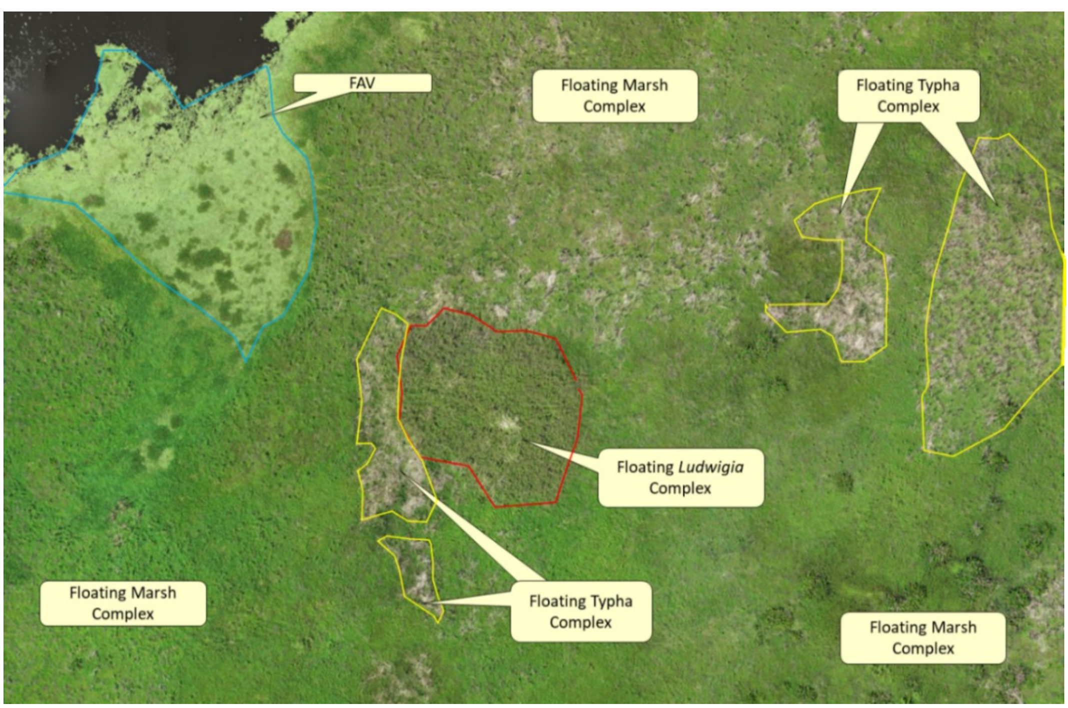

Figure 5C-4. Examples of floating wetland nomenclature applied to aerial image of STA-1W Cell 2A. (Note: FAV – floating aquatic vegetation.)

Table 5C-9. Status of the different tasks for the Tussock Study.

Task	Status and Key Findings	Reports
	Phase I	
Literature review	Initiated June 2018, this task is ongoing.	
Floating wetlands nomenclature	This task is completed. A hierarchical nomenclature scheme was developed to describe floating wetlands in STAs (**Figures 5C-3** and **5C-4**).	Clark 2019b
Assessment of floating tussocks coverage in STA EAV cells	This task is completed. Multispectral drone imagery data identified floating cattail areas that otherwise would not be apparent in satellite imagery. For accurate geo-spatial analyses of drone imagery use of a real-time kinematic (RTK) or post-processed kinematic (PPK) global positioning system (GPS) unit for the drone is highly recommended.	Clark and Glodzik 2019
Thermography assessment	This task is completed. The thermal reflectance of vegetation can differentiate between emergent and floating *Typha* when done close to solar noon in conjunction with multispectral electromagnetic spectra (i.e., red, green, blue [RGB]; near infrared [NIR]; and red edge).	Clark 2019a
	Phase II	
Data mining	This task is expected to start July 2019.	
Refine unmanned aircraft system (UAS) methodology and workflow	This task is expected to start September 2019.	
UAS assessment of STA EAV cells	This task is expected to start October 2019.	
Typha wetland buoyancy model	This task is expected to start February 2020.	
Evaluation of findings and final report	This task is expected to start March 2020.	

An unmanned aircraft system (UAS), also known as a drone, was used to evaluate the extent of floating wetlands in two EAV cells of the STAs: STA-1W Cell 2A and STA-2 Cell 7 (Clark and Glodzik 2019). Post processing and classification schemas were developed to identify floating wetlands communities in these EAV cells. Multispectral drone imagery data discovered *Typha* floating complexes that otherwise would not be apparent in satellite imagery.

Thermal-infrared images of wetlands using the UAS also were evaluated to determine if distinctions between floating and non-floating cattail communities could be determined. However, the thermal signatures of floating vegetation were not unique among the various wetland communities assessed. Any differences detected were strongly influenced by time of day making any detection of floating wetlands using thermal infrared difficult (Clark 2019a). Under very specific conditions (at solar noon when shadows are minimal) thermal-infrared imagery, when added to red, green, glue (RGB), near infrared (NIR), and red-edge spectral images, may assist in the differentiation between emergent and floating *Typha*. It might also be possible to reduce the influence of localized hot and cold spots by aggregating pixels, which would tend to average high contrast components and allow the underlying integrated energy balance to be expressed.

Phase II of this project will use the challenges and opportunities identified from the UAS multispectral image classification work evaluated in Phase I of this project to evaluate environmental factors that may have triggered floating wetlands formation through an analysis of historical data and will build upon on findings from Phase I to develop more direct measures of floating wetland formation.

