RESTORATION STRATEGIES REGIONAL WATER QUALITY PLAN

Science Plan

for the

Everglades Stormwater Treatment Areas

South Florida Water Management District
3301 Gun Club Road, West Palm Beach, Florida 33406

July 2018

EXECUTIVE SUMMARY

The *Science Plan for the Everglades Stormwater Treatment Areas* (Science Plan) is a strategic plan that guides scientific research to improve understanding of key mechanisms and factors affecting stormwater treatment area (STA) performance. Information gathered under the Science Plan will support the design, operation, and management of STAs to achieve and sustain total phosphorus (TP) concentrations that meet the water quality-based effluent limit (WQBEL). Development and implementation of the Science Plan is mandated under Consent Orders (Office of General Counsel OGC Files No. 12-1148 and 12-1149) with the National Pollutant Discharge Elimination System (NPDES) and Everglades Forever Act (EFA) Watershed Permit (No. 0311207), issued in 2012 and amended in 2017. The Science Plan is specified in the South Florida Water Management District's *2012 Restoration Strategies Regional Water Quality Plan* as one of the restoration strategies, in addition to construction of additional treatment and water storage areas.

The scope of research under the Science Plan includes hydrologic, physical, chemical, and biological processes and factors that affect TP concentrations discharged from the STAs. Processes that affect the sustainability of STA performance also are considered. Developed in 2013, the original Science Plan specified a set of key questions and sub-questions based on knowledge gaps and uncertainties, and identified nine initial studies, which were implemented beginning in 2014. For the 2018 revision of the Science Plan, these questions were re-evaluated and revised to reflect current priorities based on additional information gained during the initial 5 years of implementation (**Chapter 3**). The revised list of questions includes topics related to operations, hydrology and hydraulics, vegetation, soils, biogeochemistry, and wildlife (**Table 3-1**). Several of the original questions were archived (**Appendix C**).

Research study concepts to answer some of the research questions are included in a Five-Year Work Plan (**Appendix A**). The work plan includes the continuation of selected initial studies and implementation of new studies. Tools and frameworks for data integration and synthesis have been initiated and will continue over the next 5 years. Progress and findings from the 2018 Science Plan studies will be reported through various venues, including forums, workshops, conference presentations, the annual South Florida Environmental Report, other technical reports, and publications in peer-reviewed scientific literature. Further information on the Restoration Strategies Program, including the Science Plan, is available at www.sfwmd.gov/restorationstrategies.

This 2018 Science Plan update was developed collaboratively among South Florida Water Management District scientists and engineers with input from the Restoration Strategies Technical Representatives from the U.S. Environmental Protection Agency, Florida Department of Environmental Protection, U.S. Army Corps of Engineers, and U.S. Department of Interior (Everglades National Park and U.S. Fish and Wildlife Service) and technical consultants.

CONTRIBUTORS

The South Florida Water Management District gratefully acknowledges the many professionals who have contributed to the development of this 2018 Science Plan update. This document was developed by a team of SFWMD scientists, modelers, and engineers with input from the Restoration Strategies Technical Representatives from the U.S. Environmental Protection Agency, Florida Department of Environmental Protection, U.S. Army Corps of Engineers, and U.S. Department of Interior (Everglades National Park and U.S. Fish and Wildlife Service) and technical consultants. The professionalism and dedication of the high-caliber technical experts who prepared this complex and important document is sincerely recognized and appreciated.

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TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

$\mu g\ L^{-1}$	micrograms per liter
Al	aluminum
ATT	Advanced Treatment Technologies (Research Program)
Ca	calcium
DIP	dissolved inorganic phosphorus
District	South Florida Water Management District
DOP	dissolved organic phosphorus
DQO	data quality objective
EAA	Everglades Agricultural Area
EAV	emergent aquatic vegetation
EFA	Everglades Forever Act
EPA	Everglades Protection Area
ET	evapotranspiration
F.A.C.	Florida Administrative Code
FAV	floating aquatic vegetation
FDEP	Florida Department of Environmental Protection
Fe	iron
FEB	flow equalization basin
HLR	hydraulic loading rate
Mg	magnesium
NPDES	National Pollutant Discharge Elimination System
P	phosphorus
PDE	Process Development and Engineering
PLR	phosphorus loading rate
PP	particulate phosphorus
PSTA	periphyton-based stormwater treatment area
QA	quality assurance
QC	quality control
rFAV	rooted floating aquatic vegetation
SAV	submerged aquatic vegetation
SFER	South Florida Environmental Report
SFWMD	South Florida Water Management District

SOP	standard operating procedure
SRP	soluble reactive phosphorus
STA	stormwater treatment area
TP	total phosphorus
USEPA	United States Environmental Protection Agency
WCA	water conservation area
WQBEL	water quality-based effluent limit

1. INTRODUCTION

In accordance with the Everglades Water Quality Restoration Framework Agreement (Framework Agreement; Florida Department of Environmental Protection [FDEP] and U.S. Environmental Protection Agency [USEPA], 2012) and the Restoration Strategies Regional Water Quality Plan (South Florida Water Management District, 2012a), the *Science Plan for the Everglades Stormwater Treatment Areas* (Science Plan) was developed and is being implemented to investigate the critical factors influencing total phosphorus (TP) reduction and treatment performance in the stormwater treatment areas (STAs). The Science Plan is mandated under Consent Orders (Office of General Counsel OGC Files No. 12-1148 and 12-1149, dated August 15, 2012) with the National Pollutant Discharge Elimination System (NPDES) and Everglades Forever Act (EFA) watershed permits for the Everglades STAs (FDEP Permit Number FL0778451 and 0311207-006, respectively), issued to the South Florida Water Management District (SFWMD or District) in 2012 (FDEP, 2012a,b) and amended in 2017 (FDEP, 2017). The original Science Plan was submitted to the FDEP in 2013; this revision reflects updates to the 2013 Science Plan, results from implementation of the initial studies, and a review of the remaining knowledge gaps and uncertainties. The Science Plan has been developed in consultation with representatives designated by the FDEP and USEPA. Key topics covered in the Science Plan include vegetation sustainability, phosphorus (P) dynamics, and hydrologic and hydraulic factors. Results from studies implemented under this Science Plan will be used to enhance the design, operation, and management of the STAs to achieve discharge water quality requirements for TP.

1.1 GOALS AND OBJECTIVES

The Science Plan provides the overall framework for development and coordination of science activities to identify the critical factors influencing P reduction and treatment performance in order to meet the water quality-based effluent limit (WQBEL) for the Everglades STAs. As such, the Science Plan only includes science associated with Everglades STA performance; it does not include science on source controls or downstream marsh effects. The Science Plan is intended to be a strategic, high-level document that will be revised and updated as needed. Implementation of research studies will be guided by the Five-Year Work Plan (**Appendix A**).

The Framework Agreement (FDEP and USEPA, 2012) specifies three objectives of the Science Plan:

1. Identify the critical factors that collectively govern P treatment performance;
2. Maximize the understanding that can be gained from existing data, designs, and operations; and
3. Identify the critical information gaps and research areas that will further treatment objectives to meet the WQBEL at each STA.

These objectives also were included in the Consent Orders associated with the EFA and NPDES watershed permits. In addition, the Consent Orders specified the Science Plan be modified based on results of completed or ongoing scientific studies and to determine how the results of the studies could be used to improve P reduction performance. The Consent Orders identified key areas for further scientific studies, which was a starting point for the Science Plan:

1. P loading rates (PLR);
2. Inflow P concentration;
3. Hydraulic loading rates (HLR);
4. Inflow water volumes, timing, pulsing, peak flows, and water depth;

5. P speciation at inflows and outflows;
6. Effects of microbial activity and enzymes on P uptake;
7. P resuspension and flux and flux management measures;
8. Stability of accreted P;
9. P concentrations and forms in soil and floc;
10. Influence of water quality constituents such as calcium (Ca);
11. Emergent and submerged aquatic vegetation (EAV and SAV) speciation, density, and cover;
12. Weather conditions such as hurricanes and drought; and
13. The interrelationships among these factors.

1.2 WATER QUALITY-BASED EFFLUENT LIMIT

The WQBEL is a numeric limit applied to all permitted discharges from the Everglades STAs to ensure such discharges do not cause or contribute to exceedances of the 10 micrograms per liter (µg L^{-1}) TP criterion within the Everglades Protection Area (EPA) in accordance with Rule 62-302.540, Florida Administrative Code (F.A.C.; SFWMD, 2012b). WQBEL compliance is monitored at individual discharge points from each STA. The WQBEL consists of two components; discharge from each STA cannot exceed: 1) 13 µg L^{-1} as an annual flow-weighted mean in more than 3 of 5 water years on a rolling basis, and 2) 19 µg L^{-1} as an annual flow-weighted mean in any water year. Water year is from May 1 to April 30. The two parts of the WQBEL were developed to allow for annual variability in the STA discharge TP concentration while attaining the long-term TP criterion in the EPA described in the Consent Orders (FDEP, 2012a). The STAs are not predicted to achieve the WQBEL without additional corrective actions (e.g., additional treatment areas and features) and enhancements based on Science Plan findings. The proposed corrective actions are expected to be completed by 2025.

