Chapter 5C: Restoration Strategies Science Plan Implementation

Edited by Tom James, Delia Ivanoff, Tracey Piccone, and Jill King

SUMMARY

In 2012, the State of Florida and the United States Environmental Protection Agency (USEPA) reached consensus on new Restoration Strategies for Clean Water for the Everglades (Restoration Strategies; SFWMD 2012a). In September 2012, the Florida Department of Environmental Protection (FDEP) issued permits to the South Florida Water Management District (SFWMD or District) that included 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 the permits issued by FDEP require the District to develop and implement a science plan to improve the understanding of mechanisms and factors that affect phosphorus (P) treatment performance of the STAs, particularly those mechanisms and factors that are key drivers to performance in a low TP environment (e.g., within the outflow region where TP concentration are at or below 20 micrograms per liter [µg/L]). The original *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 for the identification of critical factors that collectively influence phosphorus (P) reduction treatment performance in the STAs. Information gathered is intended to support the design, operation, and management of STAs to achieve and sustain TP 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.

As part of the Science Plan development, existing knowledge was reviewed, information gaps and uncertainties were determined, and key questions regarding the physical, chemical, and biological processes, as well as management and operation of the STAs were formulated. These questions were the basis for formulating research studies. Nine studies were initiated as part of the 2013 Science Plan and three others were started in Fiscal Year 2017-2018 while the 2018 Science plan update was under development (**Table 5C-1**). Of these twelve studies seven are ongoing, two have been completed in 2018, and three were completed in 2017.

The status, update of progress and key findings of studies numbered 1 through 9 (**Table 5C-1**) are summarized in **Table 5C-2** and discussed further in this report. Findings for studies numbered 1, 2, 4, 9, 10, and 11 were presented in Appendices 5C-3, 5C-5, 5C-2, 5C-6, 5C-1, and 5C-4, respectively, in the *2018 South Florida Environmental Report* (SFER; Ivanoff et al. 2018). More details on findings from studies numbered 1, 2, 3, 7, and 9 are provided in Appendices 5C-1, 5C-2, 5C-3, 5C-4, and 5C-5, respectively, in this volume. More details on the study plans and results can be found in documents listed in the *Literature Cited* section at the end of this report and in the appendices. The next five-year (2018–2023) work plan, including the development of new studies, is included in the 2018 Science Plan.

Table 5C-1. List of all ongoing and completed studies for the Science Plan.

Study Number	Study Title	Initiation and Status [a]
1	**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 Ongoing
2	**Evaluation of Inundation Depth and Duration for Cattail Sustainability** – identify the inundation depth and duration threshold for cattail sustainability in the Everglades STAs.	2013 Ongoing
3	**Use of Soil Amendments and/or Management to Control P Flux** – investigate the benefits of soil amendment applications and/or soil management techniques to reduce internal loading of P in the STAs.	2013 Ongoing
4	**Investigation of STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Technology Performance, Design, and Operational Factors** – assess the chemical, biological, design, and operational factors of the PSTA Cell that contribute to the superior performance of this technology.	2013 to be completed September 2018
5	**Evaluation of the Role of Rooted Floating Aquatic Vegetation (rFAV) in STAs** – assess the ability of rFAV to further enhance low-level P reduction performance of submerged aquatic vegetation (SAV) communities.	2013 to be completed September 2018
6	**Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs** – determine key factors that cause the floating of cattail plants and tussocks in STAs.	2018 Ongoing
7	**Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs** – evaluate fauna processes and factors that affect the P treatment performance of STAs at low TP concentrations.	2018 Ongoing
8	**Improving Resilience of SAV in the STAs** – investigate the effects of operational and natural environmental conditions on SAV health in the STAs	2018 Ongoing
9	**STA Water and P Budget Improvements** – improve annual STA water and P budgets for STA treatment cells. Water and P budgets are important tools for understanding the treatment performance of STAs.	2013 Ongoing
10	**Development of Operational Guidance for Flow Equalization Basin (FEB) and STA Regional Operation** – create tools and methodologies to provide operational guidance for FEBs and STAs.	2013 Completed in 2017
11	**Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow P Concentrations** – determine if TP concentrations or loads change when conveyed through STA inflow or outflow canals, and if so, determine what factors influence the changes.	2013 Completed in 2017
12	**Evaluation of Sampling Methods for TP** – identify factors that may improperly bias water quality monitoring results to begin the process of improving sampling procedures for discharges from the STAs.	2013 Completed in 2017

a. Original: plans developed under the 2013 Science Plan. New 2018: studies initiated in Fiscal Year 2017-2018 while the 2018 Science Plan was being developed.

Table 5C-2. Status and key findings summary of the Science Plan's current nine studies.

Study Number	Study	Status & Key Findings to Date
1	Evaluation of P Sources, Forms, Flux and Transformation Processes in the STAs (P Flux Study)	This multi-component study evaluates 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, and particulate transport and settling. Seven controlled flow events and associated measurements have been carried out in STA-2 FWs 1 and 3. Three flow events are now planned for the STA-3/4 Western FW (Cells 3A and 3B) and will be completed in WY2019. Data integration efforts have been initiated with two key approaches to address study questions using all STA data sets and newly acquired data from this study. Decreasing trends of nutrients are observed in the water column, vegetation. and soils from inflow to outflow of STA-2 FWs 1 and 3, with trace amount of particulate P and dissolved organic P remaining at the outflow. The sources of the different forms of P, especially at the outflow region of the FWs remain to be identified. This study is ongoing through mid-2019. Further details on the progress and findings are provided later in this report and in Appendix 5C-1.
2	Evaluation of Inundation Depth and Duration for Cattail Sustainability	This study evaluates the inundation depth and duration threshold for cattail (*Typha domingensis*) community sustainability in the STAs through field monitoring and evaluation of growth in test cells. The field monitoring was completed in 2018. A report of the first-year field monitoring events (WY2015) from STA-1 West (STA-1W) Cell 2A and STA-3/4 Cell 2A was presented in Appendix 5C-2 of the 2018 SFER. Field monitoring was discontinued in STA-1W Cell 2A in October 2015 due to poor conditions of the cattail community. Monitoring in STA 3/4 was continued until WY2018. Daily average water depth in the inflow region of STA-3/4 Cell 2A was 79 centimeter (cm) compared to 57 cm in the outflow region. Stress on cattail due to deeper water was inferred from various measurements. For the deeper inflow region compared to the outflow region, cattail density was significantly lower in the 2016 and 2017 seasons (probability [p] < 0.05), shoot elongation rate was faster, and belowground biomass: leaf ratio was lower. For both regions, lower photosynthetic rates were observed in the June to July period when waters were deeper. The STA-1W northern test cells studies will be used to evaluate cattail responses to different water depths in a more controlled environment. Healthy cattail populations will be established and allowed to mature in 14- x 0.2-hectare (ha) cells prior to imposing treatment, which includes a range of water depth regimes and inundation durations. Cattail grow-in at the test cells was initiated in 2018 and will continue through the early months of 2019. Treatments will begin in 2019.
3	Use of Soil Amendments and/or Management to Control P Flux	This study investigates the application of soil amendments (e.g. chemical or biological materials typically rich in metal cations, primarily aluminum (Al), calcium (Ca), iron (Fe) or magnesium (Mg), that readily bond with dissolved phosphorus) and soil management to reduce internal loading of P in the STAs. A comprehensive review of the literature indicated that many technologies and amendments lower P concentrations (Chimney 2015). Because of uncertainties in treatment efficacy and potential effects to STA operations and the downstream marsh, along with high estimated costs, no further evaluation is planned for soil amendments at this time. A summary report of this study was included in Appendix 5C-1 of the 2017 SFER (Chimney 2017). A field-scale investigation of the benefits of soil inversion will be performed at the STA-1W Expansion Area #1 beginning in 2019. The effect of inversion on soils was evaluated and is reported in Appendix 5C-3.