Quantification of buoyancy measurements (Hogg and Wein 1998, Clark 2000) can provide insight into the mechanisms of buoyancy. These can be used to develop a model to estimate increased or decreased potential for formation of floating wetland communities based on environmental and management conditions. Phase II of this study will develop this *Typha* community buoyancy model to determine the probability that a floating wetland community will be parameterized for conditions occurring within the STA EAV cells. Input variables to be considered are water level, plant density, temperature, and soil holding capacity.

INVESTIGATION OF THE EFFECTS OF ABUNDANT FAUNAL SPECIES ON PHOSPHORUS CYCLING IN THE STORMWATER TREATMENT AREAS

Mark Barton[2], Joel Trexler[2], Mark Cook, and Sue Newman

The purpose of this study, referred to as the Faunal Study is to evaluate the influence of fish and aquatic invertebrates on P cycling and P reduction in the STAs. Specifically, this study estimates: (1) standing stock biomass of fish and aquatic macroinvertebrates, and aquatic faunal community compositional data in STA-2, STA-1E, STA-1W, and STA-3/4; (2) mass-specific P consumption and excretion rates of the most abundant species; and (3) the potential of benthic aquatic species to enhance water column nutrient concentrations through bioturbation. Biomass and excretion estimates are combined and scaled up to estimate areal (per hectare) P excretion by the entire aquatic faunal assemblage in STA-2 (i.e., rates of P released to the water column via excretion in micrograms P per hectare per hour [µg P/ha/h]). Excreted loads of P will be compared to external loads of P and other important nutrient cycling pathways in the STAs (e.g., the nutrient demand of SAV). Bioturbation estimates will be used to evaluate the potential of fauna to counter the efficiency of benthic sequestration of TP; these estimates may be included in nutrient budgets and provide guidance for management actions to improve P retention efficiency.

Initial results of faunal surveys, bioturbation experiment, and estimates of the total mass of P and N sequestered in STA fish based on C, N, and P are reported in Appendix 5C-4 of the 2019 SFER (Evans et al. 2019). Follow-up studies are ongoing and will be reported in future SFERs. The next phase of the study, reported here, estimates N and P excretion rates for STA fishes. Mass-specific estimates of TP, total dissolved phosphorus (TDP), total nitrogen (TN), and ammonium (NH_4) excretion were calculated for three small fish species: sailfin molly (*Poecilia latipinna*), eastern mosquitofish (*Gambusia holbrooki*), and blue killifish (*Lucania goodei*); and three large fish species: sailfin catfish (*Pterygoplichthys spp.*), largemouth bass (*Micropterus salmoides*) and blue tilapia (*Oreochromis aureus*). Mass-specific N and P excretion rates varied among species, with small-bodied fishes revealing higher mass-adjusted excretion rates than large-bodied species for all forms of P and N.

These results suggest that some fish species, like eastern mosquitofish, have the potential to increase water column TN and TP via excretion, while other species, like largemouth bass and sailfin catfish, may have minimal effects on water column nutrient concentrations. Depending on species, fish populations could significantly influence N and P cycling within and among STA habitats. Aquatic animals have a large potential for translocation of P between the benthos and water column, with implications for STA nutrient removal efficiency. Future research will focus on refining estimates and incorporating the effects of aquatic fauna into nutrient budgets for the STAs. More specific information on this project is presented in Appendix 5C-1 of this SFER.

[2] Department of Biological Science, Florida International University, North Miami, Florida.

IMPROVING RESILIENCE OF SUBMERGED AQUATIC VEGETATION IN THE STORMWATER TREATMENT AREAS

Manohardeep Josan, Kevin Grace[3],
Dawn Sierer Finn[3], and Ian Eyeington[3]

The purpose of this study, referred to as the SAV Resilience Study, is to assess physical, chemical and biological processes that reduce the sustainability of SAV plant communities. Substantial declines in SAV have occurred in several STA cells over the years. Factors that may contribute to SAV species distribution, persistence, colonization, and recovery in the STAs include SAV biology; water chemistry; nutrient loading; soil/sediment chemistry, including the deposition of fine marl sediments; physical characteristics; herbivory; and interactions among these factors (DBE 2018f). In addition to potential effects of temporal changes in sediment characteristics, weather conditions (e.g., hurricanes and drought) also resulted in stress of SAV.

Two studies are currently underway to address SAV resilience: 1) SAV growth as affected by the accumulation of new marl sediments, and 2) *Chara* sustainability at different nutrient loading regimes (**Table 5C-10**).

The first study (SAV growth) began with a field survey. Several STA FWs were assessed specifically to compare the chemical composition of new sediment material to underlying aged muck soil and to recently farmed organic muck soils. Many Everglades STAs were constructed on these recently farmed organic muck soils. New marl sediments across 9 sites in 7 SAV-rich STA FWs were low in bulk density, organic matter, N, C, sulfur, and several essential micronutrients (iron, copper, molybdenum, nickel, and zinc), relative to the underlying aged muck soils, while the marl was enriched in calcium and magnesium (DBE 2019a). Analysis of the recently farmed organic muck soils was not completed at the time of this report.

Triplicate mesocosms of *Potamogeton*, *Najas*, and *Chara* are being grown on farm muck soil, aged muck soil, and marl sediments using low nutrient water in batch-exchange of 2-week cycles (sample size = 10). Each cycle is 14 days in duration, after which the water column is replenished with fresh low nutrient water. Farm muck soil was collected from a recently farmed field within the footprint of STA-1W Expansion Area Cell 8 before the area was flooded. Aged muck soil was obtained from STA-1W Cell 4, which was converted to a treatment wetland in 1994 and represents a soil that has developed over two decades of STA operations. This aged muck soil was collected from beneath the accrued sediment layer that has formed under STA conditions. Marl sediments were collected from areas within STA-1W and STA-2 that have a history of dominance by one of the three SAV species of interest (*Potamogeton*, *Najas*, and *Chara*).

