Chapter 5C: Restoration Strategies Science Plan Implementation

Edited by Delia Ivanoff, Tracey Piccone, Tom James, and Jeremy McBryan

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) in discharges 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 < 20 micrograms per liter [μg/L]). The *Science Plan for the Everglades Stormwater Treatment Areas* (Science Plan; SFWMD 2013b) was submitted to FDEP in June 2013. The Science Plan serves as the overall framework for development and coordination of scientific research to identify the critical factors that collectively influence P reduction and treatment performance. Results gathered from the implementation of the Science Plan will be used to develop strategies to further lower outflow TP concentrations. As such, the research is specific to the Everglades STAs and does not encompass science related to source control technologies upstream of the STAs or water quality parameters other than TP.

The development of the Science Plan involved a review of existing knowledge, determining information gaps and uncertainties, and formulating questions regarding the physical, chemical, and biological processes, as well as management and operation of the STAs. The key questions, identified later in this report, were the basis for formulating studies. The initial Science Plan implementation has nine individual studies, currently at varying phases of implementation:

1. **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.
2. **Use of Soil Amendments and/or Management to Control P Flux** – investigate the benefits of application of soil amendments and/or soil management techniques on reduction of internal loading of P in the STAs.
3. **STA-3/4 Periphyton-based STA (PSTA) 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.

4. **P Sources, Forms, Flux and Transformation Processes in the STAs** – improve understanding of the mechanisms and factors that affect P reduction in the STAs, particularly in the lower reaches of the treatment flow-ways.
5. **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.
6. **Inundation Depth and Duration for Cattail Sustainability** – to identify the inundation depth and duration threshold for cattail sustainability in the Everglades STAs.
7. **Evaluation of the Role of Rooted Floating Aquatic Vegetation (rFAV) in STAs** – to assess the ability of rFAV to further enhance low-level P reduction performance of SAV communities.
8. **Evaluation of Sampling Methods for TP** – to identify factors that may improperly bias water quality monitoring results to begin the process of improving sampling procedures for discharges from the STAs.
9. **STA Water and P Budget Improvements** – to 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.

The status of each study through Water Year 2017 (WY2017; May 1, 2016–April 30, 2017) is summarized in **Table 5C-1** and an update of progress and key findings for each study is provided within this report. Findings for Study Numbers 2, 3, 4, and 5 were presented in last year's *South Florida Environmental Report* (SFER; Ivanoff et al. 2017). More details on findings from six of the studies (Study Numbers 1, 3, 4, 5, 6, and 9) are provided in Appendices 5C-1, 5C-2, 5C-3, 5C-4, 5C-5, and 5C-6, respectively, of this year's SFER. 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. Efforts to update the five-year work plan, including the development of new studies, have been initiated and an updated Science Plan will be completed in 2018.

Table 5C-1. Status and key findings summary of the Science Plan's initial nine studies.

	Study	Status & Key Findings to Date
1	Development of Operational Guidance for FEB and STA Regional Operation	Toolsets and methodologies are being prepared supporting the development of operational guidance and plans for the FEBs and STAs. This includes evaluation of hydraulics, hydrologic and operational model parameters, operating strategies, and application of system optimization tools. Field tests have been performed that yielded an improved representation of hydraulics within the STAs. These results can be applied to a variety of STA vegetation types and facility configurations. An optimization tool has been developed to help inform weekly decision making by approximating potential TP outflow under alternative operational flow routing regimes. More detailed descriptions have been published in Ali (2009), Ali (2015), and Lal (2015). A more detailed summary also is included in Appendix 5C-1 of this volume.
2	Use of Soil Amendments and/or Management to Control P Flux	A comprehensive review of literature on technologies and amendments evaluated worldwide indicated that many could lower P concentrations (Chimney 2015). Due to uncertainties in treatment efficacy and potential impacts 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 for this study was included in Appendix 5C-1 of the 2017 SFER (Ivanoff 2017). A field-scale investigation of the benefits of soil inversion will be performed at the STA-1 West Expansion Area #1 beginning in 2019.
3	STA-3/4 PSTA Performance, Design, and Operational Factors	Periphyton-based treatment is being evaluated as a final polishing step (i.e. in the downstream region of an SAV treatment cell). Since it began operation in 2007, the STA-3/4 PSTA cell has consistently achieved outflow flow-weighted mean TP concentrations of 13 µg/L or lower on an annual basis. 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) have not negatively affected TP removal performance. Lower outflow TP has been observed during the wet season. Data also indicate that when inflow concentrations to the PSTA cell exceed 22 µg/L, the outflow concentration is generally higher than 13 µg/L. A more detailed summary is included in Appendix 5C-2 of this volume.
4	P Sources, Forms, Flux and Transformation Processes in the STAs	This multi-component study is ongoing. Four substudies are presented in this report, including flow-way water quality assessment, P flux measurements, soil P characterization, and effects of faunal communities on water quality (Appendix 5C-3). Results collected in STA-2 Flow-way 3 (submerged aquatic vegetation [SAV] cell), indicate a clear reduction gradient in TP concentration from inflow to outflow region, that soluble reactive P is reduced to below detection in the first half of the flow-way, and that particulate P, which is detected at the outflow region, is generated internally. Results also show an increase in TP concentration during stagnant periods. Diffusive flux has been detected at the inflow and mid regions of the flow-way, but not at the outflow region, indicating equilibrium between the porewater and water column P concentrations. Net flux, however, which incorporates the combined movement of P into or out of the surface water, including soil, porewater, periphyton, algae, or macrophytes, has been detected at the outflow region. Efforts to further understand these findings and collect more information are under way.
5	Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow P Concentrations	All tasks planned for this study have been completed. Results from a review of existing data (Phase 1) do not suggest the need for further study or to pursue remedial field work to address water quality concerns in any of the canals that have been evaluated. P export, which is primarily in the form of particulate P, has been observed in the STA-1 Inflow Basin Canal. A reevaluation of the P export potential from this canal is recommended after the L-8 FEB has been operational for at least three years. More detailed reports on canal evaluation have been published as District technical publications (Zhao et al. 2015a, b, 2017). A summary is also included in Appendix 5C-4 of this volume.

Table 5C-1. Continued.