Table 5C-2. Continued.

Study Number	Study	Status & Key Findings to Date
4	Investigation of STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Technology Performance, Design, and Operational Factors (PSTA Study)	This study evaluates the ability of periphyton-based treatment to remove P as a final polishing step. Since operation began in 2007, the STA-3/4 PSTA Cell has achieved annual outflow flow-weighted mean TP concentrations of 13 µg/L or less for all years. The study was completed in 2018. Pulsed flows, with hydraulic and TP loading rates of up to 43.4 centimeters per day (cm/day) and 6.4 grams per square meter per day (g/m^2/day), respectively, and operating at water depths up to 0.55 meters (m) did not negatively affect TP reduction. When inflow concentrations were 22 µg/L or less, outflow concentrations were 13 µg/L or less. Accrued P content in soils from the PSTA Cell was relatively low (< 400 milligram per kilogram [mg/kg]). Submerged aquatic vegetation (SAV) tissue concentrations were above 300 milligrams total phosphorus per kilogram (mg TP/kg) near the inflow and declined to around 200 mg TP/kg in the outflow region. A more detailed summary for the PSTA Study was included in Appendix 5C-2 of the 2018 SFER. A mesocosm study that evaluated the effect of capping enriched muck with a layer of limerock was found to produce low outflow P concentrations similar to the PSTA Cell. Further details on the progress and findings are provided later in this report. This study will be completed by September 2018.
5	Evaluation of the Role of Rooted Floating Aquatic Vegetation (rFAV) in STAs (rFAV Study)	This study evaluates the potential benefit to water column P reduction from rooted floating aquatic vegetation (rFAV). rFAV species included in this study were white water lily (*Nymphaea odorata*), American lotus (*Nelumbo lutea*), and spatterdock (*Nuphar advena*). This study comprised investigations into water column chemistry, soil, and flocculent characteristics from rFAV and SAV patches. Results from rFAV patches were compared to nearby SAV-dominated patches to determine relative P reduction and the explanatory factors accounting for differences in P reduction. Results indicate that rFAV provided no direct benefit to P reduction at the outflow regions of the STAs. This study will be completed by September 2018.
6	Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs	The study evaluates potential factors that may have triggered the formation and cause of floating tussocks in the STAs. An extensive literature review encompassing previous research and existing information on floating tussocks, casual factors, and management strategies is complete. The next steps include assessment of floating tussocks to identify potential factors that may cause tussock formation and data mining. This study is ongoing through 2019.
7	Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs	This study is a continuation of an earlier effort to determine the influence of fauna population in P cycling and P reduction in the water column in the STAs. Initial results from the controlled study (enclosures) showed bioturbation by blue tilapia (*Oreochromis aureus*), stocked at densities similar to the high densities observed in STA-2, elevated water column total nitrogen (TN) and TP. In the high density treatment, mean water column concentrations of TP and TN were 2 and 1.5 times greater, respectively, than in the control and low density treatments. Excretion estimates by sailfin mollies (*Poecilia latipinna*) range from 0.01 to 0.17 kilograms per hour (kg/hr) TP and 0.078 to 1.33 kg/hr TN to STA cells. Similar estimates were found for eastern mosquitofish (*Gambusia holbrooki*), bluefin killifish (*Lucania goodei*), and vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*). More detailed information is presented in Appendix 5C-4. This study is ongoing through 2019.

Table 5C-2. Continued.

Study Number	Study	Status & Key Findings to Date
8	Improving Resilience of SAV in the STAs	This study investigates the effects of operational and environmental conditions on the health of SAV in the STAs. A review and analysis of the literature and semi-quantitative surveys of SAV conducted in the past 18 years within the STAs is complete and indicates that SAV resilience is affected by P loading, nitrogen loading, alkalinity, water depth, soil type, soil accretion, drydown/reflooding, wind/wave disturbance, herbivory, and physiological senescence, with P loading, soil type, and water depth as the most influential factors. Hypotheses and experimental methods are being developed for further investigation of these factors and how they influence SAV resilience. This study is ongoing through 2019.
9	STA Water and P Budget Improvements	The purpose of this effort is to improve annual STA water and P budgets for STA treatment cells and FWs to provide a more accurate estimation of STA cell performance 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 used for this test case is being applied to selected treatment cells to generate more accurate water and P budgets. An improved budget analysis for STA-2 was reported in the 2018 SFER. A summary of water and P budget analysis for STA-3/4 treatment cells is included in Appendix 5C-5 of this volume. This study is ongoing through 2023.

INTRODUCTION

A major component of Everglades restoration efforts, the STAs are constructed freshwater treatment wetlands operated to reduce TP concentration in surface water runoff before being discharged to the EPA (**Figure 5C-1**). There are currently 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. In addition, two flow equalization basins (FEBs), A-1 FEB and L-8 FEB, were completed in 2015 and 2017, respectively, as part of the implementation of the *Restoration Strategies Regional Water Quality Plan* (SFWMD 2012a) and are operated to attenuate peak stormwater flows and improve inflow delivery rates to downstream STAs.

The STAs were constructed primarily on former agricultural lands and retain nutrients through plant and microbial uptake, particulate settling, chemical sorption, and ultimately accretion of plant and microbial biomass to the soil layer. Over the period of record, starting 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). Performance continues to improve in recent years, although treatment performance was affected in WY2018 by two major storms (see Chapter 5B in this volume). Additional research is needed to develop strategies to further reduce STA outflows concentration to meet regulatory limits.

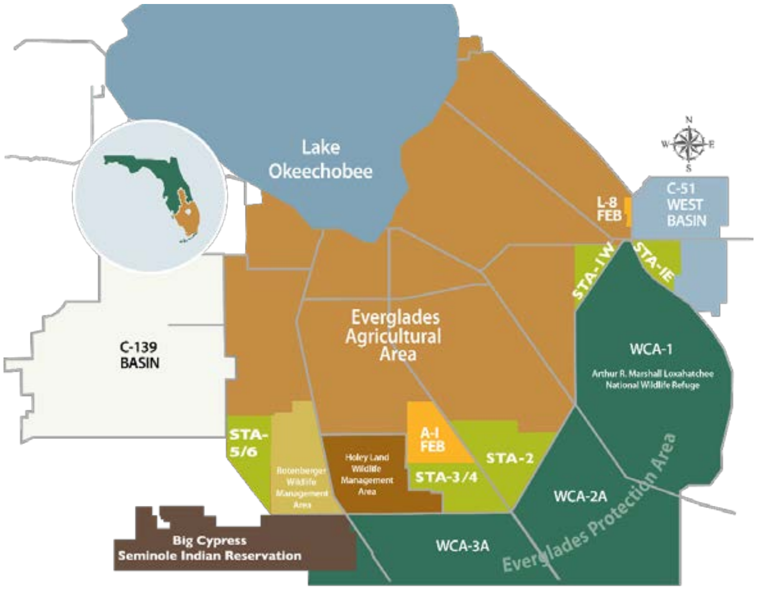

Figure 5C-1. Location of the STAs (STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6) and the FEBs (A-1 and L-8) in relation to the Everglades Agricultural Area, C-139 Basin, the EPA, and other landscape features of South Florida. Maps of individual cells and flow-ways for all STAs can be found in Appendix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