1.3 HISTORY OF STA RESEARCH

1.3.1 Advanced Treatment Technologies

The first STA in the Everglades Agricultural Area (EAA), the Everglades Nutrient Removal Project (Chimney et al., 1999), was constructed in 1992 in response to recommendations from the Lake Okeechobee Technical Advisory Council II (1988). Extensive monitoring and research activities were conducted on this project to improve STA performance and design. Between 1997 and 2002, the Advanced Treatment Technologies (ATT) Research Program focused on technologies that could be used in conjunction with cattails (*Typha domingensis*) in STAs to meet water quality standards in discharges to the EPA. Investigated technologies included an SAV treatment system; a periphyton-based STA (PSTA); chemical treatments (e.g., direct filtration, high-rate sedimentation, dissolved air flotation/filtration, microfiltration/ultrafiltration); chemical treatment/solid separation, low-intensity chemical dosing; and managed wetlands. Concurrently, the STA Optimization Research Program included various HLRs, water depth, pulsed-flow, and marsh dryout studies conducted in the 0.5-acre cattail-dominated test cells in STA-1W. The findings of the ATT and STA Optimization research programs are summarized in the 1999 to 2004 Everglades Consolidated Reports (Chimney et al., 2000, 2004; Jorge et al., 2002; Newman et al., 2003; Goforth et al., 2003, 2004). The SFWMD incorporated some of the results of the ATT Research Program into the planning, design, and optimization of the STAs (e.g., subdividing STA-3/4 Cell 3 into two cells, an upstream EAV cell and a downstream SAV cell). The results of the ATT Research Program also were used in the Basin-Specific Feasibility Studies conducted for 13 tributaries that discharge into the EPA (Brown & Caldwell, 2002; Burns & McDonnell, 2002). The studies considered environmental factors, implementation cost, scheduling, and technical aspects in evaluating measures to reduce TP levels entering the EPA. Two key findings from these studies are documented in the Water Quality Standards for Phosphorus within the Everglades Protection Area [Paragraph 62-302.540(2)(e), F.A.C.]:

1. At this time, chemical treatment technology is not cost-effective for treating discharges entering the EPA and poses the potential for adverse environmental effects.
2. Optimization of the existing STAs, in combination with best management practices, is currently the most cost-effective and environmentally preferable means to achieve further P reductions to the EPA, and to restore impacted areas.

The effectiveness of such measures should be determined and maximized prior to requiring additional measures. Optimization shall take into consideration viable vegetative technologies, including PSTAs, that are cost-effective and environmentally acceptable.

1.3.2 Long-Term Plan Process Development and Engineering

The SFWMD's commitment to continue researching ATT and modifying the Everglades P control program was documented in the 2003 Long-Term Plan (Burns & McDonnell, 2003) and its amendments. The 2003 Long-Term Plan identified specific STA enhancement activities (e.g., conversion of treatment cells from EAV to SAV to further reduce outflow concentrations, construction of interior dividing levees to improve flow distribution) and outlined additional investigations to achieve water quality standards in the EPA as part of Process Development and Engineering (PDE) activities. As a central element of the overall strategy, the PDE component was developed with the recognition that achieving long-term water quality goals involves an adaptive management approach, whereby the best available information is used to develop and expeditiously implement incremental improvement measures in a cost-effective manner. PDE activities included performing enhanced control and monitoring of the STAs, refining STA water quality modeling tools, conducting SAV and PSTA investigations, and improving the reliability of STA inflow forecasts. More than 15,000 acres of STA treatment cells were converted to SAV based on the recommendations in the Long-Term Plan.

The PDE component of the 2003 Long-Term Plan includes long- and short-term surveys and monitoring to continually assess STA conditions and apply the results in adaptive management of the STAs. Specifically, surveys and monitoring include routine and event-driven water quality and transect sampling, spatial soil sampling, topographic surveys, and vegetation surveys. These data have been used to document STA conditions, investigate poorly performing cells, and develop or evaluate management strategies for a cell or flow-way. Smaller-scale mesocosm and field studies have been conducted to supplement existing knowledge about the STAs. Results from these studies have been reported in annual South Florida Environmental Reports (SFERs; Goforth et al., 2005; Pietro et al., 2006, 2007, 2008, 2009, 2010; Germain and Pietro, 2011; Ivanoff et al., 2012, 2013). For example, studies have been implemented to understand the effects of extreme water level conditions (dryout and deepwater conditions) on cattails and to evaluate the effectiveness of SAV versus other vegetation in polishing cells. Hydrologic studies (e.g., tracer studies, vegetation resistance measurements, two-dimensional modeling) to determine flow pattern and vegetation resistance also have been conducted in certain cells. Comprehensive analyses of historical STA performance data also have been completed (Pietro, 2012). Results of these analyses have identified the important role of HLR and PLR as well as inflow TP concentration and have indicated that at very low PLRs and P concentrations, other factors are more influential in controlling STA performance. As these analyses have been conducted on long-term data collected under non-controlled environments, analyses to date have not conclusively identified the specific factors influencing STA performance.

1.4 SCOPE AND SCHEDULE

The first Science Plan was developed and submitted to the FDEP in June 2013 (**Table 1-1**). The SFWMD began implementation of an initial set of studies identified in the first Five-Year Work Plan within 12 months of permit issuance (by September 2013). This 2018 Science Plan includes highlights of the initial 5 years of implementation; a list of questions based on remaining knowledge gaps and uncertainties (**Chapter 3**); and the second Five-Year Work Plan, with specific studies planned for implementation through 2023 (**Appendix A**). This 2018 Science Plan also includes an overview of the approach to integrate and synthesize information to generate interpretations and recommendations, and effectively communicate findings of the Science Plan to management and stakeholders.

The progress of implementation and the findings of research, monitoring, and modeling efforts are communicated regularly in different forums and reports, including: 1) monthly Science Plan forums, 2) study-specific workshops, 3) Long-Term Plan public meetings, and 4) annual peer-reviewed SFERs. In addition, study-specific annual reports and scientific publications are available to stakeholders.

Table 1-1. Schedule for development and implementation of the Science Plan for the Everglades Stormwater Treatment Areas.

Activity	Target/Completion Date
Original Science Plan development (including first Five-Year Work Plan)	August 2012-March 2013
Finalization and submission of 2013 Science Plan to the FDEP	June 2013
Plan development for initial nine studies	2013-2014
Implementation of initial nine studies	2013-2018
Review of the 2013 Science Plan	2015-2017
Update to the Water Resources Analysis Coalition	January 2018
Science Plan revision draft and review	January-May 2018
Discussions with Technical Representatives	February, March, May 2018
SFWMD Management and Technical Representatives review	April-May 2018
Finalize 2018 Science Plan and second Five-Year Work Plan	May-June 2018
Presentation of 2018 Science Plan to Governing Board	July 2018
Submit 2018 Science Plan to the FDEP	July 2018
Implement second Five-Year Work Plan	2018-2023

Nine studies were implemented in the 5 years following the 2013 Science Plan development:

1. Development of Operational Guidance for Flow Equalization Basins (FEBs) and STA Regional Operation Plans (*completed*)
2. Evaluation of Canal Conveyance Features on STA and FEB Inflow and Outflow Phosphorus Concentrations (*completed*)
3. Evaluation of Inundation Depth and Duration for Cattail Sustainability (*ongoing*)
4. Investigation of STA-3/4 PSTA Performance, Design and Operational Factors (*to be completed in 2018*)
5. Evaluation of the Role of Rooted Floating Aquatic Vegetation (rFAV) in STAs (*to be completed in 2018*)
6. Use of Soil Amendments or Soil Management to Control Phosphorus Flux (*literature review of potential technologies and treatment completed; evaluation of soil inversion will begin in 2019*)

7. Phosphorus Sources, Forms, Flux, and Transformation Processes in the Everglades Stormwater Treatment Areas (*ongoing*)
8. Stormwater Treatment Area Water and Phosphorus Budget Improvements (*ongoing*)
9. Sampling Methods for Total Phosphorus (*completed*)

Six of the initial studies are completed or near completion and the remaining are continuing, along with studies initiated in Fiscal Year 2018 and studies expected to begin in the next 5-year period (**Appendix A**). As part of the adaptive management approach in implementing the Science Plan, additional studies not listed in this plan may be initiated upon review and approval.