After 10 weeks, plant biomass growth was somewhat lower in mesocosms of marl substrates than on farm muck but was positive for all three SAV taxa and on all three substrates. In general, biomass increase was lower for *Potamogeton* than for *Chara* or *Najas*, but when normalized to the initial dry weight added, the relative *Najas* growth rate was greatest among the three SAV taxa. For rooted taxa (*Najas* and *Potamogeton*), the growth was higher on farm muck soil than aged muck soil. This was not the case for the non-rooted macroalga *Chara*. Final plant biomass, soil, plant tissue, and nutrient composition will be determined at the end of the 20-week experimental period.

[3] DB Environmental Laboratories, Inc., Rockledge, Florida.

Table 5C-10. Status of the different tasks for the SAV Resilience Study.

Task	Status and Key Findings	Reports
Literature review	This task was completed in June 2018. Major factors that could influence the resilience of SAV in STAs were identified as P and N loading, turbidity, calcium concentrations, water depth, sediment accretion, dry down/reflood events, wind/wave disturbance events, and herbivory and physiological senescence. *Ceratophyllum* thrives under high P loading rates, whereas, *Chara* prefers low P loading rates. *Najas* prefers deeper (up to 1.2 meters) waters, whereas *Chara* thrives under moderate to shallow water depths.	DBE 2018b
Data analyses	This task was completed in June 2018. Historical SAV survey analyses found standing crop biomass and tissue P concentration in general decreased with distance along a FW. FAV encroachment into SAV areas, followed by herbicide treatment of FAV biomass, likely account for the limited SAV densities and the declines in P removal performance that have been observed in STA-1E Cells 4N and 4S. Random environmental events (e.g., high flows, drawdown, or cold temperatures) can change FAV community distribution.	DBE 2018b
Develop experimental methods	This task was completed in October 2018. Commercially available combination oxidation reduction potential probes have long stabilization periods, therefore a platinum-based oxidation-reduction probe prototype and procedure was developed and tested successfully to measure sediment redox potential in the field.	DBE 2018d
Study plan development for experimental methods	Completed December 2018. Two studies are currently being conducted: 1) SAV growth as affected by the accumulation of new marl sediments, and 2) *Chara* sustainability at different nutrient loading regimes.	DBE 2018d
Experimental studies	*Chara* Sustainability is ongoing and the SAV Growth study will be completed in September 2019.	DBE 2018e DBE 2019a

During the first 10 weeks (5 water exchange cycles) of the study, the accrued marl sediment layer was elevated in P and calcium, as compared to the underlying muck soil. The total P concentration in the reflood water was low, as expected, averaging 18 ± 0.2 µg/L for the first 10-week period. At the end of each 14-day cycle, the water column total P concentrations increased in columns growing *Potamogeton*, regardless of substrate. Columns with *Chara* showed no change in total P concentration, while for *Najas,* the change in TP concentration varied with substrate type. The *Najas* grown on aged muck had the lowest TP concentration of any treatment (16 ± 3 µg/L), while *Najas* grown on marl and farm muck had higher total P concentrations of 27 ± 6 and 21 ± 2 µg/L, respectively. PP in the water column also increased slightly across all treatments. A decrease in dissolved calcium was observed across all treatments, suggesting that adequate photosynthesis was occurring to facilitate calcium carbonate ($CaCO_3$) precipitation.

N concentration increased within the water column, especially where accompanied by ammonia-N, which may indicate macrophytes senescence (the gradual deterioration of vegetation or soil over time) and/or accumulation and senescence of algal biomass in the water column. Differences in ammonia-N between farm muck and the other substrates may indicate more robust plant growth/health on the farm muck (high N uptake by healthy, growing plants, and low leaching from fewer senescent plants). However, ammonia-N concentration differences due to substrate was not observed for *Potamogeton* treatments. Final plant biomass, soil and tissue nutrient composition, and water column chemistry will also be determined at the end of the 20-week experimental period.

The second mesocosm study examines the tolerance of *Chara* to a range of P concentrations. If *Chara* prove susceptible to "crashing" under selected nutrient conditions in STA flow paths, then operations to avoid these conditions could be applied, or alternative management efforts (e.g., inoculation of alternative SAV species) could be undertaken to maintain the overall resilience of the SAV community.

Three different nutrient concentration/loading rates, to simulate the range of nutrient conditions along an STA flow path (i.e., inflow, mid-cell, and outflow conditions) are being evaluated using triplicate mesocosms (surface area of 1 m^2) for each loading rate. Hydraulic loading rates (9 cm/d) are applied equally to each treatment, while inflow nutrient concentrations are varied. Two sets of three mesocosms each were established at the S-5A research site to simulate inflow and mid-cell flow conditions, while the final set of mesocosms was established at the South Site (receiving STA outflow waters) to simulate outflow TP concentrations.

The differences in TP concentrations among the three treatments from February 5 and April 30, 2019, were 108, 45, and 17 µg/L on average for the high, moderate, and low loading treatments, respectively. This equates to a daily PLR of 9.6, 4.1 and 1.5 mg P/m^2/d. For total N, the same treatments received 1.6, 1.3, and 1.3 milligrams per liter (mg/L) for the high, moderate, and low loading treatments. Inflow P was primarily in bioavailable (SRP) forms in the high nutrient regime, receiving agricultural drainage waters not yet treated by an STA. The low loading treatment received primarily DOP and PP forms with little SRP. The moderate treatment inflow water contained 20 µg/L SRP, on average. *Chara* biomass continues to develop under all three nutrient loading treatments. Changes in the P removal efficiency of these systems over time will be evaluated as the *Chara* biomass continues to develop, and eventually stabilizes or declines.