	Study	Status & Key Findings to Date
6	Inundation Depth and Duration for Cattail Sustainability	Cattail is one of the desired emergent vegetation species in the upstream region of a treatment flow-way. Dense cattail stands help settle particulates and litter is an important component of microbial P cycling. Historically, cattail decline has been observed in many STA cells. Preliminary data indicate that while water depth condition differs between STA-1 West Cell 2A and STA-3/4 Cell 2A, in both cases, daily water depths exceeded target depths most of the time, but in STA-1 West Cell 2A, depths were generally below 61 centimeters. Cattail condition declined quickly during the first year of monitoring in this cell. There was notable decline in root biomass over a one-year monitoring period in both cells. In STA-3/4, there was no significant difference in cattail densities between the inflow (deeper area) and outflow (shallower area). A more detailed summary is included in Appendix 5C-5.
7	Rooted Floating Aquatic Vegetation (rFAV) in STAs	Phase 1 of the study involved evaluation of water quality and soil characteristics in existing patches of white water lily (*Nymphaea odorata*), American lotus (*Nelumbo lutea*), and spatterdock (*Nuphar advena*s) in selected STA SAV cells. Preliminary data indicates higher water column P concentration in white water lily and American lotus patches than the adjacent areas with SAV but no rFAV, while the difference in water column P between the spatterdock patch and its paired SAV patch was minimal. Top soil characteristics differ between the areas with rFAV and those with SAV only, with more organic content and lower bulk density in the rFAV patches than in SAV only areas. This study is still under way; more data may help explain the differences.
8	STA Water and P Budget Improvements	A test case water budget improvement was performed in STA-3/4 using improved 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 improved water and P budgets. A summary of water and P budget analysis for STA-2 Flow-ways 1, 2, and 3 is included in Appendix 5C-6. Flows into and out of the structures in these flow-ways constitute an average of approximately 90 and 87%, respectively, of the total inflow and outflow volumes.
9	Sampling Methods for TP	The study, which evaluated the collection of surface water samples using flow-proportional autosamplers, time-proportional autosamplers, grab samples, and remote P analyzers, has been completed. Results have been used to evaluate sampling quality assurance, autosampler design, data interpretation, and effects from environmental factors. A summary report for this study was included in Appendix 5C-4 of the 2017 SFER (Ivanoff 2017).

INTRODUCTION

A major component of Everglades restoration efforts, the STAs are constructed freshwater treatment wetlands operated to reduce TP concentration in surface water runoff prior to these waters entering 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 a total effective treatment area of approximately 57,000 acres. 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 sediments. Over the period of record, which started in 1994, all STAs combined have reduced TP loads by 77 percent and achieved outflow concentrations of 31 µg/L (see Chapter 5B of this volume). The performance continues to improve; with a combined outflow concentration of 15 µg/L in WY2017. Additional research is needed to further lower the outflow concentration and meet regulatory limits.

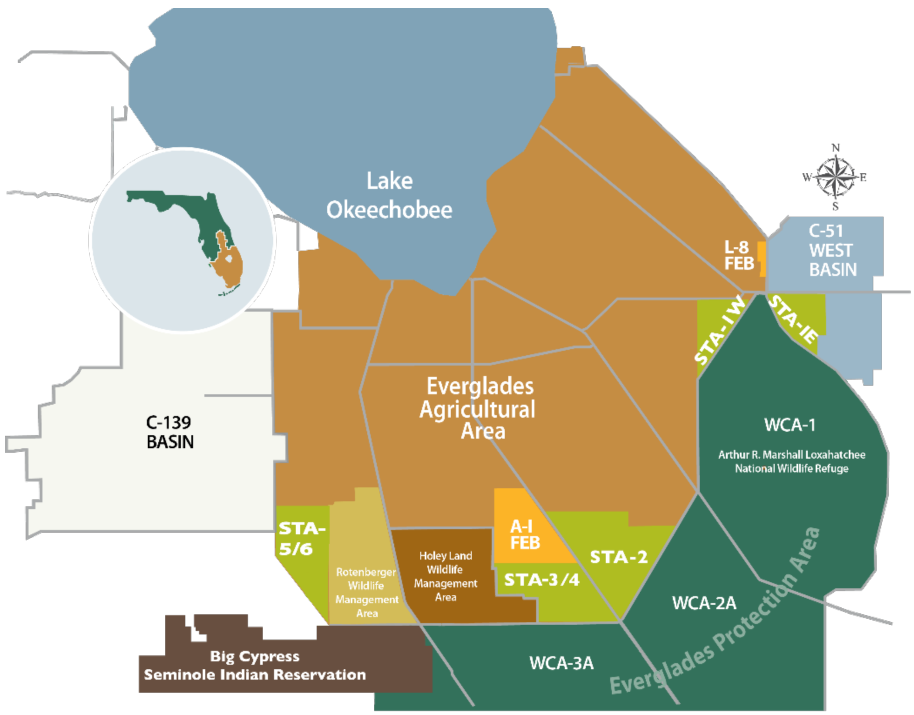

Figure 5C-1. Location of the STAs (STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6) and the FEBs (A-1 and L-8) in relation to the Everglades Agricultural Area, C-139 Basin, the EPA, and other landscape features of South Florida. Maps of individual cells and flow-ways for all STAs can be found in Appendix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

To achieve the ultra-low TP water quality standard established for the Everglades, in June 2012, the State of Florida and USEPA reached consensus on new Restoration Strategies (see Chapter 5A of this volume). A National Pollution Discharge Elimination System (NPDES) watershed permit, along with a state-issued Everglades Forever Act (EFA) watershed permit, established a stringent TP WQBEL in discharges from the Everglades STAs. The WQBEL 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 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. One of the requirements in the consent orders associated with the permits is the development and implementation of a science plan 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 2013b). A complete version of the Science Plan is available on the District's website at https://www.sfwmd.gov/our-work/restoration-strategies/science-plan.

To develop the plan, existing knowledge was reviewed, information gaps and uncertainties were determined, and questions regarding the physical, chemical, and biological processes, as well as management and operation of the STAs were formulated. Six key questions were identified and serve as the basis for formulating studies:

1. How can the FEBs be designed and operated to moderate P concentrations and optimize P loading rates and hydraulic loading rates entering the STAs, possibly in combination with water treatment technologies, or inflow canal management?
2. How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the treatment trains?
3. What measures can be taken to enhance vegetation-based treatment in the STAs and FEBs?
4. How can the biogeochemical or physical mechanisms be managed to further reduce soluble reactive P (SRP), particulate P (PP), and dissolved organic P (DOP) concentrations at the outflow of the STAs?
5. What operational or design refinements could be implemented at existing STAs and future features to improve and sustain STA treatment performance?
6. What is the influence of wildlife and fisheries on the reduction of P in the STAs?