Table 1-2. Summary of initial studies in the first 5 years of implementation of the Science Plan for the Everglades Stormwater Treatment Areas.[1]

#	Study	Description	Status and Key Findings to Date
1	Development of Operational Guidance for FEB and STA Regional Operation	Create tools and methodologies to provide operational guidance for FEBs and STAs.	Tool sets and methodologies are being prepared to support 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 system optimization tools. Field tests have been performed that yielded an improved representation of hydraulics within the STAs. The results can be applied to a variety of STA vegetation types and facility configurations. An optimization tool (iModel-RSOPD) has been developed to inform weekly decision-making by approximating potential TP outflow under alternative operational flow routing regimes. More detailed descriptions have been published in Ali (2009, 2015), Lal et al. (2015), and Lal (2017).
2	Use of Soil Amendments and/or Management to Control P Flux	Investigate the benefits of applying soil amendments and/or soil management techniques on reducing the internal loading of P in the STAs.	A comprehensive literature review of 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 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 cell (i.e., downstream of an SAV treatment cell). Assess the chemical, biological, design, and operational factors of the PSTA cell that contribute to the superior performance of this technology.	The STA-3/4 PSTA cell has consistently achieved outflow flow-weighted mean TP concentrations of 13 $\mu g\ L^{-1}$ or lower on an annual basis. Pulsed flows, with HLRs and PLRs of up to 43 cm day^{-1} and 6.4 g $m^{-2}\ day^{-1}$, respectively, and operating at water depths up to 0.55 m have not adversely affected TP reduction performance. Lower outflow TP has been observed during the wet season. Data indicate that when inflow concentrations to the PSTA cell exceed 22 $\mu g\ L^{-1}$, the outflow concentration is generally higher than 13 $\mu g\ L^{-1}$.
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.	This multi-component study is ongoing. Results collected in STA-2 Flow-ways 1 (EAV cell) and 3 (SAV cell) indicate a clear reduction gradient in TP concentration from inflow to outflow and that soluble reactive P is reduced to below detection in the first half of the flow-way. Results show an increase in TP concentration during stagnant periods, particularly in the SAV cell and in the form of particulate P. Diffusive flux has been detected at the inflow and middle regions of the flow-way, but not at the outflow region. 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. This study is expected to continue through 2019.

#	Study	Description	Status and Key Findings to Date
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.	All tasks have been completed. A review of existing data does not suggest the need for further study or to pursue remedial field work to address water quality concerns in any of the evaluated canals. P export, primarily in the form of particulate P, has been observed in the STA-1 Inflow Basin Canal. A re-evaluation of the P export potential from this canal is recommended after the L-8 FEB has been operational for at least 3 years. More thorough reports include Zhao et al. (2015a,b, 2017), and Zhao and Piccone (2018a).
6	Inundation Depth and Duration for Cattail Sustainability	Identify the inundation depth and duration threshold for cattail sustainability in the STAs.	Preliminary data for year 1 indicate that while water depth condition differs between STA-1W Cell 2A and STA-3/4 Cell 2A, in both cases, daily water depths exceeded target depths most of the time; however, in STA-1W Cell 2A, depths generally were below 61 cm. Cattail (*Typha domingensis*) condition declined quickly during the first year of monitoring (2015) in STA-1W Cell 2A. There was a notable decline in root biomass over the 1-year monitoring period in both cells. In STA-3/4, there was no significant difference ($p > 0.05$) in average cattail densities between the inflow (deeper area) and outflow (shallower area). Data collection continued in 2016 and 2017; analysis for those data is under way.
7	Evaluation of the Role of rFAV in STAs	Assess the ability of rFAV to further enhance low-level P reduction performance of SAV communities.	Phase 1 of the study involved evaluating 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 indicate higher water column P concentrations in white water lily and American lotus patches than in the adjacent areas with SAV but no rFAV; 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 nearly complete; more data may help explain the observed differences.
8	Evaluation of Sampling Methods for TP	Identify factors that may improperly bias water quality monitoring results to improve sampling procedures for STA discharges.	This study evaluated the collection of surface water samples using flow-proportional autosamplers, time-proportional autosamplers, grab samples, and remote P analyzers. The study is complete. Results have been used to evaluate sampling quality assurance, autosampler design, data interpretation, and effects from environmental factors. While autosampler results were slightly higher than grab samples. The grab samples were more representative of the STA TP concentrations, and when averaged over time, there was no significant difference ($p > 0.05$) in the means.

#	Study	Description	Status and Key Findings to Date
9	STA Water and P Budget Improvements	Improve annual water and P budgets for STA treatment cells. Water and P budgets are important tools for understanding the treatment performance of STAs.	A test case water budget improvement was performed in STA-3/4 using improved flow data and other information to improve 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 analyses for STA-2 Flow-ways 1, 2, and 3 has been completed (Zhao and Piccone, 2018b). 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. The average reduction in TP load and concentration were slightly less in Flow-way 2 (76% and 74%, respectively) compared to Flow-ways 1 (83% and 83%, respectively) and 3 (79% and 80%, respectively). Water and P budget estimations for individual cells in STA-3/4 have been completed; the report is under review.

1.5 SCIENCE PLAN OVERSIGHT

The Restoration Strategies Program has several levels of public and agency oversight guiding implementation of the construction projects and the Science Plan, as summarized below.

- **Restoration Strategies Steering Group**. This group, composed of SFWMD managers from different divisions, provides oversight for the Restoration Strategies Program, including implementation of the Science Plan, to comply with permits and Consent Orders. The Steering Group is responsible for reviewing and approving proposed studies and the resources required to implement those studies.

- **Science Plan Project Management Team**. This team is composed of the Science Plan coordinator and SFWMD managers directly involved with the development and implementation of the Science Plan. The team oversees the technical and resource aspects of the Science Plan, proposed studies, and deliverables, and makes recommendations to the Steering Group.

- **Science Plan Development Team**. This team of experts from various disciplines within the SFWMD, including biology, wetlands ecology, engineering, operations, and hydrologic and hydraulic modeling, was formed to develop and update the Science Plan. The team reviewed information gaps and primary areas of investigation. For the 2018 Science Plan, the team reviewed existing questions to determine their continued relevance and re-evaluated the ability to answer these questions through scientific research. Sub-teams were formed for more focused discussions and for review of study proposals, plans, and deliverables.

- **Science Plan Coordinator**. The Science Plan coordinator is responsible for organizing the development and update of the Science Plan; managing its implementation through various studies; ensuring studies are on time, on budget, and within approved scope; verifying data are of acceptable quality and stored properly in SFWMD databases; confirming report deliverables are complete and manuscripts are reviewed and approved prior to publication; and communicating progress and findings to management and other stakeholders.

- **Study Leads**. Study leads are the principal investigators for the studies listed herein and are responsible for developing study concepts, study plans, and statements of work for contracted studies or tasks; managing project/study budgets and contracts; reviewing deliverables from contractors; and providing updates on study progress and findings through presentations and reports. Study leads form a team and coordinate every aspect of the study with the team.

Additional input to the Restoration Strategies Program is provided through interagency and public forums, as described below.

- **Restoration Strategies Technical Representatives**. The primary role of the Technical Representatives in the Science Plan is to gather information, evaluate results of scientific studies, and assess the SFWMD's progress in achieving Consent Order deadlines. The Technical Representatives are expected to inform their respective agencies on how results of the Science Plan and interim STA operational performance could be used to optimize TP reduction and treatment performance.

- **Stakeholder Involvement.** Information on Science Plan development and progress is communicated through public meetings, including the Long-Term Plan public meetings, Water Resources Analysis Coalition meetings, and SFWMD Governing Board meetings. Descriptions of each study's findings and progress also are published in the annual SFER. Relevant publications and meeting agendas, minutes and presentations are available on the SFWMD's website (www.sfwmd.gov).

2. STA AND FEB OVERVIEW

2.1 GENERAL DESCRIPTION

The Everglades STAs, mandated by the EFA [Section 373.4592, Florida Statutes], were constructed south of Lake Okeechobee to reduce TP from runoff water prior to entering the EPA (**Figure 2-1**). STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6 are operated, maintained, and managed by the SFWMD. The total area of the STAs, including infrastructure components, is roughly 68,000 acres, with approximately 57,000 acres of effective treatment area currently permitted to operate (see **Appendix B** for detailed STA and FEB schematics). In addition, two FEBs: A-1 FEB and L-8 FEB were completed in 2015 and 2018, respectively, as part of the Restoration Strategies Regional Water Quality Plan and are operated to attenuate peak stormwater flows and improve inflow delivery rates to downstream STAs (**Figure 2-1**). The A-1 FEB is a shallow 15,000-acre impoundment with a capacity of approximately 60,000 acre-feet; the L-8 FEB is a deep 950-acre facility with a capacity of approximately 45,000 acre-feet.