STORMWATER TREATMENT AREA WATER AND PHOSPHORUS BUDGET IMPROVEMENTS

Tracey Piccone and Hongying Zhao

The purpose of this study, referred to as the Water and P Budget Study, is to improve annual STA water and P budgets for STA treatment cells for more accurate estimation of STA cell performance and to identify areas of uncertainty in these estimates. Accurate water and P budgets for the two main types of treatment cells, EAV-dominant and SAV-dominant, are important to assess STA performance and to predict future long-term STA treatment performance. STA water budgets include structure flows (inflows and outflows), rainfall, evapotranspiration (ET), seepage, and change in storage (**Figure 5C-4**). Structure flows are calculated with hydraulic equations developed for each water control structure. Rainfall is estimated from rain gauge measurements located within or near each STA. ET is estimated from a model of lysimeter measurements of wetland ET at the Everglades Nutrient Removal Project (Abtew 1996). Seepage through perimeter levees is based on head differences between the treatment cell and outside area water levels, levee length, and a first order seepage coefficient. The SFWMD's Water Budget Application Tool (BPC Group Inc. 2008) is used to develop estimates of seepage (if calculated), rainfall volume, ET, and change in storage volumes. The water budget residual, which is the mathematical difference between all outflow and inflow sources, is a measure of overall accuracy. Developing a closed water budget for the STAs is complicated by the physical characteristics of wetland systems and errors associated with the measurement and estimation of each of the components.

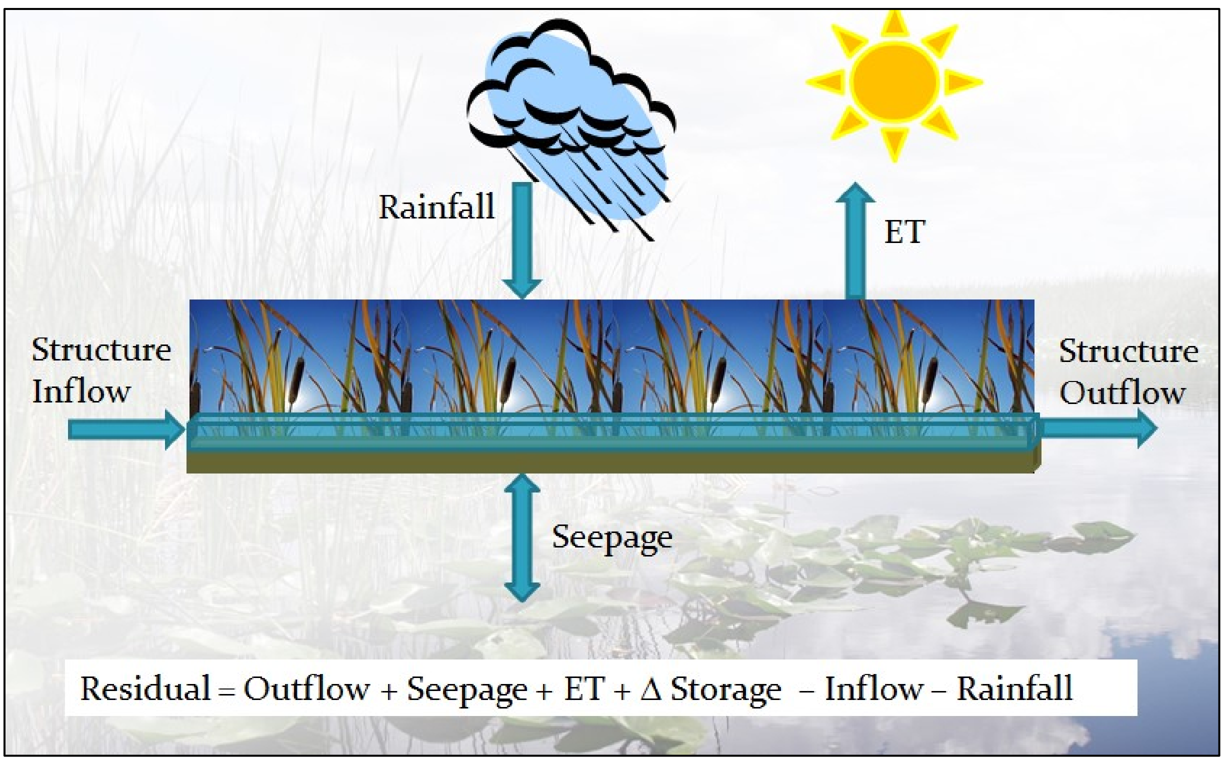

Figure 5C-5. Conceptual model for a water budget in the STAs.

The study has two phases (**Table 5C-11**):

- Phase I was a test case analysis to improve water budgets for STA-3/4 Cells 3A and 3B by improving flow data, particularly for the structures in the levee between Cells 3A and 3B.
- Phase II implements methodologies investigated during Phase I on an expanded list of treatment cells and includes the development of improved P budgets for these treatment cells.

Table 5C-11. Status and highlights of the Water and P Budget Study.