The development and implementation of the Science Plan is a key component of the Restoration Strategies to achieve the ultra-low TP WQBEL established for the Everglades (see Chapter 5A of this volume). It also is specified as one of the requirements in the Consent Orders associated with the two permits for operating the STAs: (1) National Pollution Discharge Elimination System (NPDES) watershed permit, and (2) Everglades Forever Act (EFA) watershed permit. These permits established a stringent WQBEL for TP in discharges from the Everglades STAs. The WQBEL, which is separate from the 4-part test for the Everglades TP criterion (F. A. C. 62-302.540(4)(d)1), is a numeric discharge limit applied to the permitted discharges from the STAs to assure that such discharges do not cause or contribute to exceedances of the 10 µg/L TP criterion (long-term geometric mean) within the EPA. The WQBEL has two parts: the TP concentration discharged from each STA shall not exceed: (1) 13 μg/L as an annual flow-weighted mean (FWM) in more than 3 out of 5 water years on a rolling basis; and (2) 19 μg/L as an annual FWM in any water year. The consent orders specify that the Science Plan must be developed to improve the understanding of mechanisms and factors that affect P treatment performance, particularly, those that are key drivers to performance at low TP concentrations (i.e. < 20 μg/L). In 2013, the Science Plan was developed by the District, in consultation with technical representatives designated by FDEP and USEPA (SFWMD 2013). This 2013 Science Plan defined nine studies that were implemented from 2013 to 2017. The Science Plan was updated in 2018 and this update includes a list of 3 studies initiated in 2018 and 8 additional studies proposed for the next five-year period (2018– 2023; SFWMD 2018). 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 the South Florida Water Management District's (SFWMD's or District's) operational guidance tools.

RESEARCH QUESTIONS

To improve the understanding of mechanisms and factors that affect P treatment performance, 6 key questions and 39 subquestions–formulated through workshops and meetings that reviewed existing knowledge and information gaps–were developed as an integral part of the 2013 Science Plan (SFWMD 2013). These questions were used in the development of nine original studies for the 2013 Science Plan. The 2018 Science Plan update built upon these original key questions and subquestions (SFWMD 2018). All key questions and subquestions were reviewed to assess their continued relevance to achieve 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. 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 seven 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 are the key physicochemical factors influencing P cycling at very low P environment?
4. 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?
5. What is the treatment efficacy, long-term stability, and potential impacts of soil amendment management?
6. 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?
7. 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)?

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 and two will be completed by September 2018. Three additional studies were implemented in Fiscal Year 2017-2018 during the development of the 2018 Science Plan. In addition to the completed and ongoing studies, eight additional studies have been proposed and are included in the 2018 Science Plan (**Table 5C-3**)

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

Study Name	Subquestion(s) Addressed	Associated Key Questions
1. Sustainable Landscape and Treatment in an STA	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?
2. Quantifying the Recalcitrance and Lability of P to Optimize P Retention within STAs	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?
3. The Effect of Vertical Advective Transport on TP Concentrations in the STAs	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?
4. P Reduction Dynamics in STA-1E, STA-1W, STA-2, and STA-5/6	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?

Table 5C-3. Continued.

Study Name	Subquestion(s) Addressed	Associated Key Questions
5. Prescribed Burn Effects on Cattail Communities	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?
6. Assess Benefits and Feasibility of Consolidating Accrued Marl in the STAs' SAV Cells	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 flux of P, be managed to further reduce SRP, PP, and DOP concentrations at the outflow of the STAs?
7. Quantifying P Uptake and Release of Periphyton and Phytoplankton	What are the key physicochemical factors influencing P cycling in very low P environments? What are the sources, forms, and transformation mechanisms controlling residual P pools within the STAs, and how do they compare to the natural system?	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?
8. L-8 FEB and STA Operational Guidance	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 P concentrations?	How can the FEBs/reservoirs be designed and operated to moderate inflow P concentrations and optimize the phosphorus loading rate and hydraulic loading rate in the STAs, possibly in combination with water treatment technologies or inflow canal management?

The progress and findings of research directed by this plan are being reported in annual SFERs. This chapter provides a summary of progress through WY2018 for five studies from the original Science Plan and three added in FY2018 (**Table 5C-1**, Study numbers 1 to 9). More detailed information, including findings from five of the studies (Study Numbers 1, 2, 3, 7, and 9; **Table 5C-1**) are provided in Appendices 5C-1, 5C-2, 5C-3, 5C-4, and 5C-5, respectively. A collection of STA maps, showing individual cells that are referenced in this chapter, can be found in Appendix 5B-1 of this volume. 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.

EVALUATION OF P SOURCES, FORMS, FLUX AND TRANSFORMATION PROCESSES IN THE STAS

Jill King, Odi Villapando, and Delia Ivanoff

The primary objective of this study is to enhance the understanding of mechanisms and factors that affect P treatment performance of the STAs, particularly those that are key drivers of performance at the outflow regions of the flow-ways (FWs). This study has multiple components, with a number of substudies that evaluate various pools, sources, and sinks of P under a variety of conditions (**Table 5C-4**). The results will be used to develop strategies to further reduce P in surface water discharges from the STAs. The study is being conducted primarily in STA-2 FW 1 and FW 3, and STA-3/4 Western FW under different flow conditions with runoff water as the primary water source. Seven flow events have been conducted in STA-2 FW 1 and FW 3. The study has been underway for the last three years and will conclude in 2019 with another year of sampling for three scheduled flow events in STA-3/4 Western FW. More detailed information, including the latest findings, is presented in Appendix 5C-1 on five substudies: flux measurements, soil characterization, microbial enzymatic patterns, vegetation assessments, and particulate transport and settling.

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

Substudy	Status and Comments	Publications and Reports
Data Integration	This effort explored the use of multivariate analyses such as principal component analysis (PCA) to relate P and other biogeochemical relevant state variables with each other. Two teams evaluated the data from a bottom up (University of Florida [UF] Team) and top down (DB Environmental, Inc. [DBE] Team) approach. The UF data integration team proposed the use of structural equation modeling as a tool to further evaluate data and use the relationships to test the P spiraling model. The DBE team approach uses a highly aggregated approach exploring pattern identification and exploratory analyses with a focus on water P, net P reduction, and internal load.	
Organic P Speciation	Method development was completed to optimize P-nuclear magnetic resonance (NMR) measurements to characterize and quantify the different forms of organic P in floc and soil. This optimized technique was applied to floc, recently accreted soil and pre-STA soil samples collected from STA-2. This NMR analyses found that 50 to 71% of the extractable P pool in STA-2 samples from an outflow site were phosphomonoesters (PME) and 8 to 20% were ortho-P. By contrast, the extractable pool at an inflow sites contained PME and ortho-P at similar proportions: 30 to 50% and 38 to 44%, respectively. This suggests a significant portion of P is more labile in inflow cell floc and soils, and potentially more recalcitrant in outflow areas. Methods to quantify organic P forms in water and porewater are difficult due to the relatively low concentrations of P in these media (e.g., solution NMR requires a P concentration of 1 mg/l). Concentrating P prior to analysis is essential. Preliminary results of ultra high performance liquid chromatography coupled with mass spectrometry (UHPLC-MS-MS), and using barium acetate in the extraction procedure, detected and quantified different inositol phosphates. Testing of mass spectrometry methods to determine P species in surface waters is underway. The initial phase of the project was completed December 2017. The next phase, focusing on the sources and fate of particulate organic matter, particularly the relationship between particulate organic carbon and P, was started in March 2018.	University of Florida 2017
Flow-way Assessment	Seven controlled flow events have been completed in STA-2 FWs 1 and 3. The study has now shifted into STA-3/4 Cells 3A and 3B with an anticipated completion date of May 2019. Findings indicate distinct TP concentration gradients from inflow to outflow locations for all phases of flow events. Average TP concentration reduction was higher for STA-2 FW 1 (EAV cell) when compared with FW 3 (SAV cell). More PP was produced under stagnant condition following a period of high flow but not after low flow (FW 3). SRP accounted for majority of reduction in FW 1, while PP accounted for most of the reduction in FW 3. Residual P at the outflow region of both FWs was comprised mainly of PP and DOP, with SRP at minimum detection limit. The residual P pool under both flow and no flow conditions was slightly larger in FW 3 compared to FW 1 and was slightly higher under no flow condition in both FWs.TP was significant correlated with a number of key water quality parameters in both FWs. The source of PP under stagnant condition, the actual composition of PP and DOP, and the sources of P detected at the outflow structures remain unknown and are currently being investigated.	University of Florida 2017
Flux Measurement	Based on three sampling events in STA-2 FW 3 with the mesocosm chambers and porewater equilibrators, flux measurements suggest that soil and/or biotic processes aside from porewater diffusion are substantial contributors to internal P fluxes. Porewater diffusion does occur at the inflow and midflow regions but not at the outflow. P flux rates measured in chambers located at the outflow region also were positive. P flux declined from inflow to outflow. The sources of these fluxes, especially at the outflow regions, have yet to be determined. Additional controlled flow event monitoring is underway in STA-2 FW 1. Additional flow events are planned in STA-3/4 Western FW Cells 3A and 3B.	DBE 2017a