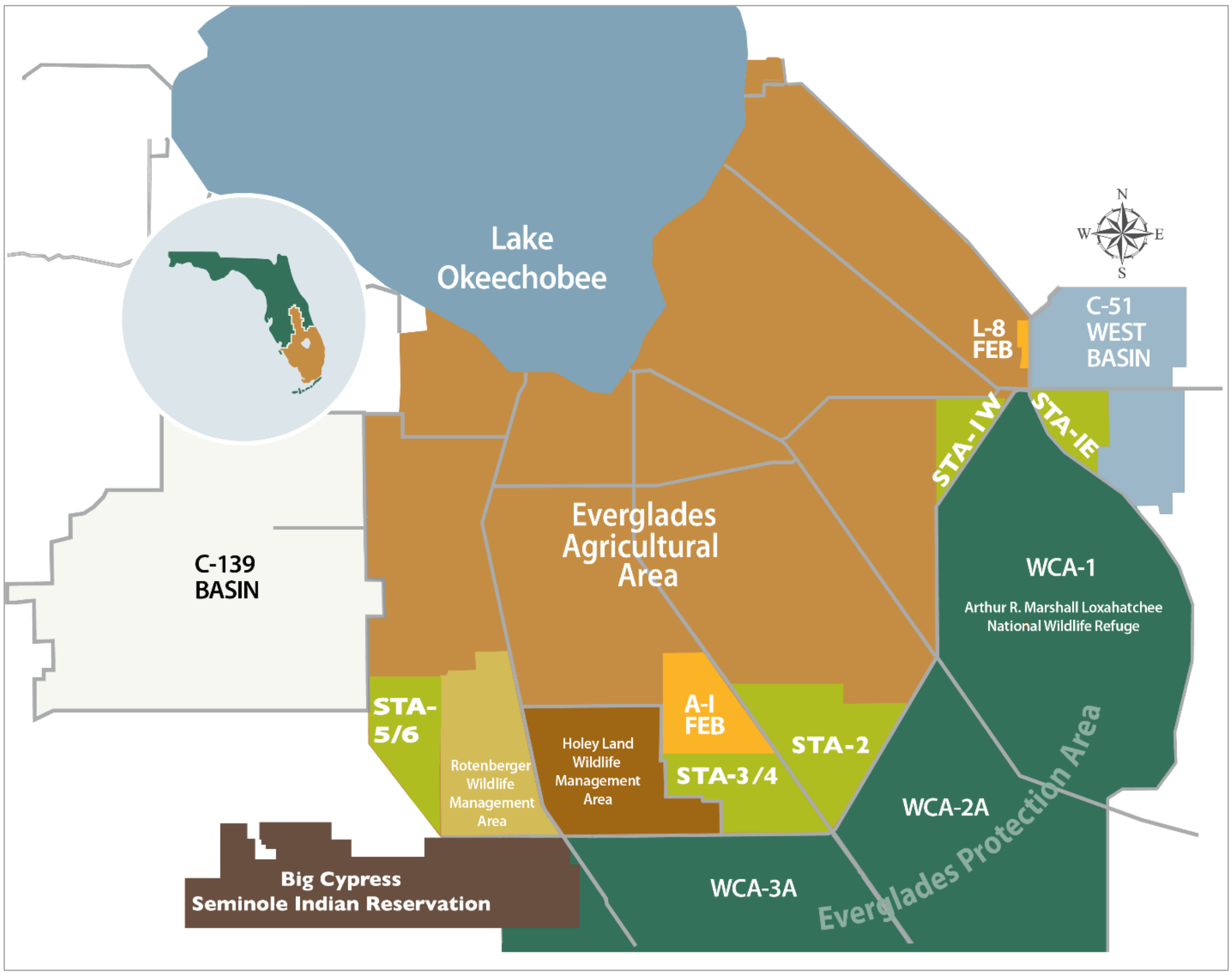


Figure 2-1. Map of the Everglades Stormwater Treatment Areas (STAs) and Flow Equalization Basins (FEBs).

The STAs retain P through several mechanisms, including plant nutrient uptake and litter accumulation, settling, sorption, co-precipitation with minerals, particulate settling, and microbial uptake (**Figure 2-2**). Varying in size, configuration, and period of operation, the STAs are divided into treatment cells and flow-ways by interior levees. Water flows through these systems via water control structures (e.g., pump stations, gates, culverts). The dominant plant communities in the treatment cells are broadly classified as EAV and SAV. In many cells, various species of floating aquatic vegetation (FAV) are present also; however, there is a continuing effort to control nuisance FAV species, especially in targeted SAV areas. Cells generally have mixed vegetation types at varying proportions, including cells that are undergoing vegetation conversion from EAV to SAV. Periphyton communities are interspersed among these vegetation communities, where conditions are favorable.

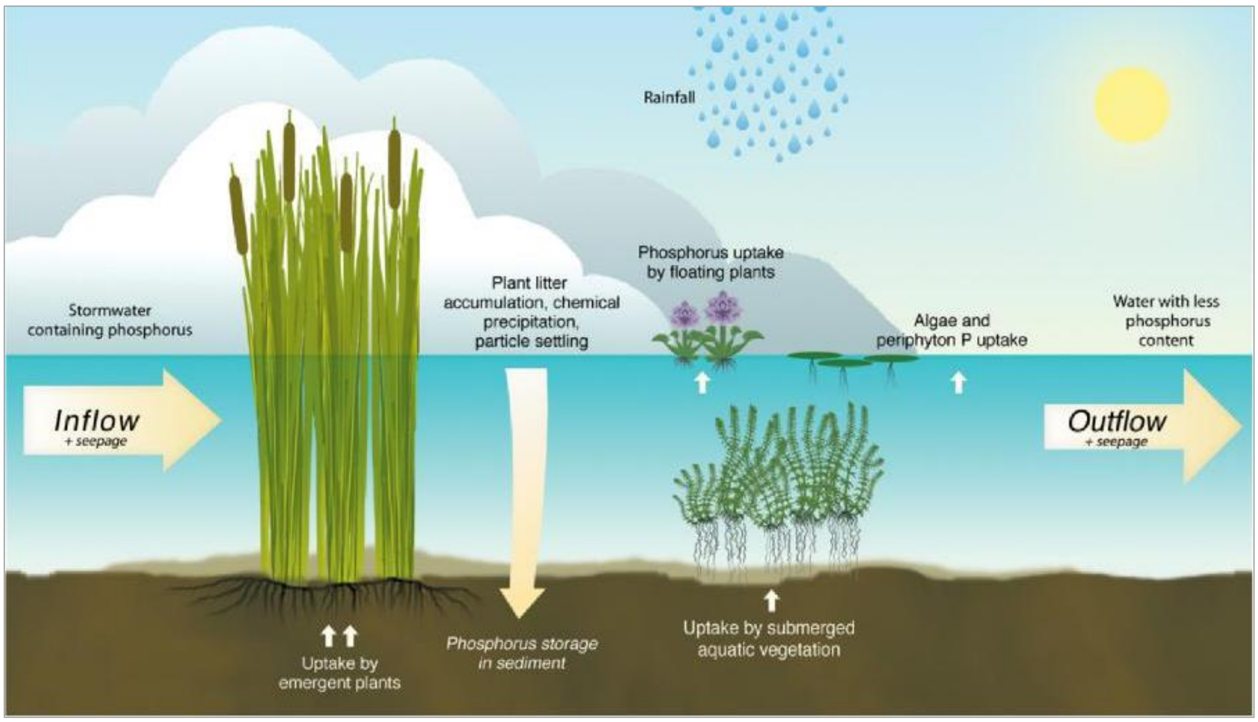


Figure 2-2. Schematic of phosphorus (P) retention process and mechanisms in the STAs.

The SFWMD uses an adaptive approach to manage the STAs, under which weekly data, including water levels, outflow TP concentrations, HLR, PLR, vegetation condition, and any wildlife restriction issues, are evaluated. This adaptive approach includes treatment of Lake Okeechobee Regulatory Releases in the STAs, when capacity exists, for delivery south to the Everglades. Supplemental water from Lake Okeechobee also is delivered to the STAs, when available, during dry conditions to avoid treatment cell dryout.

The FEBs are designed to attenuate peak stormwater flows and improve inflow delivery rates to the STAs. The improved inflow delivery provides enhanced operation and P treatment performance to achieve state water quality standards in the EPA.

2.2 KEY FACTORS AND CHALLENGES TO STA PERFORMANCE

Nutrient reduction performance in STAs is variable and affected by internal and external factors. Internal factors include antecedent land use, health of SAV and EAV communities, microbial activities, soil P dynamics, cell topography, and cell size and shape. External factors include weather patterns, inflow P concentrations, PLRs, variable water delivery rates that result in changing HLRs, water depths, hydropatterns (continuously flooded versus periodic dryout), maintenance and enhancement activities, regional operations, and wildlife use. The STAs are not operated in isolation as they are integral components of a complex water management system with multiple objectives, particularly water supply and flood control.