An initial set of nine studies was developed and initiated as part of the implementation of the Science Plan:

1. Development of Operational Guidance for FEB and STA Regional Operation Plans
2. Use of Soil Amendments and/or Management to Control P Flux.
3. STA-3/4 PSTA Performance, Design, and Operational Factors
4. P Sources, Forms, Flux and Transformation Processes in the STAs
5. Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow P Concentrations
6. Inundation Depth and Duration for Cattail Sustainability
7. Rooted Floating Aquatic Vegetation (rFAV) in STAs
8. STA Water and P Budget Improvements
9. Sampling Methods for TP

The progress and findings of research directed by this plan are being reported in annual SFERs. This chapter provides a summary of the Science Plan progress through WY2017. More detailed information, including findings on six selected studies (Studies 1, 3, 4, 5, 6, and 8 in the above list), is presented in Appendices 5C-1 to 5C-6. A collection of STA maps, showing individual cells referred to 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. 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 District's operational guidance tools.

DEVELOPMENT OF OPERATIONAL GUIDANCE FOR FEBS AND STAS

M.Z. Moustafa, W. Lal, A. Ali, J. Godin, and N. Wang

The purpose of this is study is to develop toolsets and methodologies that support the development of operational guidance and regional operation plans for FEBs and STAs that best enable STAs to consistently achieve the TP WQBEL. The study includes multiple tasks (**Table 5C-2**):

- Information gathering on STAs and field tests to evaluate hydraulics and water quality
- Development of model parameters needed to simulate hydraulics, hydrology, and operational control of STAs
- Development of local (STAs and FEBs) and regional operating strategies and rules, and application of system optimization tools

Field tests were performed in some of the STAs, improving the representation of hydraulic dynamics in the STAs. In-situ wave-based tests were conducted at low, medium, and high discharge rates within the STAs to determine the relation of discharge to the depth and the water surface slope. Wave speeds and wave decay characteristics measured at points in a triangulated network were used to calculate vegetation resistance to flow, which depends on energy gradient and depth. The results were used to produce two-dimensional maps of hydraulic transmissivities, stem-drag resistance coefficients, and parameters of power law equations describing resistance at different discharge rates (Lal 2017). The results also included bulk parameters or single parameters defined for the entire wetland. Results show that the two-dimensional patterns of many resistance parameters correspond to the general patterns of the distribution of vegetation in the STAs. The power law equations developed can represent the vegetation resistance as well as the effects of topography, resistance due to blockages, and the effects of short-circuiting and turbulent behaviors (see Equation 2 of Lal 2017). The dimensionless estimated parameters can determine if the governing equation is primarily hyperbolic or parabolic, and to what extent the flow behaves like porous media flow with diffusive wave behavior or short-circuiting stream flow with kinematic wave behavior.

These results can be applied to a variety of STA vegetation types, e.g., emergent aquatic vegetation (EAV) and submerged aquatic vegetation (SAV), and facility configurations allowing for improved estimation of water depths and residence times in real-world application and enhanced representation in physically-based models for project planning or design. Vegetation resistance properties obtained using in situ testing of STAs are used to simulate hydraulics within STAs. The resistance properties expressed using power law equations are used to represent flow resistance during the simulation. The depth averaged flow equations are assumed to be adequate for simulating the hydraulics. The numerical solution for the problem is obtained using one-dimension implicit total variation diminishing Lax-Friedrichs (TVDLF) model (Lal 2017). The TVDLF method simulates depth averaged flow in a vegetated wetland to give very reasonable results. The TVDLF method has been implemented into a simple computational model that couples near real-time water elevation observations and flows with ground topography to simulate flow-through hydraulic gradients of an STA flow-way (two interconnected STA cells). This simple framework forecasts short-term (~7 day) trajectories of water elevations and associated water depths under multiple management scenarios/flow regimes (e.g. 300, 600, and 900 cubic feet per second [cfs]). At present, this tool is capable of being deployed on a fully automated basis to provide a decision support system for the Western Flow-way of STA-3/4. Considering the steps used to calibrate the TVDLF method to the observed data, numerical models can be developed for all the STA cells by using the headwater, tailwater, and gate opening data.

Table 5C-2. Status and highlights on the Development of Operational Guidance and Regional Operation Plans for FEBs and STAs study.

Task	Status and Comments	Publication or Report
Information gathering – existing information	Subject matter expert search and historical data compilation tasks were completed. Literature review, information consolidation is ongoing.	SFWMD 2013a
Information gathering – field tests	Field tests were performed across a wide range of STA vegetation types, examining both hydraulic and P dynamics. STA-3/4 Cell 3A completed in 2013. STA-2 Cell 3 completed in 2014. STA-3/4 Cell 2A completed in 2015.	Lal 2015a, b Lal and Moustafa 2014 Lal et al. 2013, 2015, 2016 Moustafa et al. 2014
Development of hydraulic and model parameters	Field test results were used to produce two-dimensional maps of hydraulic transmissivities, stem-drag resistance coefficients, and parameters of power law equations describing resistance. The power law equations and parameters were developed to represent not just the vegetation resistance but also the effects of topography, resistance due to blockages, and the effects of short-circuiting and turbulent behaviors. Results from the field tests provided updates to Regional Simulation Model (RSM)-total variation diminishing Lax-Friedrichs (TVDLF) model parameters. RSM source code efforts restructured RSM libraries to allow for increased model portability and ability to incorporate new algorithms. A guidance matrix was provided upon initial startup of the A-1 FEB that provided desirable seasonal FEB depth and discharge ranges for operations consistent with the Restoration Strategy planning work performed with the Dynamic Model for Stormwater Treatment Areas (DMSTA) model.	Lal 2017 Lal and Godin 2017
Development of operational strategies and operational support tools	A series of control-room support tools—Wave-Bot, Wave-Op, and supervisory control and data acquisition (SCADA)/Inverse Flow Program—provided recommended gate openings at 15-minute intervals to achieve target flow rates into STA cells. Wave-Bot is a Microsoft Excel-based tool that calculates gate changes as necessary to follow a corresponding target flow time series. Wave-Op is a fully automated enhancement of this tool that uses real-time data and notifies water managers and the control room about the necessary gate changes. Application with TVDLF method using the headwater, tailwater, and gate opening data is used to simulate depth averaged flow in a vegetated wetland with reasonable results.	Ali 2017 Lal 2017 Lal and Godin 2017 Moustafa and Lal 2016
Application of system optimization tools	An investigation into the application of control theory to the STAs concluded that STAs could be conceptualized and modeled as controlled systems.	Ali 2014

Study efforts to determine enhanced operational protocols also have generated useful outcomes. Real-time automation tools such as supervisory control and data acquisition (SCADA)/Inverse Flow Program developed by SFWMD staff have been used to assist in defining structure gate openings needed to achieve desired flow targets at structures.