Table 5C-4. Continued.

Substudy	Status and Comments	Publications and Reports
Particle Dynamics	The particulate study field work has been completed and the final report drafted. The project is scheduled to end in October 2018. Field studies showed a diurnal pattern of particle dynamics driven by high afternoon winds. These high afternoon winds resulted in the highest particulate resuspension rates and high water column particulate concentrations that ultimately settled out. These effects were greatest at the inflow region of STA-2 FW 3 where there is a long fetch and little vegetation. Cores from soils accumulating in STA-2 FW 3 show P sequestration with TP concentrations declining from inflow to outflow. Sedimentation rates decreased from inflow to outflow with the particle size in the water column increasing from inflow to the outflow region.	FIU 2018
Soil Characterization	The last phase of benchmark soil sampling in STA-2 FWs 1 and 3 and the Western FW of STA-3/4 was completed in March 2018. P fractionation of floc and soil samples from these FWs is complete. The laboratory work associated with the P sorption/desorption study is complete, but data analysis and interpretation are still ongoing. Additional experiments, including P dosing, litter decomposition, and abiotic degradation of DOP and carbon in the same test FWs are in different stages of implementation. All laboratory and field work associated with these studies will be completed by December 2018.	University of Florida 2017
Vegetation Assessment	Vegetation monitoring continues using Worldview 2 satellite imagery supplemented with box-on-aircraft data collected. Ground surveys of SAV continue for STA-2 FW 3 and STA-3/4 Cell 3B. Hurricane Irma resulted in substantial loss of SAV in both cells, with almost 100% of SAV in STA-2 FW 3 lost. Biomass harvesting has been completed for STA-2 FW 1 (EAV) and FW 3 (SAV), with the study now shifting to STA-3/4 Cells 3A and 3B. Results to date indicate TP storage in the vegetation is substantially higher at the inflow region for EAV compared to SAV. TP concentrations in SAV tissues at the inflow region of FW 3 are higher than in EAV tissues at the inflow region of FW 1, indicating higher P uptake by SAV; this trend reversed at the middle and outflow regions.	
Enzyme Activity	Enzyme assay analyses, including alkaline phosphatase, bis-phosphatase, leucine aminopeptidase, N-acetyl-glucosaminidase and, β-glucosidase, have been completed for surface water, periphyton, floc, and litter for all 7 flow events conducted in STA-2 FW 1 and FW 3. Results to data indicate microbial activity in periphyton is highly variable. Flow conditions appear to have an effect on microbial abundance and activities with periphyton and benthic communities responding differently. Responses are believed to be related to the vegetation community and related to the delivery of nutrients and carbon substrates for the associated microbial community. In both EAV and SAV, flow appears to enhance nutrient limitation at the outflow regions. Additional sampling events are planned for STA-3/4 Cells 3A and 3B in sync with the FW assessments and P Flux Study.	
Aquatic Fauna	Field work for the throw trapping, excretion, and bioturbation is complete and the final report is anticipated in August 2018. Results indicated that STA fish nutrient content and stoichiometric ratios were similar to values reported for enriched areas of Water Conservation Area 2A. In the three months sampled, fish tissues contained 980 to 1,130 kilograms (kg) of TP and 3,673 and 3,801 kg of TN in STA-2 Cells 3, 4, 5, and 6. Because of the substantial fish population, further analyses on the contribution of fauna to the water column P in the outflow regions of STAs is being investigated as a separate study. More information is found in Appendix 5C-4.	

EVALUATION OF INUNDATION DEPTH AND DURATION FOR CATTAIL SUSTAINABILITY

Orlando Diaz

The purpose of this 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 conducted in two cells where significant cattail decline has been observed through years of operation: STA-1W Cell 2A and STA-3/4 Cell 2A. These two cells differ in soil depth, cattail density, and hydrologic condition.

A summary of the 2015 monitoring events from STA-1W Cell 2A and STA-3/4 Cell 2A was presented in Appendix 5C-5 of the 2018 SFER (Diaz 2018). Field monitoring was discontinued in STA-1W Cell 2A after October 2015 due to poor conditions of the cattail community. Results from the three-monitoring seasons (2015, 2016, and 2017) in STA-3/4 Cell 2A are reported in Appendix 5C-2 of this current volume. The inflow region, where most of the cattail losses have been observed in previous years, has a daily average water depth of 79 cm, while the outflow region has an average depth of 57 cm. Total shoot density was not significantly different between the inflow and outflow regions for the 2015 wet season. This likely was due to more rigorous growth following a planned drawdown in the 2014 dry season, and the cattail communities had not been exposed to prolonged deep water condition at the initiation of this study in 2015. However, data from the 2016 and 2017 wet seasons indicate that cattail density was significantly lower (probability [p] < 0.05) in the inflow region than the outflow region of this cell. Prolonged water depths over time may have negatively affected the cattail population in the inflow region, which experienced a total of 114 days at water depths above 91 cm (3 ft) in the 2016 wet season and another 104 days above 91 cm in the 2017 wet season.

Total live biomass sampled in November 2014, October 2015, and November 2017 was not significantly different ($p > 0.05$) between inflow and outflow plots. However, combined total live biomass for the inflow and outflow regions declined significantly ($p < 0.05$) over time, with 1,947, 1,224, and 681 grams per square meter (g/m^2) in 2014, 2015, and 2017, respectively. There also was a noticeable decrease in the belowground biomass:leaf ratio in the inflow region over the same time period, suggesting that the root and rhizomes of the cattail communities were stressed more than leaves in this region of the cell. A more detailed summary of the results from the in situ study in STA-3/4 Cell 2A is presented in Appendix 5C-2.

For the next phase of this study—the Test Cell Component—a healthy cattail population will be established and allowed to mature in the STA-1W northern test cells (14- x 0.2-ha cells) prior to imposing treatment, which includes a range of water depth regimes and inundation durations. Cattail grow-in at the test cells was initiated in 2018 and will continue through the early months of 2019 (**Table 5C-5**).

Table 5C-5. Status and highlights for the Evaluation of Inundation Depth and Duration for Cattail Sustainability study.