The primary source of water to the STAs is stormwater runoff; therefore, flow volume, TP loads, and TP concentrations vary. The goal is to treat the stormwater before it is discharged to the EPA. High loadings and extended periods of deepwater conditions can occur, which can adversely affect STA performance. Another challenge related to STA operations occurs during the dry season, particularly during droughts, when sufficient water is not always available to keep the cells hydrated, and some cells dry out. Prolonged dryout conditions can cause spikes in TP concentrations upon rehydration. FEBs were built to provide water during dry periods and to store excess water during wet periods. The SFWMD has implemented a drought contingency strategy to minimize drought effects on STA performance. STA operations also are affected by wildlife use; in particular, species protected under the Migratory Bird Treaty Act and Endangered Species Act. STA water depths and flow conditions have been affected as a consequence of implementing measures of the Avian Protection Plan (Pandion Systems, Inc. 2008). The FEBs should reduce the need to implement these contingency strategies.

Effective management of desirable and undesirable vegetation in the STAs is critical to achieve and sustain required treatment performance. Herbicides are routinely used in the STAs for exotic/nuisance species control. This is particularly critical for FAV, which can shade out and adversely affect SAV community health. To accelerate SAV recruitment in areas converting from EAV to SAV, and in SAV cells undergoing rehabilitation, SAV inoculation has been implemented using equipment on land, in water, and in air via helicopter (Ivanoff et al., 2018). EAV strips have been and are continuing to be added in SAV areas to protect SAV from strong winds and flows. In recent years, the SFWMD has been planting alternative EAV (e.g., bulrush [*Schoenoplectus californicus*], fire flag [*Thalia geniculata*]) in areas of the EAV treatment cells that have experienced chronic cattail decline and loss.

The STAs are highly managed systems involving various personnel for routine operation and maintenance of pumps, gates, structures; planting of desired vegetation; and removal of unwanted vegetation. Scientists and engineers provide technical information and evaluation to ensure proper operation and optimal management, including collection and analysis of water quality, soil, vegetation, flow, and performance data. Cross-disciplinary teams participate in weekly, biweekly, and monthly communication and coordination meetings. Water levels in each cell are monitored, and target stages are set from average ground elevations, depending on the dominant vegetation community and condition of the treatment cell. Site managers and scientists frequently visit the STAs. Following extreme weather conditions (e.g., droughts, storm events), plant communities and infrastructure components of the STAs are assessed. When desired performance is not being achieved, the technical team examines potential causes and implements corrective actions when feasible. Corrective actions can be operational such as reducing inflow loading to one flow-way by redirecting flows to another flow-way or reducing target stages to allow vegetation to rejuvenate. Corrective actions also can include structural changes such as adding temporary pumps or constructing divide levees to increase compartmentalization, or major rehabilitation activities such as the earthwork completed in STA-1W (2007) and STA-5/6 (2009).

2.3 WATER QUALITY AND FLOW MONITORING

Water quality and flow are regularly monitored at various locations in the each STA. Compliance monitoring sites are at the STA inflow and outflow sites of the STAs (SFWMD 2017a,b,c,d,e) and FEBs (SFWMD, 2016a,b) to capture the overall treatment performance of the Everglades STA system. Additional monitoring sites are located at many of the inflows and outflows of individual flow-ways and, in some cases, individual treatment cells. Together, the data collected at these monitoring sites are used to evaluate STA performance, develop weekly summaries of flow and water quality monitoring data used for operational decision making, and support continued improvement of analytical and forecasting tools.

3. SCIENCE PLAN QUESTIONS

3.1 BACKGROUND

The 2013 Science Plan was structured around 6 key questions and 39 sub-questions formulated through a series of workshops and meetings and based on a review of existing knowledge and information gaps regarding P reduction mechanisms and regulating factors, including physical, chemical, and biological processes. Each STA was evaluated qualitatively to isolate issues affecting P reduction performance, identify areas for further investigation, and consider possible remedies.

This 2018 Science Plan builds on the original key questions and sub-questions. All key questions were retained, with some minor edits for clarity. The sub-questions were reviewed to assess their continued relevance to achieve the WQBEL, to determine if they had been fully addressed in the initial 5 years of study, and to re-evaluate if a meaningful and cost-effective study could be designed to address them (i.e., testability, timeliness, and feasibility). In addition, several sub-questions were revised for clarity and generalized to encompass multiple variables. This evaluation resulted in archiving some of the original sub-questions (**Appendix C**). In addition, new sub-questions were formulated, based on remaining knowledge gaps and uncertainties. The sub-questions are discussed in this section and summarized in **Table 3-1**.

The key questions are used to guide and prioritize studies to enhance the design and operation of projects under the Restoration Strategies Program. Some of the sub-questions have been or are being addressed in past or current studies, and others will be investigated in studies included in the Five-Year Work Plan (**Table 3-1**; **Appendix A**). Not all the questions can be addressed at the same time; therefore, the planned studies focus on a subset of 10 sub-questions:

1. 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?
2. Will reduced advective loading from the soil to the water column reduce P concentrations out of the STAs?
3. What are the effects of topography on STA performance?
4. What key factors affect and what management strategies could improve system resilience of SAV communities?
5. What key factors affect and what management strategies could improve system resilience of EAV communities?
6. What are the key physicochemical factors influencing P cycling in very low-P environments?
7. 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?
8. What is the treatment efficacy, long-term stability, and potential impact of soil amendment management?
9. What are the sources, forms, and transformation mechanisms controlling residual P pools within the STAs, and how do they compare to the natural system?
10. What are the direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (i.e., are they net sinks or sources)?

The research questions and any new questions that arise will be evaluated and prioritized annually through an adaptive management process outlined in **Chapter 5**.

Table 3-1. Science Plan for the Everglades Stormwater Treatment Areas key questions and associated sub-questions.[1]

Key Question	Sub-Questions	Status	**Notes**
1. How can the FEBs/reservoirs be designed and operated to moderate inflow P concentrations and optimize PLR and HLR in the STAs, possibly in combination with water treatment technologies or inflow canal management?	How should storage in the FEBs/reservoirs be managed throughout the year so water can be delivered to the STAs in a manner that allows them to achieve the lowest outflow P concentrations?	Original	a
2. 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?	Are there operational refinements or improvements to the regional water management system that can be implemented to enhance FEB and STA performance while maintaining existing levels of flood protection?	New	c
	Will reduced advective loading from the soil to the water column reduce P concentrations out of the STAs?	Original, revised	b
	What are the best structural design features for delivering water to and from the STAs and FEBs?	Original	a
	What are the effects of topography on STA performance?	Original, revised	b
3. What measures can be taken to enhance vegetation-based treatment in the STAs?	What key factors affect and what management strategies could improve system resilience of SAV communities?	Original, revised	b
	What key factors affect and what management strategies could improve system resilience of EAV communities?	Original, revised	b
	What are the differences in long-term P reduction between pure SAV communities and mixed SAV/EAV communities?	New	c
	Can various vegetation types (subtypes) enhance P uptake and reduction in SAV cells?	Original, revised	c
	What are the short-term and long-term P reduction capacities of the dominant and other vegetation species in the STAs?	Original, revised	c
4. How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the STAs?	What are the key physicochemical factors influencing P cycling in very low-P environments?	Original	a, b
	Are there design or operational changes that can be implemented in the STAs to reduce PP and DOP in the water column?	Original, revised	a, b
5. 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?	What is the treatment efficacy, long-term stability, and potential impact of soil amendment or soil management?	Original	a, b
	What are the sources, forms, and transformation mechanisms controlling residual P pools within the STAs, and how do they compare to the natural system?	Original, revised	a, b
	What is the role of vegetation in modifying P availability in low-P environments, including the transformation of refractory forms of P?	Original, revised	a, b
	Do water level drawdowns improve soil consolidation and compaction?	Original	c
6. What is the influence of wildlife and fisheries on the reduction of P in the STAs?	What are the direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (i.e., are they net sinks or sources)?	Original	a
	What options are there for mitigating or reducing the impacts of fish and wildlife on STA performance through wildlife management or changes in operations?	Original	a

Notes: a = question addressed in past or current studies; b = question addressed in planned study; c = question has not been addressed.

3.1.1 Key Question 1

How can the FEBs/reservoirs be designed and operated to moderate inflow P concentrations and optimize PLR and HLR in the STAs, possibly in combination with water treatment technologies or inflow canal management?

FEBs are impoundments constructed to attenuate peak stormwater flows, temporarily store stormwater runoff, and improve inflow delivery rates to downstream STAs, thereby enhancing operation and P treatment performance. FEBs also serves as water supply to the STAs during the dry season to maintain minimum water depths critical for vegetation and reduce the frequency of dryout conditions within STAs (McBryan, 2018). FEBs serve a key role in meeting the Restoration Strategies Program objectives, and their operation and performance are important for sustainable performance of the STAs. As such, it is important to determine how storage and outflow hydraulics of the FEBs should be managed, to define the optimal and minimum water depths in the STAs, and to identify how discharge rate and timing should be controlled for consistent STA performance.