To develop an operational protocol to optimize flow releases along the Central Flow Path FEB/STAs (A-1 FEB, STA-2, and STA-3/4) for optimal flow attenuation and treatment, Restoration Strategy Operation Plan Development iModel (iModel-RSOPD) was developed and implemented (Appendix 5C-1). The Hydrologic Model Emulator (HME; Ali 2015) is implemented to simulate the hydrologic and hydrodynamic processes of the A-1 FEB and the eight treatment flow-ways in the two STAs. The HME uses water quality and quantity historical time series data to predict stage and outflow P concentration. To meet the WQBEL (13 µg/L), the Central Flow Path is optimized for each time step by iterative and concurrent HME simulations across all flow-ways and the FEB using an Augmented Lagrangian Genetic Algorithm technique subject to linear and non-linear constraints.

iModel-RSOPD consists of (1) a simulation engine represented by HMEs that simulate flows and TP concentrations through STA cells, and (2) an optimization engine that uses a genetic algorithm along with a set of constraints to run the HMEs multiple times to find optimal flows that minimize outflow TP concentration and maintain STA stages within a small range of the specified target values (see Appendix 5C-1 of this volume). The iModel-RSOPD was applied to four alternative scenarios. The base alternative is the STA system without the FEB (noFEB) to treat EAA runoff plus Lake Okeechobee water through the Central Flow Path. The second alternative is the base alternative with EAA runoff only, without the Lake Okeechobee water. These two alternatives are repeated with the FEB in place. The iModel achieves TP concentration reduction for flow-ways where the observed outflow TP concentration is higher than 13 µg/L. Flow-ways with TP concentration lower than 13 µg/L can sustain a limited concentration increase to help improve the performance of other flow-ways with higher outflow TP concentration. The improvement is more significant for the FEB scenarios compared to the noFEB scenarios demonstrating the advantage of the FEB efficacy to reduce TP concentrations. Despite the inherent difficulties to predict TP concentrations, these iModel preliminary results are promising; the tool can be improved as new data becomes available.

INVESTIGATION OF STA-3/4 PSTA PERFORMANCE, DESIGN, AND OPERATIONAL FACTORS

Manuel Zamorano and Tracey Piccone

The primary objective of this multi-component study is 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. During nine years of operation the outflow flow-weighted mean TP concentrations ranged from 8 to 13 µg/L. The operational ranges under which the PSTA Cell has achieved ultra-low outflow TP levels are being evaluated. A summary of progress on this study is presented in **Table 5C-3**, and more detailed information on this study is presented in Appendix 5C-2.

Table 5C-3. Status and highlights for the Investigation of STA-3/4 PSTA Performance, Design, and Operational Factors study.

Task	Status and Comments	Publications and Reports
Effects of pulse flows	Task was completed in WY2016. 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 WY2017. Moderate flow levels for extended periods of time did not negatively impact the performance.	James and Zamorano 2017
Effects of season, time of day, water depth, and inflow concentration	Task was started in WY2012 and will be completed in WY2018.There was no significant difference in treatment performance between two operational depths (0.40 meter and 0.55 meter). Generally, lower outflow TP was observed during the wet season. Data also indicate that when inflow concentrations to the PSTA cell exceeded 22 µg/L, the outflow concentration is generally higher than 13 µg/L. This confirms the suitability of PSTA treatment as a final polishing step, i.e. in the downstream region of an SAV cell.	James 2015 Zamorano 2015
Effects of seepage	Task was started in WY2012 and will be completed in WY2018. Stage differences between the PSTA Cell and adjacent Lower SAV Cell and canal was the driving force for seepage flow. 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. 2015c Zamorano 2016 Polatel and Zamorano 2016
Evaluation of limerock cap as an alternative to scraping of muck	Task was started in WY2012 and will be completed in WY2018. Preliminary data show that limerock-capped mesocosms produced outflow concentrations similar to the muck-scraped PSTA Cell. Muck soil with P content that is low (and chemically stable) can produce ultra-low outflow water P concentrations, with or without a calcareous substrate. A separate evaluation of soil amendments, including limerock capping, and associated cost estimates is summarized in Chimney, 2015.	DBE 2015a DBE 2016b
Influence of sediment accrual and vegetation nutrient contents	Task was started in WY2012 and will be completed in WY2018. Data indicate that there was no difference in sediment accrual depth or sediment P content between inflow and outflow regions of the PSTA Cell. Macrophyte tissues and periphyton showed decreasing P content with distance through the PSTA Cell. The PSTA Cell SAV communities generally had lower tissue P content than SAV in the outflow region of P-enriched muck-based STA cells.	DBE 2015a DBE 2015b

EVALUATE P SOURCES, FORMS, FLUX, AND TRANSFORMATION PROCESSES IN THE STAS

Odi Villapando, Jill King, and Delia Ivanoff

The primary objective of this study is to enhance the understanding of the mechanisms and factors that affect P treatment performance of the STAs, particularly those that are key drivers of performance at the lower reaches of the treatment flow-ways. The study has multiple components, with a number of substudies: data mining and literature review; organic P speciation; flow-way water quality assessments at different flow conditions; comparison of processes, mechanisms, and factors relevant to uptake in Water Conservation Area (WCA) 2A; particle transport; soil characterization; measurement of P flux; evaluation of trends and patterns of enzyme activity; vegetation assessments; and quantification of faunal assemblages and excretion. 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's Cell 1, STA-2, and Cell 3, and STA-3/4's Western Flow-way under different flow conditions with runoff water as the primary water source. A summary of progress on this study is presented in **Table 5C-4**; more detailed information, including some initial findings, is presented in Appendix 5C-3 on four substudies: flow-way assessments, soil characterization, P flux measurements, and faunal quantification.