Task	Status and Comments
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. Results from the first year of monitoring were included in Appendix 5C-5 of the 2018 SFER (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 are included in Appendix 5C-2 of this volume.
Test cell study	Refurbishment of the STA-1W Northern Test Cells was completed in late 2016. Preparations of test cells including weed control and inflow pump testing continued through 2017. Test cells were seeded the first week of May 2018. Young cattail seedlings of 12 to15 cm in height (50 to 55 days old) were transplanted from mid-May 2018 through mid-June 2018 at a density of approximately 140 cattail plants per cell for grow-in purposes. Water levels will be maintained at about 4 to 6 inches above the soil surface for the next 2 to 3 months to encourage growth on the young seedlings.

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

Michael Chimney and Manohardeep Josan

This study investigated soil amendments (e.g. chemical or biological materials typically rich in metal cations, primarily aluminum (Al), calcium (Ca), iron (Fe) or magnesium (Mg), that readily bond with dissolved phosphorus) and soil management techniques to reduce the flux of soluble P from the soil to the water column of STAs and lower outflow TP concentrations. The original study included three phases. Phase I is complete and findings are summarized in a District technical publication (Chimney 2015, **Table 5C-6**). This report proposed two options for conducting Phase III large-scale field trials within the STAs. However, considering the uncertainties in treatment efficacy, potential effects to STA operations, the estimated cost of conducting large-scale field trials, and the practicality of implementing any of these technologies at full-scale in the STAs, a decision was made to test only soil inversion at a large scale in the STA-1W Expansion Area #1.This approach inverts the soil column through deep tilling so that oxidized, P-rich surface soil is deeply buried and lower-P soil at depth is brought to the surface. Work on Phases II and III for the other technologies outlined in Chimney (2015) has been postponed indefinitely. More detailed information was reported in Appendix 5C-1 of the 2017 SFER Volume 1 (Chimney 2017).

The STA-1 Expansion Area #1 will add three new cells to STA-1W (Cells 6, 7, and 8). Soils have been tilled to a depth of at least 60 centimeters (cm; 2 feet [ft]) in Cell 7 and part of Cell 6 to remediate for high copper levels in the surface soil that are a legacy of past agricultural practices (AECOM Technical Services, Inc. 2016). A preliminary soil study assessed the effectiveness of deep tilling to reduce the TP content of surface soil (**Appendix 5C-3**). 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). To measure soil P flux 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 soluble reactive phosphorus (SRP) flux rate in these cores after 42 days of incubation was 3.3, 1.6, and 0.1 milligrams phosphorus per square meter per day (mg $P/m^2/d$), respectively.

Once operational, the treatment performance of Cell 7 will be compared to Cell 8 through comparison of inflow and outflow TP concentrations. This test will begin sometime in 2019.

Table 5C-6. Progress to date of the Use of Soil Amendments and/or Management to Control P Flux 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.	All tasks completed in October 2015 (Water Year 2016; May 1, 2015–April 30, 2016). Many soil amendments and technologies have been demonstrated (by various researchers) to sequester phosphorus in aquatic environments. Application can be very costly and there are several uncertainties concerning 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	Based on these projected costs and other considerations evaluated in Phase I, a decision was made not to evaluate soil amendments further, but to proceed with field-scale testing of soil inversion in the STA-1 W expansion area 1.	

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

Tracey Piccone and Hongying Zhao

The objective of this multi-component study was to assess the chemical and biological characteristics and the design and operational factors of the Periphyton-based Stormwater Treatment Area (PSTA) Cell in STA-3/4 that contribute to the superior treatment performance of this technology (**Table 5C-7**). During ten years of operation, the outflow FWM TP concentrations ranged from 8 to 13 µg/L. The operational ranges under which the PSTA Cell achieved ultra-low outflow TP levels was evaluated. 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 Investigation of STA-3/4 PSTA Technology Performance, Design, and Operational Factors 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 was no significant difference in treatment performance between two operational depths (0.40 and 0.55 meter). 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 was 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 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 2016b DBE 2018b
Influence of soil accrual and vegetation nutrient contents	Task was completed in WY2018. No significant difference in soil accrual depth or soil P content between inflow and outflow regions of the PSTA Cell were found. 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 2018b

ANNUAL PERFORMANCE

To assess the PSTA Cell's treatment performance, data from Water Year 2008 (WY2008; May 1, 2007–April 30, 2008) to WY2018 were used to calculate the cell's annual hydraulic loading rate (HLR), P loading rate (PLR), hydraulic residence time (HRT), and TP settling rate (k) (**Table 5C-8**). As in previous annual reports, these calculations accounted for the duration of the PSTA Cell's operational period. 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 from the operational period.

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 WY2018. [a]

Water Year	HLR (cm/d)	HRT (d)	Q_{in} (ha-m)	Q_{out} (ha-m)	FWM TP_{in} (µg/L)	FWM TP_{out} (µg/L)	PLR ($g/m^2/yr$)	k (m/yr)	Operational Period	Operational Period (d)
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
WY2017	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

a, Key to Units: µg/L – micrograms per liter; cm/d – centimeters per day; d – day; $g/m^2/yr$ – grams per square meter per year; ha-m – hectare-meter; and m/yr – meters per year.

Calculations of HLR, PLR, HRT, and k for the PSTA Cell for each water year took into account the differing operational period. The equations used for these calculations are as follows:

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

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

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

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

Where

HLR = surface water hydraulic loading rate (centimeters per day [cm/d])

PLR = TP loading rate (grams per square meter per year [$g/m^2/yr$])

HRT = nominal hydraulic residence time (day [d])

k = TP settling rate (i.e., removal coefficient) (meter per year [m/yr])

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

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

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

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

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

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

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

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

C^* = background TP concentration (micrograms per liter [µg/L]) (background concentration in STA design)

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

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

In summary, for WY2018, the PSTA Cell produced an annual outflow FWM TP concentration of 9 µg/L with an inflow TP FWM concentration of 10 µg/L. The inflow concentration was the lowest for the 11-year operational period from WY2008 to WY2018. For WY2018, the HLR and PLR of 5.0 cm/day and 0.19 $g/m^2/yr$, respectively, were within the same range as previous water years. Due to the low HLR and the inflow FWM TP concentration, the settling rate k (3.7 m/yr) was the lowest in the 11-year operational period. This research study will be completed by September 2018; however, inflow and outflow monitoring will continue.

EVALUATION OF THE ROLE OF ROOTED FLOATING AQUATIC VEGETATION IN STAS

Matt Powers

The objective of this study was to determine if different rooted floating aquatic vegetation (rFAV) species could enhance P reduction performance in SAV communities in the outflow region of STAs. In addition, data collected was used to assess potential adverse effects on water quality by rFAV species that have formed dense stands in some STA cells. The study focused on three specific rFAV species common in the STAs: *Nymphaea odorata* (white water lily), *Nelumbo lutea* (American lotus), and *Nuphar advena* (spatterdock) (**Table 5C-9**). Some of these species thrive in the SAV areas of the STAs and in the low P regions of the Everglades Water Conservation Areas (WCAs). The first phase of the study included field reconnaissance for rFAV+SAV and SAV only patches within the STAs, initial spatial monitoring, and a more long-term temporal monitoring (**Table 5C-10**). Patches were defined as contiguous areas dominated by a single vegetation type larger than one half acre. Concentrations of P species in the water column of each patch were monitored to determine if differences existed between rFAV and SAV patches. The second phase of the study, to be completed by September 2018, investigates the mechanisms and processes responsible for these differences.

Table 5C-9. Vegetation types and species in selected monitoring patches to evaluate the difference in water column P concentration in SAV cells with and without the presence of rFAV species.