Reducing flow pulses to the STAs is a key objective of the water quality projects discussed herein; therefore, FEBs are included for all three project flow paths (**Table 3-2**). Two FEBs (A-1 and L-8) have been constructed and add flexibility in the delivery of water to the STAs. An additional FEB (C-139) and a reservoir (A-2) are planned for future construction. To date, the A-1 FEB has provided an additional benefit, reducing TP concentrations from an inflow concentration of approximately 100 $\mu g\ L^{-1}$ to an outflow concentration 20 $\mu g\ L^{-1}$ or less. While the outflow TP concentrations from the L-8 FEB during the initial operation phase have been erratic, they are anticipated to decrease as normal operation continues.

Table 3-2. Operational and planned FEBs and reservoir for the Everglades STAs.[1]

Flow Path	FEB	Storage Volume (ac-ft)	Vegetated	Completion Date	Supplies Water To
Eastern	L-8 FEB	45,000	No	6/2017	STA-1E; STA-1W
Central	A-1 FEB	60,000	Yes	6/2015	STA-2; STA-3/4
	A-2 Reservoir	240,000	To be determined	To be determined	
Western	C-139 FEB	11,000	Yes	12/2023	STA-5/6

Sub-Question: FEB/Reservoir Management

How should storage in the FEBs/reservoirs be managed throughout the year so water can be delivered to the STAs in a manner that allows them to achieve the lowest outflow P concentrations?

The FEB-STA system has been operating for only a few years. An in-depth analysis of collected data and observed conditions is needed to better understand how to operate and manage the system to maximize STA performance.

The influence of operating the Central Flow Path FEB (A-1) initially was evaluated using the iModel for Restoration Strategies Operational Protocol Development (iModel-RSOPD; Ali, 2018). Specifically, the iModel-RSOPD was used to optimize water flow through the flow-ways of STA-3/4 and STA-2 such that discharge TP concentrations met the WQBEL. Results showed the increased flexibility to reduce peak flows to the STAs using the A-1 FEB improved overall performance of these STAs.

Flow and water quality data from the A-1 FEB are reported in the annual SFER (Laham-Pass, 2018). Initial operation of the A-1 FEB began in 2015. In Water Year 2017, the FEB met the operational goals of reducing high-water events and supplementing dry periods. The A-1 FEB captured more than 318,000 acre-feet of water from May to November 2016, while releasing 241,000 acre-feet (76 percent) to STA-3/4 and STA-2. An additional 30,000 acre-feet was released to these STAs during the dry season (January to March 2017). The benefit of this operational flexibility should be evaluated in future iModel enhancements.

Investigation of this sub-question will continue as the SFWMD continues to operate the FEBs and improves understanding of how this management influences STA performance. Performance and operational data and the use of analytical tools such as the iModel-RSOPD will be evaluated. Flow volume and velocity will be investigated as part of several ongoing and planned studies to evaluate various aspects of STA performance.

3.1.2 Key Question 2

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?

To achieve the WQBEL for discharges to the Everglades, operational or design refinements to improve P treatment performance in the STAs must be explored further. Current operational and management strategies for the STAs include controlling water depths and loading rates to protect the vegetation and maintain optimal performance. While analyses conducted in previous years have suggested negative effects of loading rates on STA performance, more recent results from 2013 Science Plan data mining indicate higher flows at downstream cells that achieve TP concentrations of 20 $\mu g\ L^{-1}$ or less could result in even lower outflow TP concentrations. Collection of additional data across various flow regimes will help verify this observation and improve understanding of the mechanisms and factors affecting the observed P reduction. Reducing inflow rates also can minimize impairment of STA vegetation that occurs due to high flow velocity or resulting deepwater conditions in the upstream EAV cells. Evaluation of hydrologic conditions on vegetation sustainability is included in several ongoing studies.

The timing of STA discharges may affect outflow TP concentrations through factors such as diurnal changes in photosynthesis and diel movements of phytoplankton and microfauna. For example, differences in TP concentrations over the course of a day were observed at pump station G-310, which discharges from STA-1W (Rawlik, 2017). While diurnal factors could result in small differences over a day, the magnitude of influence on annual outflow TP concentrations in the various STAs is unknown. The causes of concentration changes in the water column may be more useful to understand than small variations in outflow TP concentrations. A vast amount of data has been collected at short time intervals (every 3 to 4 hours) in treatment cell interiors under the STA 3/4 PSTA Performance, Design, and Operational Factors study and the P Sources, Forms, Flux, and Transformation Processes in the STAs study (**Table 2-1**). These data, combined with data collected at outflow structures of selected cells, will be investigated to better understand diurnal or diel patterns of key parameters in the STAs. The influence of high rates of photosynthesis in STA marshes is of interest, especially in relation to pH, Ca, and dissolved oxygen dynamics.

Occasionally, water levels in individual cells are drawn down (or dried out) to allow for construction access, planting, or vegetation rejuvenation. When feasible, SAV cells should remain hydrated, even during dry periods, through supplemental water deliveries. Maintaining this hydration avoids a flush of TP to the water column that occurs upon rewetting of dried out STA soils (Moustafa et al., 2012). Structural changes or an increase in the number of permanent or mobile pumps could allow water to transfer between STA cells and flow-ways. Supplemental water supply pumps have effectively sustained SAV cells in STA-5/6. Additional pumps and structures increase flexibility but also increase operations and maintenance costs. The benefit of increased flexibility is of interest to studies that evaluate SAV sustainability and P reduction dynamics in the next 5 years.

Under ideal conditions, water flows in a uniform sheet through an STA for optimal interaction with EAV, SAV, and periphyton. Improved hydraulic condition increases hydraulic residence time and reduces localized advective velocities and turbulence. However, short-circuits can occur, altering the flow patterns in part or all of the flow-way. Short-circuits in STAs can result from non-uniform flow distribution across inflow/outflow levees (i.e., structures behaving as point sources), spatial variation in topography across treatment cells, and changes in vegetation condition/density and resulting differences in flow resistance. Non-uniform inflow from point sources (i.e., a series of structures along an inflow levee) can erode areas immediately downstream of the structures, short-circuiting flow past the front end of the cell. Wider and deeper STA inflow distribution/spreader canals and energy dissipaters may minimize localized high velocities at some structures where short-circuiting occurs.

One successful method to eliminate short-circuiting has been planting bulrush in deeper areas. Bulrush plantings have been used to reduce open water in EAV and SAV cells, which reduces flow velocities through short-circuits. Quantifying improvements in TP reduction efficiency as a result of these plantings is difficult. However, vegetation planting is a relatively inexpensive and simple management tool compared to earthwork or structural features. Where vegetation plantings are not sufficient, other structural measures may be used to improve flow distribution, reduce short-circuiting, and enhance treatment performance. For example, areas of treatment cells with extreme topographic variability may require filling/grading. Reducing peak inflows to STAs with upstream FEBs should minimize the frequency and duration of high-velocity flows, which lead to short-circuits downstream of inflow structures. Issues regarding short-circuiting and flow distribution apply to existing and future STAs. A few studies are planned, in part, to investigate short-circuits through field studies or data mining efforts to determine their effect on TP reduction in STAs.

Sub-Question: Operational Refinements

Are there operational refinements or improvements to the regional water management system that can be implemented to enhance FEB and STA performance while maintaining existing levels of flood protection?

Optimal operation of the FEB-STA system requires evaluating the volume and timing of inflows to determine how such operations affect the water storage capacity of the FEBs and TP loading into the STAs. For example, near-real-time forecasting of EAA canal levels and flows can benefit near-real-time water control operations to balance flood control in the EAA and treatment efficiencies of the STAs. Forecasting EAA canal levels and conveyance may enhance the flexibility of FEB and STA operations to achieve optimal water quality improvements. Planning-level forecasting of EAA canals and conveyance has been done using the EAA Regional Simulation Model – Basin (SFWMD, 2005a,b). Such planning-level forecast studies would be valuable to estimate the range of flow options available for STA operations, particularly during flood events, as modeling efforts move forward from the P Sources, Forms, Flux, and Transformation Processes in the STAs study (**Table 2-1**).

Sub-Question: Vertical Advective Loading

Will reduced advective loading from the soil to the water column reduce P concentrations in STA outflow?

Vertical advective loading is one mechanism of P translocation from the soil to the water column in an STA. Other exchanges involve physical, chemical, and biological processes such as turbulent resuspension and deposition, macrophyte mining, plant transpiration induced flux, bioturbation, and chemical diffusion. Combined, these processes in the lower end of the STAs likely reach an equilibrium, resulting in a minimum TP concentration in the water column. It might be possible to increase downward movement or reduce upward movement of water and P by modifying the vertical advective loads from the soil to the water column, which should result in lower TP concentrations.

The magnitude of the water exchange (and the associated DOP or PP concentrations) between the soil and water column depends on the hydraulic conductivity, surface area, and gradient between the aquifer and surface water. It may be possible to affect hydraulic gradients that reduce upward or increase downward advective flow of water from/to the soil by increasing the difference between the water levels in an STA cell and the surrounding cells or by increasing the reduction of water through enhanced seepage canals. The difference in water levels (head difference), even at a small scale, might induce enough flow into the soil to change the static equilibrium, resulting in lower TP concentrations in the water column. Several approaches to quantify vertical advective loading will be explored.