Task	Status and Comments	Publications and Reports
STA-3/4 Cells 3A and 3B water budget improvement test case (Phase I)	Completed in WY2014. Key findings include the following: • Structure flows were the largest component of the water budgets and the largest source of uncertainty. • Low head differentials across mid-levee culverts were the main source of error. • Seepage was a significant source of residual uncertainty for the test case despite contributing a small fraction of water budgets. • Rainfall, ET, and change in storage were minor components of the water budgets, and current estimation methods for these components were found to be acceptable. • Annual water budgets for the test case were greatly improved with revised flow data for the mid-levee culverts; residuals were reduced from as high as 100 to 8% or less. Flow data were improved through improved flow rating equations, review and correction of flow data (e.g., by setting small head differentials to zero), and back calculations by redistributing water budget residuals to both inflow and outflow cells and by using weighted averages of inflows and outflows (instead of using flow data at cell inflow and outflow structures).	Polatel et al. 2014
STA-2 and STA-3/4 period of record flow data and flow rating improvements	Improvement of flow data for STA-2 FWs 1, 2, and 3, and STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B for the period of record was completed in 2015.	
STA-1E flow data and flow rating improvements	Flow data for all STA-1E structures starting in WY2014 has been improved.	
Water Budget Application Tool improvements	Updates to the Water Budget Application Tool, including improved seepage estimations, were completed in WY2017 for STA-2 FWs 1, 2, and 3. Water budget estimates using the Water Budget Application Tool were updated in WY2018 for STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B.	
Period of record STA-2 and STA-3/4 water and TP budgets	Water and TP budgets for STA-2 FWs 1, 2, and 3 were updated and results were summarized. Water and TP budgets for STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B were completed in WY2018.	Zhao and Piccone 2018 Zhao and Piccone 2019
STA-5 flow data and flow rating improvements	Flow data for select STA-5 structures were improved starting with WY2015 and completed in WY2017.	

QUANTIFYING LIFE CYCLE AND PHOSPHORUS UPTAKE AND RELEASE FROM PERIPHYTON AND PHYTOPLANKTON COMMUNITIES

Kathleen Pietro

The purpose of this study, referred to as the Periphyton Study, is to evaluate nutrient dynamics of periphyton and phytoplankton in downstream STA treatment FWs where TP concentrations are very low (≤ 20 µg/L). Periphyton is defined here as a biological matrix composed of algae, fungi, bacteria, and detritus attached to submerged surfaces in the water column. This study focuses on measurements of nutrient uptake and release, growth, respiration, senescence, and death. These processes may be significant factors in P retention by areas with low P water column concentration near outflow regions of STAs. For example, in well performing outflow regions of STAs, the TP is primarily PP and DOP. The microorganisms within the periphyton matrix may produce exoenzymes, enzymes that acts outside the cell that produces it, that degrade or transform DOP into SRP, which in turn is used for growth and energy needs. Exoenzyme activity may reduce DOP in the water column and may contribute to increased PP in the formation of periphyton biomass. Quantification of these transformations and the effect of the periphyton uptake, growth, respiration, and death on the P cycle within this region is critical to understanding overall STA P removal efficiency.

Phase I of this study quantifies the rates of periphyton nutrient cycling and life cycle responses, such as growth, biomass accretion, and P turnover due to senescence. A review of the literature on periphyton dynamics and nutrient cycling in tropical and subtropical oligotrophic (low nutrient) or mesotrophic (moderate nutrient) freshwater wetlands subjected to relatively low P conditions (< 20 µg/L) has been completed to determine what is known and to identify data gaps (**Table 5C-12**). A list of the methods to measure these rates at mesocosm or field-scale studies has been compiled. These methods include pigment measurements (chlorophylls and phycocyanin), periphyton taxonomic composition, or cell biovolume to quantify periphyton abundance, amplicon sequencing, metagenomics (which can provide information about all the genes, metabolism, and potential function), or metatranscriptomics (which can indicate metabolic and enzymatic function) to quantify community structure and changes in community processes, or stable isotopes (^{31}P, ^{32}P, ^{15}N, ^{14}C) and enzyme activity to measure nutrient uptake. The next part of this study will evaluate the potential use of these methods to evaluate the effect of periphyton dynamics in nutrient sampling.

Table 5C-12. Status and highlights for the Periphyton Study.

Task	Status and Key Findings	Publication or Report
Phase 1: (1) Literature review of periphyton nutrient and life cycles rates within freshwater oligotrophic or mesotrophic tropical or subtropical wetlands; (2) Compile table of methodologies that could be used to measure rates at mesocosm and field scales.	Final draft of the literature review and methodology table was completed. Incorporation of review comments is underway. There was only a limited number of rates found in the literature for periphyton nutrient uptake and life cycle processes. Isotopic and genomic methods may be the best methods to use to quantify rates.	Laughinghouse et al. 2019
Phase 2: Review and compile research findings from periphyton related studies conducted in the STAs	This task is ongoing.	
Phase 3: Design mesocosm and field-scale study to measure periphyton life cycle and nutrient uptake rates within EAV and SAV communities.	This phase will be started in WY2021.	

L-8 FLOW EQUALIZATION BASIN AND STORMWATER TREATMENT AREA OPERATIONAL GUIDANCE

Matt Powers and Tracey Piccone

The purpose of this study, referred to as the L8-FEBOG, is to collect the necessary water quality, stage, flow, and groundwater data from within the L-8 Flow Equalization Basin (FEB) to improve predictive understanding of the relationships among these factors. Findings from this study should contribute to the development of operational guidance for the L-8 FEB. The primary objective of this FEB is to improve the operations of STA 1 East (STA-1E) and STA 1 West (STA-1W) by attenuating peak flows and temporarily storing stormwater runoff (SFWMD 2015), which will support these STAs to achieve compliance with the WQBEL.