Table 5C-4. Status and highlights of the Evaluating P Sources, Forms, Flux, and Transformation Processes in the STAs study.

Substudy	Status and Comments	Publications and Reports
Data mining	Various methodologies have been used, including bivariate correlations, principal component analysis, cluster analysis, classification and regression trees, and Bayesian belief network. Summaries of the initial data mining efforts were included in Chapter 5C of the 2016 and 2017 SFERs (Schwartz and Jacoby 2016, Ivanoff 2017).	Ivanoff et al. 2017 Schwartz and Jacoby 2016
Organic P speciation	Method development to characterize and quantify the different forms of organic P in soil and water is near completion. Nuclear magnetic resonance (NMR) methods for soils have been optimized. NMR analyses to compare P forms in WCA-2A with those measured in the STAs are in progress. Surface water samples have been collected and testing of mass spectrometry methods (liquid chromatography-mass spectrometry; ultra-high pressure liquid chromatography-mass spectrometry; and Fourier transform ion cyclotron resonance mass spectrometry) to determine P species is under way.	University of Florida 2016a
Flow-way assessment	Five controlled flow events have been completed in STA-2 Flow-ways 1 and 3. Initial findings indicate distinct TP concentration gradients from inflow to outflow locations for all phases of flow events. TP concentrations were elevated along flow-way under stagnant condition following period of high P loading. More detailed discussion is included in Appendix 5C-3. Additional controlled flow events are planned for the study flow-ways through 2020.	University of Florida 2016b
Flux measurement	Five controlled flow events have been completed in STA-2 Flow-ways 1 and 3. Based on the three sampling events to date in STA-2 Flow-way 3 with the mesocosm chambers and porewater equilibrators, data suggest substantial contributions to net internal fluxes from other soil and/or biotic processes aside from the diffusion from soil porewater. Positive net flux was consistently detected in the outflow region, where diffusion potentials were negligible. These flux mechanisms are important and may control outflow concentrations. More detailed discussion is included in Appendix 5C-3. Additional measurements are planned until 2020.	DBE 2017b

Table 5C-4. Continued.

Substudy	Status and Comments	Publications and Reports
Particle dynamics	Twelve sediment cores from STA-2 Flow-way 3 and STA-3/4 Flow-way 3B were collected and analyzed for physicochemical attributes at 1-centimeter intervals to the determine critical shear stress thresholds (for erosion), particulate entrainment, and particle settling rates. Analysis of cores, via chamber and flumes, will provide information on TP-containing particulate erosion, suspension, transport, and settling rates. Deployment of continuous monitoring acoustic Doppler velocimeters show mid-water column velocities in interior portions of inflow, mid-flow, and outflow of STA-2 Flow-way 3 are typically below critical entrainment thresholds required to entrain benthic sediments. Evaluation of diurnal patterns in wind, shear stress, and suspended sediment concentrations is ongoing. Preliminary findings from velocity surveys indicate areas of high flow (> 10 centimeters per second) occur in remnant ditches in the outflow cells of STA-2 Flow-way 3. These results will be reported in next year's SFER.	FIU 2017
Soil characterization	The second-year soil sampling in STA-2 Flow-ways 1 and 3, STA-3/4 Flow-ways 3A and 3B, and WCA-2A was completed in late 2016. Soil chemistry data is presented in Appendix 5C-3. Fractionation of P in floc and soil from STA-2 Flow-ways 1 and 2, STA-3/4 Flow-ways 3A and 3B, and WCA-2A was completed in 2016. Studies on P sorption/release characteristics of floc and soil from the same test flow-ways are currently under way. Additional experiments, including litter decomposition, core P dosing, and abiotic degradation of DOP and carbon in the STAs will be conducted in late 2017. Results of these additional studies will be presented in next year's SFER.	
Vegetation assessment	Vegetation monitoring using low altitude aerial remote sensing continues. This, along with available aerial imagery of the areas, should provide a temporal and spatial characterization of vegetation in the STAs to help explain patterns in water quality and soil data. Ground surveys of SAV also continued to monitor changes in species composition and relative abundance. The second biomass sampling was completed and analyzed in STA-2 Flow-way 1 (EAV) and Flow-way 3 (SAV). Samples were analyzed for biomass, TP, total nitrogen, total carbon, total calcium, and ash content. Initial results indicate that both EAV and SAV flow-ways showed a declining gradient in tissue TP concentrations from inflow to outflow locations. EAV biomass was higher at the upstream end than the downstream end of the flow-way while SAV biomass was lower at the front end. EAV had substantially higher tissue TP storage at the front end compared to the SAV. Data will be presented in next year's SFER. Additional vegetation harvesting sampling is planned into 2019.	
Enzyme activity	Enzyme assays have been completed for surface water, periphyton, floc, and litter for all three flow events conducted in STA-2 Flow-way 3. Data analysis is underway to evaluate enzyme assay data and microbial carbon, nitrogen, and P in the periphyton, litter, floc, and soil. Analysis for potential mineralizable P and nitrogen and respiration in floc and soil is currently under way. Results of these ongoing analyses will be presented in next year's SFER. Further sampling events are planned in sync with the flow-way assessments and flux measurements studies.	
Aquatic fauna	Field work is ongoing and will be completed in late 2017. Preliminary sampling of biomass and community composition of small fish and macroinvertebrates (STA-2) and large fishes (STA-1W, STA-1E, and STA-2) in 2016 revealed high variability. Power analyses of these data indicated the need for relatively large sample sizes for each habitat type in the STA outflow cells. Preliminary analyses of small fish, macroinvertebrates, and large fish biomass and community composition were completed and those data were compared among four Everglades regions. A literature review of excretion rates in fishes revealed that insufficient published data are available to parameterize nitrogen and P budgets. Nitrogen and P excretion and egestion rates are currently being experimentally measured for some common small and large fish species in STA-2. All avian surveys for WY2016 were completed (bi-weekly from October to May). The first year of the video data has been analyzed. More detailed discussion is included in Appendix 5C-3.	