Location	rFAV species	Associated SAV Species
STA-1W Cell 5B	White water lily	Southern naiad (*Najas guadalupensis*) and chara (*Chara* sp.)
STA-5/6 Cell 3B	Spatterdock	Southern naiad and coontail (*Ceratophyllum demersum*)
STA-1E Cell 4S	American lotus	Hydrilla (*Hydrilla* sp.) and southern naiad

Table 5C-10. Status of the different tasks for the Evaluation of the Role of rFAV in STAs study.

Task	Status and Comments	Publications and Reports
Initial spatial water sampling of P variability in patches	Completed in June 2016	DBE 2016a
Temporal water sampling measuring P species at patches	Initiated August 2016; ongoing	DBE 2016a
Soil and flocculent characterization; measurement of physical parameters and mineral and nutrient content	Completed August 2016 and March 2017	DBE 2016a DBE 2018c
Porewater sampling of P species	Completed April 2017	DBE 2017b
Deployed sonde measurements of temperature, dissolved oxygen, pH, and specific conductivity measurements	Completed September 2017	DBE 2018a
rFAV tissue nutrient content sampling	To be completed by September 2018	DBE 2018a
Anoxic P release from soils	To be completed by September 2018	DBE 2018c
Flocculent suspension effect on P species in water column	To be completed by September 2018	DBE 2018c

Consistently higher water column P concentrations were found in white water lily, spatterdock, and American lotus compared to SAV. At every patch monitored, the mean P concentration in the water column was greater in the rFAV patch than the SAV patch with statistically significant differences in six of the nine patches monitored. This suggests that rFAV provide no direct benefit to P reduction performance at the outflow regions of the STAs. Continued temporal monitoring of additional patches in other STAs is underway to confirm findings presented here and to determine if findings are consistent among other STAs.

Soil characterization and deployed sonde readings from rFAV and their paired SAV patches have led to insights on the causal factors influencing performance of these patches. Soils in white water lily patches exhibited low bulk density, higher organic matter content, and lower calcium content compared to their paired SAV patch. Low bulk density soils can be easily resuspended and may contribute to higher PP values in the water column of these lily patches. Deployed sonde measurements of dissolved oxygen (DO) indicate greater aquatic metabolism in the SAV patches relative to the rFAV patches. Greater aquatic metabolism results from increased photosynthesis in the water column, which leads to higher pH during daylight hours. This higher pH results in greater co-precipitation of P with calcium leading to increased P reduction. The soil from American lotus patches also had higher organic content and lower density than paired SAV patches but otherwise did not exhibit many differences. Measurements of DO in SAV patches showed more distinct diurnal patterns than in associated rFAV patches. This pattern was characterized by peak DO concentrations reaching supersaturation during the day and little to no DO in the water column at night resulting in anoxic conditions. Low oxygen concentrations in the water column can affect the top layer of the soil resulting in numerous biological and chemical processes related to anaerobic conditions affecting P release from the soil.

The spatterdock community did not shade out SAV to the degree that lotus and lily did, therefore SAV had relatively high coverage in the spatterdock patch. Despite the high SAV coverage in the spatterdock patch, the soil was found to have higher organic matter content and lower calcium content than their paired SAV patches without spatterdock. Also, aquatic metabolism in the SAV patches was higher than spatterdock counterparts.

Measurements of P flux in soil cores were taken from Cattail, SAV, and rFAV patches in STA-1W Cell 5B and STA-5 Cell 3B. SAV and rFAV soil cores from STA-1W Cell 5B had lower release of P, (0.14 and 0.20 mg P/m^2/day, respectively), than soil cores from cattail patches (2.77 mg P/m^2/day; DBE 2018b). Cattail and spatterdock soil cores from STA-5/6 Cell 3B had similar P release rates (2.07 and 2.40 mg P/m^2/day, respectively), while the SAV patch P release was approximately 1 mg P/m^2/day. The P released was 85 to 94% SRP for all soil cores from STA-5/6 and from the cattail soil core in STA-1W. The rFAV and SAV soil cores in STA-1W released P in the form of particulate phosphorus. Soil cores that released most of their P in the form of SRP had a higher mean rate of P release, 2.06 mg P/m^2/day, than soil cores that released most of their P in the form of PP, with a mean rate 0.17 mg P/m^2/day.

Although not the only factor, vegetation type plays a major role in determining the physical and chemical characteristics of floc. Vegetation directly creates floc when it decomposes. White water lily was found to have the lowest P concentration in its leaf tissue of the rFAV species. Spatterdock and lotus had similar P concentrations. Soils and flocculent data show that P concentration of the soil and floc is uncorrelated or negatively correlated to the leaf tissue P concentration. This suggests that processes other than litter accumulation affect soil P concentrations in these patches. One potential process is pH, which is more alkaline in SAV patches and results in flocs with higher calcium content than the associated rFAV patches. This builds a denser flocculent layer at SAV sites than rFAV sites.

EVALUATION OF FACTORS CONTRIBUTING TO THE FORMATION OF FLOATING TUSSOCKS IN THE STAS

Manohardeep Josan

The overall objective of this study is to determine the key factors that cause the formation of floating tussocks (primarily composed of cattail [*Typha* sp.]) in the STAs. Specifically, the study will do the following:

- Characterize and compare conditions between areas of healthy cattail coverage (without signs of floating tussocks) versus areas prone to chronic floating tussock formation in the STAs.
- Assess the effects of floating tussocks on STA treatment performance.
- Provide an understanding of the factors that contribute to the formation of floating tussocks in the STAs.

The information derived from this study will inform management decisions aimed to reduce the formation of floating tussocks and/or their effects in the STAs.

This study was initiated in 2018; initial tasks include completion of a literature review, development of a nomenclature scheme to accurately describe various types of floating vegetation and/or floating muck in STAs, assessment of current areas of floating cattail communities and tussocks in STA EAV cells, and data mining to identify environmental factors that may have triggered floating tussocks formation (**Table 5C-11**).

Table 5C-11. Status of the different tasks for the Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs study.

Task	Status	Reports
Literature review	Initiated in June 2018; ongoing	
Assessment of floating tussocks coverage in STA EAV Cells	Initiated in June 2018; ongoing	
Data Mining	Starts in 01/2019	
Evaluation of findings and final report	Starts in 03/2019	

INVESTIGATION OF THE EFFECTS OF ABUNDANT FAUNAL SPECIES ON P CYCLING IN THE STAS

Nathan Evans, Joel Trexler, and Mark Cook

The objective of this faunal study, part of the P Flux Study, is to evaluate the influence of large populations of fish and aquatic invertebrates on P reduction in STAs. Specifically, this study estimates (1) standing stock biomass of fish and aquatic macroinvertebrates (STA-2), and aquatic faunal community compositional data (STAs -2, -1E, and -1W); (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 phosphorous 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 aimed at improving P retention efficiency.

Initial results of fish surveys, reported in Appendix 5C-3 of the 2018 SFER (Villapando and King 2018), estimated fish and macroinvertebrate biomass of STA-2 outflow FWs 3, 4, 5, and 6 using electrofishing methods for large fish and throw traps for small fish and invertebrates. The next phase of the study, reported here, estimates the total mass of P and nitrogen (N) sequestered in STA fish based on carbon (C), N, and P content in tissue samples and total dry weight biomass for the 10 most abundant species in STA-2. Further details can be found in Appendix 5C-4 of this volume.