In WY2017 and WY2019, TP FWMCs in the outflow were lower than inflow FWMCs. However, in WY2018, outflow TP concentrations were higher than inflow TP concentrations (Xue 2019). Elevated TP outflow concentrations occurred from May to June 2017 and during April 2018 when little flow entered the FEB and water levels were low. This is undesirable as elevated TP concentrations from the FEB will increase P loading to the downstream STAs making it more difficult for the STAs to meet compliance standards. Although the L-8 FEB was not designed as a P removal facility and marked reductions in FEB water column P concentrations were not expected, an increase in TP from inflow to outflow was not anticipated. Identifying the cause(s) of elevated outflow TP concentrations from the FEB is the focus of the first part of this study.

This is anticipated to be a three-year study, beginning in October 2018 and ending by September 2021. This study is separated into three phases with STOP/GO points between each phase. Phase I includes monthly water quality sampling in the interior compartments of the FEB and quarterly water quality sampling in the surrounding groundwater wells from January to August 2019 (**Figure 5C-6**). Analysis of Phase I results will determine activities in the subsequent study phases.

Figure 5C-6. Sampling sites of the L8-FEBOG study.

Data from surface water sampling conducted during the first half of Phase I shows stratification of P by depth with the highest P concentrations, primarily in particulate form, at the bottom of the FEB. The source of this PP is unlikely to be groundwater as a sampling of the groundwater wells surrounding the FEB (**Table 5C-13**) found that TP concentrations in these wells are lower than that of the surface water and the seepage volume is small (**Table 5C-14**). Evidence to date excludes groundwater as the major contributor of P in discharges from the FEB. A final report of Phase I should confirm this finding.

Table 5C-13. Comparison of groundwater and surface water values.

Parameter (Units [a])	Groundwater		Surface Water	
	Mean	Range	Mean	Range
Dissolved Oxygen (mg/L)	0.57	0–2.7	6.14	0.01–12.8
pH	7.21	6.9–7.6	8.26	7.3 10
Conductivity (μS/cm)	1,739	516–9,229	1,623	1,226–2,624
Temperature (°C)	25.6	24.3–27.9	23.2	16.9–29
Total Phosphorus (mg/L)	0.028	0.008–0.075	0.112	0.025–0.675
Particulate Phosphorus (mg/L)	0.013	0.002–0.042	0.095	0.021 -0.511
Total Dissolved Phosphorus (mg/L)	0.015	0.006–0.033	0.017	0.004–0.164
Orthophosphate (mg/L)	0.012	0.004–0.028	0.012	0.001–0.153
Dissolved Organic Carbon (mg/L)	14.23	6.5–18.8	18.77	16.8–21.2
Total Nitrogen (mg/L)	1.859	0.429–5.97	2.223	1.17–4.33
Ammonia (mg/L)	1.122	0.148–4.95	0.193	0.005–2.502
Nitrate + Nitrite (mg/L)	0.006	0.005–0.015	0.475	0.005–2.33
Hardness	470	163.3–1,029.2	352	308.4–487.3
Alkalinity (mg/L)	277	148–610	221	186–284
Chloride (mg/L)	265	22.1–2,320	268	192–670
Sulfates (mg/L)	184	18–712	156	116–266
Dissolved Calcium (mg/L)	132.4	48.8–353.1	99.4	88.1–121.1
Dissolved Potassium (mg/L)	7.1	3.7–18.3	8.9	8.4–13.1
Dissolved Magnesium (mg/L)	23.9	6.2–102	24.1	21.5–43
Dissolved Sodium (mg/L)	189.9	23.8–1,588	184.2	128.4–461.3

a. **Key to units:** °C – degrees Celsius; μS/cm – microsiemens per centimeter; and mg/L – milligrams per liter.

Table 5C-14. Status and highlights of the L8-FEBOG study.

Task	Status and Key findings	Reports
	PHASE I	
Detailed study plan	This task was completed in 2019. The plan describes water sampling for Phase I and potential phases to evaluate sediments, runoff, and biota as sources of P.	SFWMD 2019a
Fiscal year quarter 2 water quality sampling	Characterization of surface water and groundwaters from January to February 2019.	DBE 2019c
Fiscal year quarter 3 water quality sampling	Characterization of surface water and groundwater from January to May 2019.	DBE 2019d
Fiscal year quarter 4 water quality sampling	This task is ongoing	
	PHASE II	
Surface water monitoring	This task will continue in WY2020.	
Sediment characterization	This task requires chemical and physical analyses of soils and sediments. The start date has not yet been determined.	
Event based surface water quality sampling	This task involes sampling water chemistry during different inflow outflow conditions. The start date has not yet been determined.	

LITERATURE CITED

AECOM Technical Services, Inc. 2016. *STA-1W - Expansion #1 Corrective Actions Report – Copper and Organochlorine Pesticide Impacted Soil Inversion, Palm Beach County, Florida*. Submitted to South Florida Water Management District, West Palm Beach, FL.

Abtew, W. 1996. Evapotranspiration measurements and modeling for three wetland systems in South Florida. *Journal of American Water Resources Association* 32(3):465-473.

BPC Group Inc, 2008. *STA Water Budget Application User Guide Version 1.0*. Submitted to South Florida Water Management District, West Palm Beach, FL.

Clark M. 2019a. *Assessment of Thermography as a Possible Tool to Determine Floating vs. Emergent Vegetation under Agreement No. 4600003031-W004, Task 3a*. Soil and Water Science Department, University of Florida, Gainesville, FL.

Clark M. 2019b. *Proposed Floating Wetlands Nomenclature under Agreement No. 4600003031-W004, Task 2b*. Soil and Water Science Department, University of Florida, Gainesville, FL.