Sub-Question: Design Features

What are the best structural design features for delivering water to and from the STAs and FEBs?

Flows to and from STAs and FEBs are managed through different configurations of canals, pumps, gated culverts, gated spillways, and weirs. Gated structures are needed to control flows into individual flow-ways, and these structures are point sources of flow. FEBs do not require even flow distribution to achieve their operational purpose, which is to quickly capture stormwater runoff and release it when needed; therefore, they may have fewer control structures and less compartmentalization than an equivalent-sized STA. For STAs, the goal is to enhance STA performance through even distribution of flow, which has been accomplished using spreader canals downstream of inflow structures. To mitigate the effect of point source flow, energy dissipaters (e.g., rock piles, concrete structures, EAV-bulrush plantings) have been used to reduce velocity and deflect flow from continuing straight down the flow-way. At the outflow region of flow-ways, water is discharged via gated culverts, spillways, weirs, or pumps. In most cases, similar to the inflow region, outflow spreader/distribution canals are used to evenly convey water from the marsh to the outflow structures. Ideally, outflow structures from the STAs should minimize soil buildup and transport to downstream receiving areas. Overall, the best structural design features for delivering water to and from the FEBs and STAs balance the ability to control water flows to and from the STA flow-ways and to maintain water quality treatment. Flow data from a variety of structures and at various flow rates could be evaluated to optimize current and future design features and water deliveries to reduce TP outflow concentration.

Sub-Question: Topography

What are the effects of topography on STA performance?

Ideally, STA topography should be relatively level to provide even sheetflow across the marsh and to minimize short-circuiting. Even topography will result in relatively consistent water depths when treatment cell target stages are maintained, which will promote favorable conditions for even distribution of target vegetation. To achieve this in STA cells, farm ditches and borrow canals parallel to flow typically are filled (or plugged) as part of construction. However, some cells still have variations in topography that affect hydraulics and the ability to maintain water depths to sustain the desired wetland vegetation. Topographic variability occurs in several existing STA cells and may contribute to their poor performance (Pietro et al., 2010; Ivanoff et al., 2013).

The two-dimensional Regional Simulation Model (Total Variation Diminishing Lax-Friedrichs; Lal, 2017) has successfully simulated the hydraulics of two treatment cells within STA-3/4. The model demonstrated the complex internal flow patterns that exist even in a well-performing treatment cell due to vegetation, short-circuiting flows, and variable topographic features. Future STA designs, as well as the existing poor-performing STA treatment cells, would benefit from further analysis to determine topographic conditions that promote optimal STA treatment performance. The model also could be used in numeric experiments to isolate the dominant source of short-circuiting (e.g., topography, vegetation density, inflow structures) by changing one element while keeping the others constant and evaluating the effects on short-circuits. Topographic effects, particularly related to short-circuits, should be evaluated further to determine its influence on flow movement, P reduction, and vegetation growth.

3.1.3 Key Question 3

What measures can be taken to enhance vegetation-based treatment in the STAs?

In wetlands designed to treat surface water for nutrient reduction, macrophytes reduce water column nutrients through physical, biological, and biochemical processes. Macrophytes provide resistance to flows that result in particulate settling; decrease soil and floc resuspension and transport; and provide a large surface area for particle impaction, interception, and settling (Kadlec and Wallace, 2009). Reduced water velocity allows for increased settling of PP, while reduced turbulent mixing, particularly at the soil-water interface; stabilizes the soil surface; and minimizes movement of superficial soil and floc. In addition, transpiration (the process of moving water from the roots to the shoots of plants) could result in water and P movement from the water column into the soils. The root systems of these plants store P, increase soil stability, and reduce soil resuspension and P flux into the water column. Improved sediment stability is beneficial for growth and maintenance of EAV and SAV. EAV is used as a management tool in areas where short-circuits have occurred, allowing more even flow throughout each cell, thereby increasing the effective treatment area.

Photosynthesis within dense beds of SAV elevates the water column pH, which facilitates co-precipitation of P with cationic minerals such as Ca (Brix, 1997; Reddy and DeLaune 2008; Kadlec and Wallace, 2009). Macrophytes also provide contact surface for microbes and periphyton, which can reduce soluble reactive phosphorus (SRP) from the water column by storing it as cellular organic P and/or through extracellular processes of metal-phosphate deposition, co-precipitation with Ca and magnesium (Mg), and adsorption to inorganic compounds like calcium carbonate ($CaCO_3$; Hagerthey et al., 2011).

Certain factors related to plant structure and density can alter P reduction by macrophytes or result in net P addition to the water column. Dense vegetation cover can inhibit periphyton establishment, which also could negatively affect P reduction in the water column. P can be released from periphyton and macrophytes following cell death, desiccation, and subsequent rehydration. Macrophytes primarily take up nutrients from the soil root zone. P translocates from macrophyte roots to the leaves, where it may reside or be solubilized directly to the water column or indirectly through periphyton uptake, mineralization of organic P, and release. This translocation can be an important internal source of P, particularly in enriched soil areas (Noe and Childers, 2007).

Alternatively, macrophytes move P down into the roots, and storage belowground in roots and tubers can exceed the amount of P stored aboveground (Reddy and DeLaune, 2008). Eventually, dead and detrital plant biomass decomposes, with some nutrients released back into the water column. Mineralization of macrophyte detritus can create residuals and accrete P through burial in soils. The importance of this mechanism is evident from the rapid turnover of macrophyte biomass, which can be up to five times per year in subtropical settings (Davis, 1994).

These vegetation-based processes of P reduction demonstrate the value of sustaining a healthy plant community. Understanding the conditions for optimal vegetation growth and P uptake mechanisms is important and will serve as a basis in formulating recommendations for STA performance improvements.

Sub-Question: ***SAV Resilience***

What key factors affect and what management strategies could improve system resilience of SAV communities?

Factors that may affect system resilience of SAV communities include the following:

- Water quality;
- Water levels;
- Light penetration;
- Community composition, cover, and density;
- Nutrient loadings;
- *Chara* subtype inoculation and distribution;
- EAV planting, rotation, distribution, and abundance;
- Rate of change and duration of water levels;
- Flow velocity;
- Dryout;
- Photolytic degradation (e.g., hydrogen peroxide [H_2O_2], dissolved organic matter degradation products);
- Herbicides; and
- Soil characteristics.

SAV species can grow naturally and rapidly with appropriate water chemistry (e.g., inorganic carbon, low nutrient concentration, water clarity), water levels, and sunlight/light penetration. In most STA cells, plant community composition varies, but the most common SAV species in the STAs are hydrilla (*Hydrilla verticillata*), southern naiad (*Najas guadalupensis)*, Illinois pondweed (*Potamogeton illinoensis)*, muskgrass (*Chara* sp.), and coontail (*Ceratophyllum demersum*). Historical observations in the STAs indicate a quicker turnover of *Chara* and hydrilla, while other species tend to persist longer. Southern naiad and pondweed distributions also have shifted in some cells over years of STA operation. Additionally, a diverse community of *Chara*, southern naiad, and pondweed tends to persist longer than a monoculture of *Chara*. Some SAV species are less tolerant of water depth fluctuations and high nutrient loads than EAV species. High nutrient concentrations can lead to epiphytic growth on SAV communities, creating a shading effect that results in their decline (Phillips et al., 2016).

Temporal shifts in SAV community composition, including seasonal and inter-annual variation, need to be investigated to better understand conditions that inhibit or favor growth. Temporal changes in community composition may indicate declining sustainability and P retention performance. Loss of SAV generally results in reduced P retention. A sudden loss of SAV (particularly *Chara* and hydrilla) typically causes an immediate increase in water column turbidity and nutrient concentration, which often results in temporarily increased phytoplankton productivity. If water column turbidity persists, it inhibits re-establishment of SAV. Such a situation was observed in STA-1W from 2004 to 2006 when entire cells lost their SAV communities and required major rehabilitation to re-grow the vegetation. In some cases, SFWMD vegetation management teams inoculate STA cells with desired SAV species such as spiny naiad (*Najas marina*) and subtypes of *Chara* to expedite their establishment and improve STA cell functionality.

Event-related stressors can affect SAV communities. Increasing water levels and flow are related to increased nutrient load and turbidity, which can affect SAV through light limitation, scouring, poor water quality, and potential die-off. Dryouts, although rare due to drought management operations, can result in desiccation and death of SAV. Wind events, including hurricanes and thunderstorms, can increase turbulence and scouring of SAV as well. Storm assessments have shown that EAV can act as a wind barrier and maintain SAV communities, and the SFWMD's vegetation management group has an EAV-planting program in place.

Other factors not yet studied that may reduce SAV resilience include herbicides, photolytic degradation, and soil characteristics. Herbicides from vegetation management activities may hinder SAV growth. Ultraviolet light can degrade dissolved organics in the water column and produce toxins, including hydrogen peroxide, which may affect SAV growth. Soil characteristics likely are a factor in SAV growth and sustainability. Hydrilla and *Myriophyllum* (watermilfoil), for example, do not grow well in highly organic soils and sands compared with fine-textured inorganic soils (Barko and Smart, 1986).