The third phase of this study, to estimate N and P excretion rates for STA fishes, was developed in the past year. Mass-specific estimates of TP excretion were calculated for sailfin molly (*Poecilia latipinna*), eastern mosquitofish (*Gambusia holbrooki*), and vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*), while estimates of TN excretion were calculated for sailfin molly, bluefin killifish (*Lucania goodei*), and vermiculated sailfin catfish. Preliminary mass-specific N and P excretion rates varied among species, with small-bodied fishes revealing higher mass-adjusted excretions rates than large-bodied species.

Large fish relative abundance, collected using electrofishing, was consistent among the sampling events (February, April, and October 2016 and March 2017). Largemouth bass (*Micropterus salmoides*), sunfish (*Lepomis* spp.), Seminole killifish (*Fundulus seminolis*), and blue tilapia (*Oreochroms aureus*) were among the most commonly collected species. Mean catch per unit effort (CPUE; individuals per minute of electrofishing) in April 2016 was on average 1.8 times greater than in February 2016 and October 2016 (repeated measures analysis of variance [rmANOVA], $p < 0.01$). This difference in fish catches appears to be heavily influenced by relatively more fish caught in STA-1W during the April 2016 sampling and relatively fewer fish caught in in STA-2 and STA-1W during the October 2016 and March 2017 sampling events.

The average P content in body tissue of fish ranged from 2.0 ± 0.8% (mean ± standard deviation [SD]) (blue tilapia) to 3.7 ± 1.2% (Mayan cichlid [*Cichlasoma urophthalmus*]). Generally, P content varied more within species (among individuals) than among species. Intraspecific differences in P content among individuals ranged from 1.1% (bluefin killifish) to 5.1% (Mayan cichlid). The average N content in body tissue ranged from 9.3 ± 0.7% (blue tilapia) to 11.6 ± 0.8% (largemouth bass). Differences in N content were similar both within and among species and ranged from 0.8% to 2.5%. The average C content in body tissue ranged from 37.4 ± 4.5% (Mayan cichlid) to 47.7 ± 3.6% (blue tilapia). Stoichiometric ratios (C:P, C:N, and N:P) varied, but were highest for blue tilapia compared to the other species. Total areal estimates of the mass of P and N stored within the tissue of the ten most abundant fish species were similar for both the first and second sampling periods, at approximately 1,065 kg of P and 3,733 kg of N in STA 2 Cells 3, 4, 5, and 6.

Bioturbation measurements were conducted in enclosures that contained fish at high and low densities (see Appendix 5C-4 of this volume for more details). Mean water column TP was approximately two times higher in the high density blue tilapia enclosures than the control treatment and low-density treatment enclosures (rmANOVA, $p < 0.05$). No significant differences in water column TP were observed among the largemouth bass or Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*) treatments. Mean water column TN was also significantly greater (rmANOVA, $p < 0.05$) by 1.5 times in the high density blue tilapia enclosures than in the control treatment enclosures. Mean water column TN in the low density treatment enclosures was intermediate and not significantly different from either the control treatment or the high density treatment enclosures.

These results suggest that some fish species, like blue tilapia, have the potential to increase water column TN and TP via excretion and bioturbation, while other species, like largemouth bass and Orinoco sailfin catfish, may have minimal effects on water column nutrient concentrations. These 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.

IMPROVING RESILIENCE OF SAV IN THE STAS

Manohardeep Josan

Submerged aquatic vegetation (SAV) resiliency can be affected by both operational and natural environmental conditions such as water depth, nutrient and mineral concentrations, soil type, seasonality, light penetration, competition with epiphytic periphyton, etc. The objective of the study is to investigate the effects of nutrient loading concentration and soil types (e.g., farm muck versus marl sediments) on the SAV (e.g. *Chara* spp., *Najas guadalupensis*, and *Potamogeton illinoensis)* health in the STAs. SAV loss due to herbivory or extreme weather events is being addressed in another study. The first phase of this study includes a literature review on the biology and relevant attributes of the most common SAV species in the STAs, an analysis of existing data to assess temporal changes in SAV relative abundance in STAs over time using semi-quantitative SAV field surveys, the development of methods and an experimental study plan for assessing key factors that influence SAV resilience in the STAs, and a set of experiments based on the study plan (**Table 5C-12)**.

SAV plays a significant role in reducing nutrients, especially P, in the water column in some of the downstream treatment cells of the EAA STAs. SAV species, especially *Chara* spp. (e.g., muskgrass) can grow rapidly, provided enough light penetration into the water column, the right water chemistry (e.g., inorganic carbon, low P, and calcium), and adequate water levels are maintained. Sudden declines of SAV, (e.g., *Chara* spp.) have been observed in the STAs resulting in a shift from clear water to turbid water and impairment of P reduction performance.

Semi-quantitative surveys of SAV spatial coverage and relative density in the STAs have been performed over the past 18 years. Survey results have been presented in numerous reports, including Chapter 5C of previous SFERs. Most of the SAV taxa found in the STAs are primarily native to Florida (**Table 5C-13),** with one exception, hydrilla (*Hydrilla verticillata*), an aggressive exotic plant. The present study will review SAV-related literature to better understand the different species' biology and growth factors, analyze trends in historical data and some of the key factors, and determine the need for and design further studies to better understand effects of key variables on SAV resiliency.

Table 5C-12. Status of the different tasks for the Improving Resilience of SAV in the STAs study.

Task	Status and Comments	Reports
Literature review	Completed in June 2018	DBE 2018d
Data analyses	Initiated June 2018; ongoing	
Develop experimental methods	Initiated July 2018; ongoing	
Study plan development for experimental methods	Initiated August 2018; ongoing.	
Experimental studies	Planned for 2019	

Table 5C-13. SAV taxa found in the Everglades STAs.

Scientific Name	Common Name
Ceratophyllum demersum	Hornwort or coontail
Chara spp.	Muskgrass
Hydrilla verticillata	Hydrilla
Najas guadalupensis	Southern naiad
Najas marina	Spiny naiad
Potamogeton illinoensis	Illinois pondweed
Utricularia foliosa	Leafy bladderwort
Utricularia gibba	Humped bladderwort
Utricularia purpurea	Purple bladderwort
Vallisneria americana	Eelgrass

The literature review of STA studies conducted at field and mesocosm scales identified several factors that could affect SAV resilience: P loading, nitrogen loading, alkalinity, water depth, soil type, soil accretion, drydown/reflooding, wind/wave disturbance, herbivory, and physiological senescence (DBE 2018d). P loading, soil type, and water depth are likely the major factors controlling SAV resilience. Specifically, the literature review revealed that SAV standing crop biomass and tissue P contents decreased from the inflow to outflow regions of STA FWs. Certain SAV, such as *Ceratophyllum demersum* thrive under high P loading rates, whereas *Chara* spp. prefer low P loading rates. *Najas guadalupensis* prefers deeper (up to 1.2 meter) waters, whereas *Chara* spp. flourish under moderate to shallow water depths (DBE 2018d). Also, soil characteristics may affect SAV root development, viability, and/or growth. Marl soils that accumulate in the SAV-dominated STA FWs have very different physical and chemical characteristics than the farmed muck soils upon which many STA cells were constructed. The study plan will consider methods to evaluate these specific factors.

STA WATER AND P BUDGET IMPROVEMENTS

Tracey Piccone and Hongying Zhao

The purpose of this study is to produce improved annual STA water and P budgets for STA treatment cells to provide a more accurate estimation of STA cell performance and to identify areas of uncertainty in these calculations. 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 are comprised of structure flows (inflows and outflows), rainfall, evapotranspiration (ET), seepage, and change in storage (**Figure 5C-2**). Structure flows are calculated using hydraulic equations developed for each water control structure. Rainfall is estimated from rain gauge measurements located within or near each STA. ET is estimated with a model that was developed from lysimeter measurements of wetland ET at the Everglades Nutrient Removal Project (Abtew 1996). Seepage is estimated as flow through perimeter levees and is based on head differences between the treatment cell and outside area water levels, levee length, and a first order seepage coefficient. The District's Water Budget Application Tool 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 of these estimates. 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.