EVALUATION OF THE INFLUENCE OF CANAL CONVEYANCE FEATURES ON STA AND FEB INFLOW AND OUTFLOW P CONCENTRATIONS

Hongying Zhao and Tracey Piccone

The purpose of this study was to determine if TP concentrations change when conveyed through STA inflow or outflow canals and, if so, what factors influence such changes. The study also included estimates of sediment and TP accumulation in the canals over the analysis period. This study focused on the following six canals (Appendix 5C-4):

1. STA-1 Inflow Basin Canal
2. STA-1W Discharge Canal
3. STA-2 Supply/Inflow Canal
4. STA-2 Discharge Canal
5. STA-3/4 Supply/Inflow Canal
6. STA-1E Discharge Canal

The original study plan was organized in two phases: Phase I, which included a review of literature, as-built drawings, and relevant water quality and flow data (Zhao et al. 2015c), and Phase II, which was for field assessment. In Phase I, existing water quality and flow data were analyzed to determine if TP concentrations changed in each canal and if the canal was a source or a sink for TP using concentration-based analyses and a mass balance approach in combination with statistical analysis tools. Results of Phase I were used to determine if Phase II field work was needed. Of the six canals investigated, one canal (STA-1 Inflow Basin Canal) was found to be a source of TP export, primarily in the form of particulate P. Only one canal (STA-2 Supply/Inflow Canal) underwent a limited Phase II study, which is described in **Table 5C-5**.

All tasks planned for this study have been completed. Results obtained to date do not suggest the need to continue, or to pursue remedial field work to address water quality concerns in any of the studied canals.

Table 5C-5. Status and highlights of the Evaluation of the Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow P Concentrations study.

Task	Status and Comments	Publications and Reports
Literature review, as-built drawing review, and data query	Completed in July 2015.	Zhao et al. 2015a
STA-1 Inflow Basin Canal evaluation	Phase I was completed in July 2015. Data analyses suggested that this canal was a TP source and that the TP load exported was primarily PP. Implementation of upstream FEB (L-8 FEB) should reduce the TP export through reduction of peak flows. Recommendation is to reevaluate this canal after the L-8 FEB has been operational for at least three years and sufficient data have been collected.	Zhao et al. 2015b
STA-1W Discharge Canal evaluation	Phase I was completed in June 2017. Analyses suggested that this canal was a TP sink over the period evaluated. No further work is recommended for this canal.	Zhao et al. 2017
STA-2 Supply/Inflow Canal evaluation	Phase I was completed in May 2016. The load-based analyses suggested that this canal was a TP source and the TP load exported was primarily PP. The concentration-based analyses suggested different source/sink behaviors depending on the flow scenarios. When higher flows occurred via S-6 pumping, the canal appeared to be a TP sink, but when lower flows occurred (including seepage pumping), the canal appeared to be a TP source. A limited Phase II field survey was completed in February 2017 to address Phase I uncertainties with the Phase I results and to identify areas of suspected canal bank erosion. A bathymetric cross-sectional survey with manual probing was compared to the as-built drawings. The results indicated notable erosions from canal side slope areas and sediment accumulations in some segments of the canal. The results of this effort have been conveyed to the SFWMD's canal and structure maintenance team, however, together, results suggest that no further water quality-based evaluation is needed for this canal.	Ecology and Environment, Inc. and SFWMD 2016a Ecology and Environment, Inc. and SFWMD 2017
STA-2 Discharge Canal evaluation	Phase I was completed in February 2017. Data analyses suggested that TP changes in the canal were not practically significant (i.e. less than 1 µg/L).	Ecology and Environment, Inc. and SFWMD 2017
STA-3/4 Supply/Inflow Canal evaluation	Phase I was completed in May 2016. Data analyses suggested that this canal behaved as a TP sink. No further work is recommended for this canal.	Ecology and Environment, Inc. and SFWMD 2016b
STA-1E Discharge Canal evaluation	A review of available data suggested that TP concentrations were not increasing in the canal, therefore no further work is recommended for this canal.	

INUNDATION DEPTH AND DURATION THRESHOLD FOR CATTAIL SUSTAINABILITY

Orlando Diaz

The purpose of this study is to identify the inundation depth and duration threshold for the sustainability of cattail (*Typha domingensis*) communities in the STAs. Dense cattail communities in the upper region of a treatment flow-way are important to reduce particulates in the water column and to facilitate microbial P cycling through production of litter. Previous field observations and studies have indicated that inundation exceeding certain water depths over long periods causes increased physiological stress to cattail plants, reducing growth, biomass, density, and anchorage capacity in EAV treatment cells. The study has two main components, in situ surveys and a test cell study (controlled depth study). The in situ component of this study was originally planned to be 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.

Monitoring in STA-1W Cell 2A was discontinued after one year of the in situ study due to the eventual widespread decline of cattail community in this cell. An analysis of historical water depths from WY2011 to WY2016 indicates that values were generally above target stage (38–45 centimeters [cm]), but rarely at or exceeding 91 cm. The most prominent effects, in both inflow and outflow regions of the cell, were the declines in biomass (total, roots, rhizomes, and shoot bases) in approximately a one year-period (between 2014 and 2015). In STA-3/4 Cell 2A, water depths also generally exceeded the target stage, more frequently and at deeper levels than in STA-1W Cell 2A. Water depths were deeper at the front region of the cell. The inflow region experienced deeper water (> 91 cm) about 13% of the time, more frequently than at the outflow region of this cell. The first-year surveys did not indicate any significant difference in cattail density between the inflow (deeper area) and the outflow (shallower area). This could be because this cell was rehabilitated in the year preceding the start of the study, hence the cattail community was healthier and relatively young. There was a significant decline in total biomass and shoot base biomass in a one-year period (between the 2014 and 2015 sampling events).

In both cells, while water depth is likely a factor, it is uncertain if other factors contributed to this decline, including soil factors, the presence of floating cattail mats/tussocks, and floating aquatic vegetation, which could have outcompeted the cattail vegetation. Further study is being planned to evaluate the effects of soil factors (e.g. soil structure and gas ebullition).

For the test cell component, a healthy cattail population will be established and allowed to grow and mature in the STA-1W northern test cells prior to imposing treatment, which is a range of water depth regimes. Cattail grow-in at the test cells will occur in 2017 and 2018. A summary of progress on this study is presented in **Table 5C-6**. A more detailed summary of the preliminary findings on the in situ investigation is presented in Appendix 5C-5.