Clark M. and K. Glodzik. 2019. *Assemsent of Floating Wetland Coverage in STA EAV Cells under Agreement No. 4600003031-W004, Task 3a*. Soil and Water Science Department, University of Florida, Gainesville, FL.

Clark, M. 2000. *Biophysical Characterization of Floating Wetlands (Flotant) and Vegetative Succession of a Warm-Temperate Aquatic Ecosystem*. PhD Dissertation, University of Florida, Gainesville, FL.

Chimney, M.J. 2015. *Phase I Summary Report for the Use of Soil Amendments/Management to Control P Flux Study*. Technical Publication WR-2015-006, South Florida Water Management District, West Palm Beach, FL.

Chimney, M.J. 2017. Appendix 5C-1: Use of Soil Amendments/Management to Control Phosphorus Flux. In: *2017 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Chimney, M.J. 2019. Chapter 5B: Performance and Operation of the Everglades Stormwater Treatment Areas. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

DBE. 2015a. *Draft Comprehensive Interim Report, Inter-Agency Agreement to Conduct Scientific Studies Relevant to the Stormwater Treatment Areas, Agreement No. 4600003125*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL and Everglades Agricultural Area Environmental Protection District, West Palm Beach, FL.

DBE. 2015b. *Quarterly Report #1 under Agreement No. 4600003298*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE. 2016. *Quarterly Report #3 under Agreement No. 4600003298*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE. 2018a. *Deliverable 4A Quarterly Report #3 under Agreement No. 4600003695, Investigations of STA-3/4 PSTA Performance, Design, and Operational Factors*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE. 2018b. *Deliverable 4B under Agreement No. 4600003695, SAV Resilience in Everglades STAs: Literature Review*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2018c. *Deliverable 5A:Quaterly Report #4 under Agreement No. 4600003695, Investigations of STA-3/4 PSTA Performance, Design, and Operational Factors*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2018d. *Deliverable A1.1 under Agreement No. 4600003883, SAV Resilience in Everglades STAs: SAV Resilience Study Work Plan including Details for the Two Sub-studies including Protocols for QA, Sampling and Analysis*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2018e. Deliverable A1.2 under Agreement No. 4600003883, SAV Resilience in Everglades STAs: A Brief Update on the Progress of the Two Sub-studies, Experimental Setup Progress and Pictures of Study Sites. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2018f. *Inter-Agency Agreement to Conduct Scientific Studies Relevant to the Stormwater Treatment Areas Deliverable 4B under Agreement 4600003695: SAV Resilience in Everglades STAs: Literature Review*. Submitted by DB Environmental, Inc. to South Florida Water Management District, West Palm Beach, FL. June 29, 2018.

DBE 2019a. *Deliverable A1.4 under Agreement No. 4600003883, SAV Resilience in Everglades STAs: A Brief Update on the Progress of the Two Sub-studies, Experimental Setup Progress and Pictures of Study Sites*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2019b. *Deliverables A2.1 and A2.2: under Agreement 4600003883: Soil Sampling Report and Soil Management Study Sampling and Survey Report* Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2019c. *Deliverable A3.3 under Agreement No. 4600003883, Sampling Report 1 L-8 FEB Surface Water and Groundwater Quality Monitoring*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2019d. *Deliverable A3.4 under Agreement No. 4600003883, Sampling Report 1 L-8 FEB Surface Water and Groundwater Quality Monitoring*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

Diaz, O. 2018. Appendix 5C-5: Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability: In Situ Study. In: *2018 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Diaz, O. and K. Vaughan. 2019. Apppendix 5C-2: Evaluation of Inundation Depth and Duration Threshold for Cattail Sutainability: In Situ Study. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, west Palm Beach, FL.

Evans, N., J. Trexler, M. Cook, and S. Newman. 2019. Appendix 5C-4: Effects of Abundant Faunal Species on Phosphorus Cycling in the Stormwater Treatment Areas. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

FDEP. 2012a. *STA Everglades Forever Act (EFA) Watershed Permit (No. 0311207) and Associated Consent Order (OGC 12-1149)*. Florida Department of Environmental Protection, Tallahassee, FL. September 10, 2012.

FDEP. 2012b. *STA National Pollutant Discharge Elimination System Watershed Permit Number FL0778451 and Associated Consent Order OGC 12-1148*. Florida Department of Environmental Protection, Tallahassee, FL. September 10, 2012.

Florida International University. 2019. *Settling and Entrainment Properties of STA Particulates Draft Final Report. Prepared under Agreement No. 4600003032-WO02-9500006758* for South Florida Water Management District, West Palm Beach, FL. April 30, 2018.

Gann, D. M. Bernardo, and J. Richards. 2019. *Detection and Differentiation of Submerged Aquatic and Emergent/Floating Marsh Vegetation using Remote Sensing Methods -- Spectral Separability from WorldView Data (Pilot Study)*. Submitted to South Florida Water Management District, West Palm Beach, FL.

Hogg, E.H., and R.W. Wein. 1987. Buoyancy and growth of floating cattail mats in a Dyked impoundment in New Brunswick. Pages 213–218 in: Rubec, C.D.A, and R.P. Overend (eds.), *Proceedings of a Symposium on Wetlands and Peatlands, August 1987, Edmonton, Alberta, Canada*.

James, T. D. Ivanoff, T. Piccone, and J. King. 2019. Chapter 5C: Restoration Strategies Science Plan Implementation In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

James, R.T. 2015. *Evaluation of Remote Phosphorus Analyzer Measurements and Hydrologic Conditions of the STA-3/4 Periphyton-based Stormwater Treatment Area.* Technical Publication WR 2015-002, South Florida Water Management District, West Palm Beach, FL.