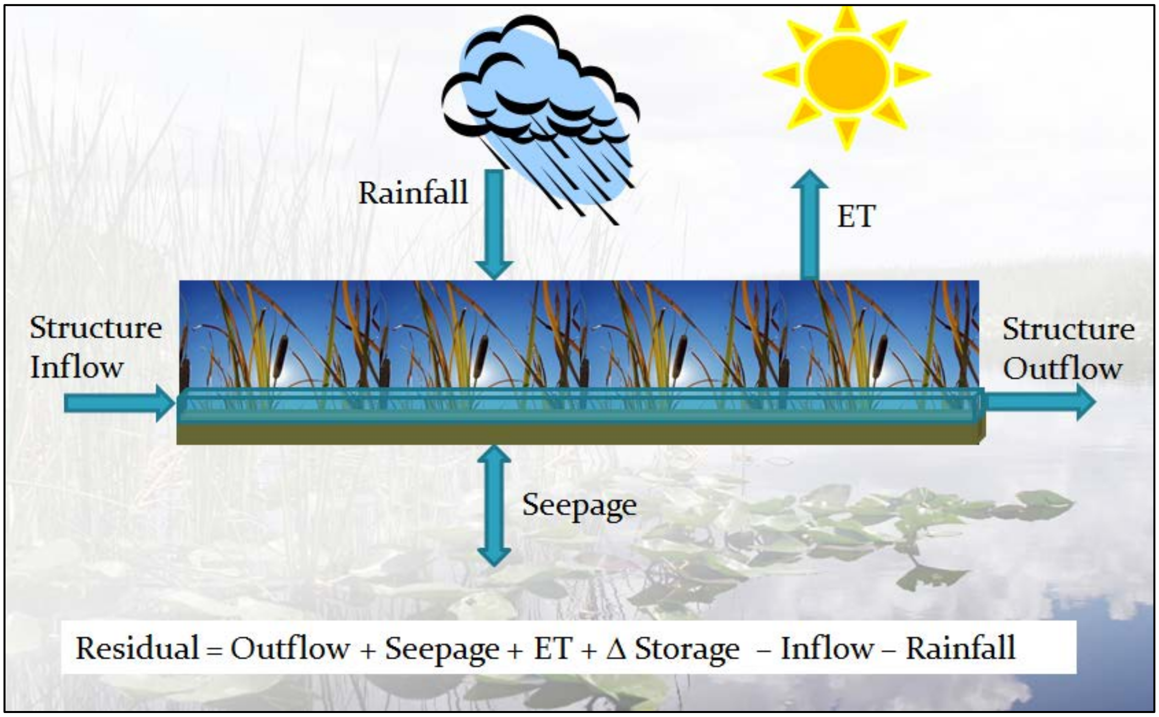

Figure 5C-2. Conceptual model for a water budget in the STAs.

The study is being implemented in two phases:

- Phase I included a test case analysis for improving 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 includes implementing the methodologies investigated during Phase I on an expanded list of treatment cells and includes developing improved P budgets for these treatment cells.

A summary of progress on this study is presented in **Table 5C-14**. Updated period of record analysis of water and P budget is summarized in Appendix 5C-5 of this volume.

Table 5C-14. Status and highlights of the STA Water and P Budget Improvements study.

Task	Status and Comments	Publications and Reports
STA-3/4 Cells 3A and 3B water budget improvement test case (Phase I)	This task was completed in WY2014. Key findings of the task include the following: • Structure flows were the largest component of the water budgets and the largest source of uncertainty in the residuals. • Low head differentials across mid-levee culverts were the main source of error. • Seepage was identified as a significant contributor of residual uncertainty for the test case despite constituting a small fraction of water budgets. • Rainfall, ET, and change in storage were minor contributors, 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 a series of steps and methods, including an improved flow rating equation, review and correction of flow data (e.g., by setting small head differentials to zero), and back calculations by redistributing FW water budget residuals to both cells and by using weighted average of FW 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	Work on updated period of record water and TP budgets for STA-2 FWs 1, 2, and 3 was completed in WY2018; results are summarized in Appendix 5C-6 of the 2018 SFER (Zhao and Piccone 2018). Updates on period of record water and TP budgets for STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B was completed in WY2018; results are summarized in Appendix 5C-5 of this volume.	Appendix 5C-6 of 2018 SFER (Zhao and Piccone 2018
STA-5 flow data and flow rating improvements	Improvement of flow data for select STA-5 structures starting with WY2015 was completed in WY2017.	

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.

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.

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

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

DBE. 2016a. *Quarterly Report #1 under Agreement No. 4600003298*. Prepared by DB Environmental, Inc. for the South Florida Water Management District, West Palm Beach, FL. December 2016.

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

DBE. 2017a. *Field and Supplemental Laboratory Support for Evaluating Phosphorus Sources, Flux, and Transformation Processes in the Stormwater Treatment Areas – Annual Report*. Prepared by DB Environmental, Inc. under Agreement 4600003029-WO01 for South Florida Water Management District, West Palm Beach, FL. June 2, 2017.

DBE. 2017b. *Quarterly Report #3 under Agreement No. 4600003475*. *Investigation of Rooted Floating Aquatic Vegetation in Stormwater Treatment Areas: Update on Progress and Key Findings*. Prepared by DB Environmental, Inc. for South Florida Water Management District, West Palm Beach, FL. June 2017.

DBE. 2018a. *Deliverable 3B Quarterly Report #2 under Agreement No. 4600003695. Enhancing Vegetation-based Treatment in the STAs: Evaluations of Rooted Floating Aquatic Vegetation and SAV Resilience*. Prepared by DB Environmental, Inc. for South Florida Water Management District, West Palm Beach, FL.

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

DBE. 2018c. *Deliverable 4B Quarterly Report #3 under Agreement No. 4600003695. Enhancing Vegetation-based Treatment in the STAs: Evaluations of Rooted Floating Aquatic Vegetation and SAV Resilience*. Prepared by DB Environmental, Inc. for South Florida Water Management District, West Palm Beach, FL.

DBE. 2018d. *Deliverable 4B under Agreement No. 4600003695, SAV Resilience in Everglades STAs: Literature Review*. Prepared by DB Environmental, Inc. for 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.

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.

FIU. 2018. *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.

Ivanoff, D., T. Piccone, T. James and J. McBryan. 2018. Chapter 5C: Restoration Strategies Science Plan Implementation In: *2018 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.

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. Available online at https://www.sfwmd.gov/sites/default/files/documents/rs_scienceplan_060713_final.pdf.

SFWMD. 2018. *Science Plan for the Everglades Stormwater Treatment Areas*. South Florida Water Management District, West Palm Beach, FL. July 2018. Available online at https://www.sfwmd.gov/sites/default/files/documents/rs_scienceplan_update_july2018.pdf

University of Florida. 2017. *Evaluation of Soil Biogeochemical Properties Influencing Phosphorus Flux in the Everglades Stormwater Treatment Areas (STAs) Annual Report*. Submitted to South Florida Water Management District, West Palm Beach, FL.

Villapando, R and J. King. 2018. Appendix 5C-3: Evaluation of Phosphorus Sources, Forms, Flux, and Transformation Processes in the Stormwater Treatment Areas. In: *2018 South Florida Environmental Report – Volume I*, 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.