Table 5C-6. 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. Further evaluation of this site was discontinued due to eventual widespread decline in cattail condition, including the presence of floating cattails. Results from the first year of monitoring are included in Appendix 5C-5.
In situ surveys – STA-3/4 Cell 2A	Cattail monitoring began in 2015 and will continue until 2017.
Test cell study	Test cell preparations continued in early 2017, including topographic survey, soil addition and leveling, and preparations for vegetation grow-in.

WATER AND P BUDGET IMPROVEMENTS

Tracey Piccone

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.

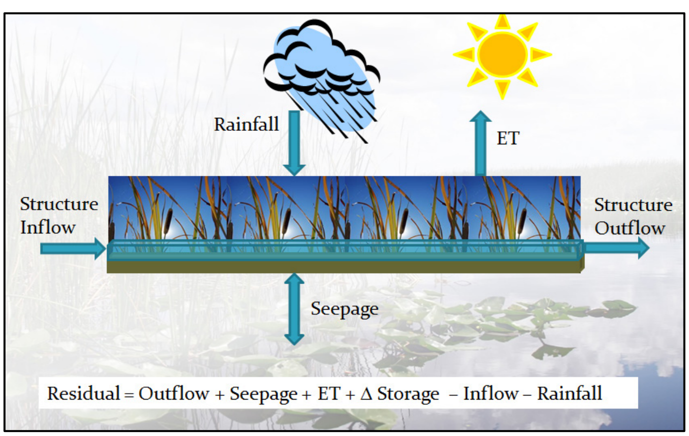

Figure 5C-2. Conceptual model for a water budget in the STAs.

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-7**. Updated period of record analysis of water and P budget is summarized in Appendix 5C-6.

Table 5C-7. 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 flow-way water budget residuals to both cells and by using weighted average of flow-way inflows and outflows (instead of using flow data at cell inflow and outflow structures).	Polatel 2014
STA-2 and STA-3/4 period of record flow data and flow rating improvements	Improvement of flow data for STA-2 Flow-ways 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 with WY2014 data 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 Cells 1, 2, and 3. Updates to the Water Budget Application Tool will occur in WY2018 for STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B. Work will continue in WY2018.	
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 Cells 1, 2, and 3 began in WY2017; results are summarized in Appendix 5C-6 of this report. Updates on period of record water and TP budgets for STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B will begin in WY2018.	Appendix 5C-6 of this Volume
STA-5 flow data and flow rating improvements	Improvement of flow data for select STA-5 structures starting with WY2015 was completed in WY2017.	

ROLE OF ROOTED FLOATING AQUATIC VEGETATION

Matt Powers

The objective of this study is to determine if different rFAV species could enhance P removal performance in SAV communities in the outflow region of STAs. In addition, data collected will be used to assess potential adverse effects on water quality by rFAV species that have formed dense stands in some STA cells. The study focuses on three specific rFAV species: *Nymphaea odorata* (white water lily), *Nelumbo lutea* (American lotus), and *Nuphar advena* (spatterdock). Some of these species thrive in the SAV areas of the STAs and the low P regions of the WCAs. The first phase of the study includes field reconnaissance for rFAV+SAV and SAV only patches within the STAs (**Table 5C-9**), initial spatial monitoring, and a more long-term temporal monitoring. The monitoring measures P species in the water column in each patch to determine if there are differences in these patches. Phase II will examine the mechanisms and processes responsible for these differences. A summary of progress on this study is presented in **Table 5C-10**.

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 Investigation of rFAV in STAs study.

Task	Status and Comments	Publications and Reports
Initial spatial sampling	Completed in June 2016.	DBE 2016a
Temporal sampling	Initiated August 2016; ongoing.	DBE 2016a
Soil characterization	Completed August 2016 and March 2017.	DBE 2016a DBE 2017c
Porewater sampling	Completed April 2017.	DBE 2017c
Deployed sonde sampling	Initiated February 2016; ongoing.	DBE 2017c

Preliminary data indicate higher water column P concentration in white water lily and American lotus patches than the adjacent SAV only patch. The difference in water column P between the spatterdock patch and its paired SAV patch is minimal. Monitoring of all patches is continuing. Seasonal effects and variability of rFAV performance between STAs will also be examined in Phase II.

Soil characterization and deployed sonde readings from rFAV and their paired SAV patches has 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. The low bulk density soil is likely prone to resuspension contributing to higher PP values in the water column. Deployed sonde readings indicate greater aquatic metabolism in the SAV patches relative to the rFAV patches. Greater aquatic metabolism results from increased photosynthetic rate in the water column, which leads to higher pH during daylight hours. This higher pH may lead to greater co-precipitation of P with calcium resulting in enhanced P removal. The soil from American lotus patches had higher organic content than paired SAV patches but otherwise did not exhibit great differences. The lack of a clear difference in soil characteristics will be examined in Phase II. The spatterdock community did not shade out SAV as much as lotus and lily did, therefore there was relatively high coverage of SAV in the spatterdock patch. Despite the high coverage of SAV in the spatterdock patch, the soil was higher in organic content and had lower calcium content than their paired SAV patches without spatterdock. Also, aquatic metabolism in the SAV patches was higher than rFAV patches. Continued study of these rFAV species should explain their role in affecting P concentrations in the water column and inform on their desirability in the downstream end of the STAs.

LITERATURE CITED

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

Ali, A. 2009. Nonlinear multivariate rainfall–stage model for large wetland systems. *Journal of Hydrology* 374(3-4):338-350.

Ali, A. 2014. *Development of Optimization Framework for Central Flow Path of the EAA Incorporating STA-2 and STA-3/4 Facilitates along with the Corresponding Flow Equalization Basin (FEB)*. South Florida Water Management District, West Palm Beach, FL.

Ali, A. 2015. Multi-objective operations of multi-wetland ecosystem: iModel applied to the Everglades restoration. *Journal of Water Resources Planning and Management* 141(9).

Ali, A. 2017. Ali, A. 2017. *iModel for Restoration Strategy Operational Protocol Development*. South Florida Water Management District, West Palm Beach, 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.

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 the South Florida Water Management District, West Palm Beach, FL and the 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 the 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 the South Florida Water Management District, West Palm Beach, FL. June 2016.

DBE. 2016c. *Technical Environmental Services in Support of the Restoration Strategies (RS) Science Plan, 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. for the South Florida Water Management District, West Palm Beach, FL. July 2016.