James R.T. and M.F. Zamorano. 2017. *Analysis of Effects of Sustained Moderate Flow at the Stormwater Treatment Area 3/4 Periphyton-based Stormwater Treatment Area*. Technical Publication WR-2017-003, South Florida Water Management District, West Palm Beach, FL.

Jerauld, M. J. Juston, T. DeBusk, D. Ivanoff, and J. King. 2019. *Measurement of Internal Phosphorus Loading Rate (IPLR) in a Low-P Stormwater Treatment Wetland*. Submitted to South Florida Water Management District, West Palm Beach, FL, in fulfillment of Work Order 4600003029-WO01.

Josan, M., B. Taylor, and K. Grace. 2019. Appendix 5C-3: Use of Soil Inversion to Control Phosphorus Flux. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Juston, J and B. Kadlec. 2019. Data-driven modeling of phosphorus (P) dynamics in low-P stormwater wetlands. *Environmental Modelling & Software* 118: 226-240.

Laughinghouse, H.D., D.E. Berthold, M. Barbosa, and F.W. Lefler. 2019. *A Review an Tropical and Subtropical Periphyton and Phytoplankton Processes and Methods of Quantification*. Submitted to South Florida Water Management District, West Palm Beach, FL.

Morrison, E.S., M.R. Shields, T.S. Bianchi, Y. Liu, S. Newman, N. Tolic, and R.K. Chu. In review. Mutiple biomakers highlight the importance of water column processes in treatment wetland organic matter cycling. Submitted to *Water Research*.

Polatel, C., A. Wossenu, S. Krupa, and T. Piccone. 2014. *Stormwater Treatment Area Water and Phosphorus Budget Improvements, Phase I STA-3/4 Cells 3A and 3B Water Budgets*. Technical Publication WR-2014-004, South Florida Water Management District, West Palm Beach, FL.

Polatel, C. and M. Zamorano. 2016. *Estimating Seepage Using Historical Stage and Flow Data: Application to PSTA Project*. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2012a. *Restoration Strategies Regional Water Quality Plan*. South Florida Water Management District, West Palm Beach, FL. April 27, 2012.

SFWMD. 2012b. *Technical Support Document for Derivation of the Water Quality Based Effluent Limit for Total Phosphorus in Discharges from Everglades Stormwater Treatment Areas to the Everglades Protection Area*. South Florida Water Management District, West Palm Beach, FL. June 27, 2012.

SFWMD. 2013. *Science Plan for the Everglades Stormwater Treatment Areas*. South Florida Water Management District, West Palm Beach, FL. June 2013.

SFWMD. 2015. *L-8 Reservoir/Flow Equalization Basin Draft Project Operational Manual*. West Palm Beach, FL.

SFWMD. 2018. *Science Plan for the Everglades Stormwater Treatment Areas*. South Florida Water Management District, West Palm Beach, FL. July 2018.

SFWMD. 2019a. *L-8 FEB and STA Operational Guidance Study*. South Florida Water Management District, West Palm Beach, FL. April 2019.

SFWMD. 2019b. *Review of 'Data-driven modeling of phosphorus (P) dynamics in low-P stormwater wetlands' by John M. Juston and Robert H. Kadlec, 2019*. South Florida Water Management District, West Palm Beach, FL. June 2019.

University of Florida. 2019. *Evaluation of Soil Biogeochemical Properties Influencing Phosphorus Flux in the Everglades Stormwater Treatment Areas (STAs) Final Report*. Submitted to South Florida Water Management District, West Palm Beach, FL.

Villapando, R and J. King. 2019. Appendix 5C-1: Evaluation of Phosphorus Sources, Forms, Flux, and Transformation Processes in the Stormwater Treatment Areas. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Xue, S. K. 2019. Appendix 2-2 Annual Permit Report for the L-8 Flow Equalization Basin. In: *2019 South Florida Environmental Report – Volume III*, South Florida Water Management District, West Palm Beach, FL.

Zamorano, M.F. 2015. *Effects of Pulse Flow Events on the STA-3/4 PSTA Cell's Phosphorus Treatment Performance*. Technical Publication WR 2015-007, South Florida Water Management District, West Palm Beach, FL. September 2015.

Zamorano, M. 2016. *Influence of Seepage on the STA-3/4 PSTA Cell's Treatment Performance*. Technical Publication WR-2017-004, South Florida Water Management District, West Palm Beach, FL.

Zamarano.M., K. Grace, T. DeBusk, T. Piccone, M. Chimney, R.T. James, H. Zhao and C. Polatel. 2018. Appendix 5C-2: Investigation of Stormwater Treatment Area 3/4 Periphyton-based Stormwater Treatment Area Performance, Design, and Operational Factors. In: *2018 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Zhao, H., T. Piccone, and M.F. Zamorano. 2015. *STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Cell Water and Total Phosphorus Budget Analyses, Investigation of STA-3/4 PSTA Technology Performance, Design and Operational Factors*. Technical Publication WR-2015-001, South Florida Water Management District, West Palm Beach, FL.

Zhao, H., and T. Piccone. 2018. Appendix 5C-6: Summary Report for Stormwater Treatment Area 2 Flow-ways 1, 2, and 3 Water and Total Phosphorus Budget Analyses In: *2018 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Zhao, H., and T. Piccone. 2019. Appendix 5C-5: Summary Report for Water and Total Phosphorus Budget and Performance Analysis for STA-3/4 Treatment Cells. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.