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

DBE. 2017b. *Quarterly Report #2 under Agreement No. 4600003475*. Prepared by DB Environmental, Inc. for the South Florida Water Management District, West Palm Beach, FL. March 2017.

DBE. 2017c. *Quarterly Report #3 under Agreement No. 4600003475*. Prepared by DB Environmental, Inc. for the South Florida Water Management District, West Palm Beach, FL. June 2017.

Ecology and Environment, Inc. and SFWMD. 2016a. *STA-2 Supply/Inflow Canal Technical Analyses Final Report*. Prepared by Ecology and Environment, Inc. for the South Florida Water Management District, West Palm Beach, FL. May 2016.

Ecology and Environment, Inc. and SFWMD. 2016b. *STA-3/4 Supply/Inflow Canal Technical Analyses Final Report*. Report prepared by Ecology and Environment, Inc. for the South Florida Water Management District, West Palm Beach, FL. May 2016.

Ecology and Environment, Inc. and SFWMD. 2017. *Evaluation of the Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow TP Concentrations STA-2 Discharge Canal Technical Analyses (Phase I) and STA-2 Supply/Inflow Canal Technical Analyses (Phase II)*. Prepared by Ecology and Environment, Inc. for the South Florida Water Management District, West Palm Beach, FL. February 2017.

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 (NPDES) Watershed Permit (No. FL0778451) and Associated Consent Order (OGC 12-1148)*. Florida Department of Environmental Protection, Tallahassee, FL. September 10, 2012.

FIU. 2017. *Settling and Entrainment Properties of STA Particulates. Second Interim Progress Report*. Prepared by Florida Atlantic University under Agreement 4600003032-WO02-9500006758, for South Florida Water Management District, West Palm Beach, FL. June 2, 2017.

Ivanoff, D., J. McBryan, K. O'Dell, T. Piccone, L. Schwartz and R. Villapando. 2017. Chapter 5C: Update for the Restoration Strategies Science Plan. In: *2017 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. Zamorano M. F. 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.

Lal, A.M.W. 2015a. *Design of Stormwater Treatment Area (STA) Internal Hydraulic Configuration Technical Report: STA Design Modeling Tool*. South Florida Water Management District, West Palm Beach, FL. November 2015.

Lal, A.M.W. 2015b. *Stormwater Treatment Area 3/4 Cell 2A Field Experiment Technical Report: The Use of Discharge Perturbations to Characterize Vegetation Resistance in STA-1W Cell 2A*. South Florida Water Management District, West Palm Beach, FL. October 2015.

Lal, A.M.W. 2017. Mapping Vegetation-Resistance Parameters in Wetlands Using Generated Waves. *Journal of Hydraulic Engineering* 143(9).

Lal, A.M.W. and J. Godin. 2017. *Simulation of Hydraulics in STA-3/4 Using an Implicit TVDLF Model (RSM) for Decision Support*. Draft report. South Florida Water Management District, West Palm Beach, FL.

Lal, A.M.W. and Z. Moustafa. 2014. *Stormwater Treatment Area-2 Cell 3 Field Experiment Technical Report: Vegetation Resistance & Treatment Efficiency*. South Florida Water Management District, West Palm Beach, FL.

Lal, A.M.W., Z. Moustafa and W. Wilcox. 2013. *Stormwater Treatment Area 3/4 Cell 3A Field Experiment Technical Report: The Use of Discharge Perturbations to Characterize In-situ Vegetation Resistance*. South Florida Water Management District, West Palm Beach, FL.

Lal, A.M., M.Z. Moustafa and W. Wilcox. 2015. The use of discharge perturbations to understand in-situ vegetation resistance in wetlands. *Water Resources Research* 51:2477-2497; doi: 10.1002/2014WR015472.

Lal, A.M., M.Z. Moustafa and W. Wilcox. 2016. Dam-Break Wave Fronts in Vegetated Wetlands. In: American Society of Civil Engineers, *Proceedings of Environmental Water Resources Institute, World Environmental and Water Resources Congress 2016*, West Palm Beach, FL.

Moustafa, M.Z., A.M. Lal and W. Wilcox. 2014. Estimates of In-situ Vegetation Resistance in Large Constructed Wetlands. In: G.T. Papanikos (ed.), *Ecology and Water, Second Annual International Conference on Ecology, Ecosystems and Climate Change & Second Annual International Conference on Water, 14–17 July 2014, Athens, Greece*, The Athens Institute for Education and Research, Athens, Greece.

Moustafa, M.Z. and A.M. Lal. 2016. *Vegetation Resistance Users' Manual (STA-3/4 Cell 2A)*. 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.

Schwartz, L. and M. Jacoby. 2016. Chapter 5C: Update for the Restoration Strategies Science Plan. In: *2016 South Florida Environmental Report – Volume I*, 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 2013a. *Information Gathering Document for RS SP Study: Development of Operational Guidance for FEB and STA and Regional Operation Plans*. South Florida Water Management District, West Palm Beach, FL.

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

University of Florida. 2016a. *Quarterly Report # 2 and #3: Identification and Quantification of Organic Phosphorus Forms in the Eater Column and Soils of the Everglades Stormwater Treatment Areas (STAs)*. Prepared for the South Florida Water Management District, West Palm Beach, FL. July 2016.

University of Florida. 2016b. *Quarterly Report #3: Evaluation of Soil Biogeochemical Properties Influencing Phosphorus Flux in the Everglades Stormwater Treatment Areas (STAs)*. Prepared for the South Florida Water Management District, West Palm Beach, FL. March 2016.

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.

Zhao, H., T. Piccone, O. Diaz and Tetra Tech, Inc. 2015a. *Supporting Information for Canal Evaluations*. Technical Publication WR-2015-003, South Florida Water Management District, West Palm Beach, FL. July 2015.

Zhao, H., T. Piccone and S. Hill. 2015b. *STA-1 Inflow Basin Canal Investigation Phase I Report*. Technical Publication WR-2015-004, South Florida Water Management District, West Palm Beach, FL. July 2015 and Revised May 2016.

Zhao, H. Diaz. O. and T. Piccone. 2017. *Stormwater Treatment Area 1 West Discharge Canal Evaluation Report*. Technical Publication WR-2017-005. South Florida Water Management District, West Palm Beach, FL.