More detailed and predictive information is needed on SAV community dynamics and associated influences on P cycling. An SAV resilience study is under way to investigate operational (e.g., water depth, flow velocity, nutrient concentration, mineral concentration) and environmental (e.g., seasonality, light penetration, water clarity) conditions that support healthy and diverse SAV communities in the STAs. The study includes the following components: 1) an evaluation of vegetation morphological and life cycle aspects that lead to good or poor SAV health; 2) a comparison of annual biomass and P turnover rates of SAV species; 3) an assessment of the role of soil and water properties, hydrology, and weather on SAV growth cycles; and 4) identification of the most limiting growth factors. The study also will investigate allelopathic effects from *Chara* that inhibit growth of other species. Based on analysis of historical vegetation data and additional data that will be gathered for this study, a more in-depth analysis of the pattern of vegetation cover and species distribution should provide better understanding of SAV loss and resilience, and the factors influencing these patterns. Waterfowl herbivory also plays a role in SAV community structure and sustainability (**Section 3.1.6**).

Sub-Question: EAV Resilience

What key factors affect and what management strategies could improve system resilience of EAV communities?

Factors that may affect system resilience of EAV communities include the following:

- Soil characteristics;
- Community composition, cover, and density;
- Rate of change and duration of water levels;
- Dryout;
- Nutrient loadings;
- EAV planting, rotation, distribution, and abundance; and
- Prescribed burns.

The upstream regions of STA cells are dominated by dense stands of cattail, which typically are very hardy plants with rapid and sustained growth in enriched environments. However, die-backs have occurred in the STAs, reducing the ability of the emergent wetland to reduce P from the water column. While the proximal causes are not well understood, continuous periods of deepwater conditions sometimes are associated with cattail stress and mortality (Chen et al., 2010).

Target stages for STA cells range from 1.25 to 1.50 feet between flow events, based on prior experience in wetlands and observations in the STAs. However, during peak flow events, water depths can increase well above target and remain high for extended periods of time. These factors have been observed to coincide with cattail community decline. Results from earlier studies indicated that 6 weeks of continuous inundation at water depths between 3.0 and 4.5 feet produced multiple signs of stress in cattail communities (Chen et al., 2010, 2013). While these results suggest a threshold of harm, they do not provide a predictive understanding of a threshold for sustainability in EAV communities. In addition, the depth and duration thresholds may differ depending on vegetation composition and health as well as other factors such as soil type and condition.

From 2014 to 2017, the SFWMD conducted a cattail sustainability investigation that included *in situ* monitoring of cattail growth and productivity in STA-1W Cell 2A and STA-3/4 Cell 2A. Results suggested water depth likely was a factor in cattail community decline in one of the study cells, but it is uncertain if other factors (e.g., soil characteristics, presence of floating cattail mats/tussocks, and competitive interactions with FAV) contributed to the decline. A controlled experiment at 15 STA-1W North Test cells (0.5-acre cells) will be conducted to further evaluate the effects of water depth and inundation duration on cattail growth and productivity. Investigations on the role of water depth, flow pulses, and substrate quality in cattail community sustainability will be needed.

In early 2018, a study was initiated to determine the key factors that lead to the formation of floating cattail tussocks in the STAs. The study will characterize and compare conditions between areas of healthy cattail coverage (without signs of floating cattail tussocks) and areas prone to chronic floating tussock formation in the STAs. The study also will examine STA water level ranges that may promote the formation of floating tussocks. The results should increase understanding of the factors that contribute to tussock formation, thereby improving STA operation and management strategies to limit their occurrence.

Prescribed burns may enhance overall STA performance by: 1) improving hydraulic conditions through reduction of excessive biomass obstructing desired flow distribution within a cell; 2) translocating or reducing P by burning excessive biomass in strategic locations within a cell; 3) improving cattail community sustainability; and 4) reducing the depth of accrued soil through drawdown following a prescribed burn. In 1994, a prescribed burn experiment conducted in Cell 3 of the Orlando Easterly Wetland reduced cell biomass by 60 to 70 percent (University of Florida, 2001). An increase in water column nutrient concentrations was observed following the gradual rehydration of the cell, but the water was not discharged until concentrations declined to an acceptable level. A similar result was observed in a prescribed burn experiment in Water Conservation Area 2A (WCA-2A; Miao and Thomas, 2011). If burning is considered for management, detailed chemical and physical modeling will be needed to determine the transport and fate of PP and aerosol P. Phosphorus pentoxide (P_2O_5), generated by oxidation during burning, may re-deposit quickly and is highly biologically available after hydration. While surface burning can cause temporary spikes in water column P, its long-term benefits in controlling P flux need further investigation. Other potential responses to periodic burning such as improved hydraulic efficiency, improved sheetflow, increased long-term nutrient sequestration, and improved plant community health should be evaluated.

Sub-Question: Mixed Vegetation

What are the differences in long-term P reduction between pure SAV communities and mixed SAV/EAV communities?

Information on SAV composition and dynamics may lead to other innovative and important areas of applied STA research involving plant species (e.g., to assess if EAV cover enhances P uptake in SAV cells, to determine the optimal mixture and distribution of EAV and SAV communities).

Vast expanses of SAV beds are highly susceptible to uprooting by wind and high flows. Strips of EAV to compartmentalize SAV cells can buffer the effects of wind and flow events. For instance, STA-3/4 Cell 3B has a high proportion (40 percent) of EAV cover and retained a substantial amount of SAV after Hurricane Irma (SFWMD, 2018a). Introducing other plant species as buffers may be considered, and the relative value of placing vegetation strips in various arrays can be modeled and explored in the field to determine the optimal size and distribution of EAV strips to sustain SAV cover. Also, the utility of rotating SAV and EAV to enhance SAV sustainability, stabilize accrued material, and increase microbial activity needs further study. Understanding the relative effectiveness of SAV versus SAV mixed with EAV in reducing water column P and stabilizing accreted P in the soil would help long-term planning for vegetation landscape design in the STAs.

Sub-Question: Other Vegetation

Can various vegetation types (subtypes) enhance P uptake and removal in SAV cells?

The following species will be considered as part of the Science Plan investigations into P reduction by vegetation:

- Sawgrass (*Cladium jamaicense*)
- Illinois pondweed (*Potamogeton illinoensis*)
- American eelgrass (*Vallisneria americana*)
- American lotus (*Nelumbo lutea*)
- White water lily (*Nymphaea odorata*)
- Yellowpond lily (*Nuphar lutea*)
- Spatterdock (*Nuphar advena* spp. *advena*)
- Fire flag (*Thalia geniculata*)
- Denseflower knotweed (*Persicaria glabra*)
- Bulrush (*Schoenoplectus californicus*)

The oligotrophic Everglades ecosystem is dominated by sawgrass ridges and water lily sloughs. Species that thrive in this very low-nutrient environment have efficient P uptake and accumulation mechanisms and much higher tissue P concentrations relative to the external habitat. These plants retain P for long periods due to slow turnover and decomposition rates (Davis, 1991; Lorenzen et al., 2001; Miao, 2004; Brix et al., 2010; Miao and Zou, 2012).

Less dominant vegetation, such as sawgrass, can be studied at a larger scale to determine optimum hydraulic regimes (water depth and flow rate) for nutrient reduction efficacy. Sawgrass communities established near the STA outflows should achieve lower outflow TP concentrations. Other promising macrophyte species could be tested specifically on how they translocate and store P in the rhizosphere. The species-specific ecologies of native vegetation types are expected to improve P reduction and enhance STA performance, especially near the outflows.

There are other species-specific studies besides those involving Everglades oligotrophic species. Fire flag and denseflower knotweed may be used to increase plant diversity and provide vegetation-based treatment in areas where other dominant plant species do not occur or persist, and to complement P uptake and reduction in emergent cells. Floating-leaved species such as water lilies (e.g., white water lily, yellowpond lily, *Lotus* spp.) also may thrive in areas where dominant plant species do not persist. Field trials can be conducted to determine whether Illinois pondweed and American eelgrass cover should be enhanced to complement dominant SAV species and improve performance by transforming refractory forms of P. The results of species-specific studies can be used to focus and extend investigations involving the structure of SAV communities.

A previous attempt to compare P uptake performance of sawgrass and water lily in a mesocosm was unsuccessful due to complications of experimental design and biases; alternative study platforms (e.g., field exclosures) could provide further understanding on the potential of these vegetation types. A study investigating the benefits rFAV in SAV cells is under way.

Sub-Question: Vegetation P Reduction Capabilities

What are the relative short-term and long-term P reduction capacities of the dominant and other vegetation species in the STAs?

The following vegetation species have been or may be investigated in the STAs under the Science Plan:

- Cattail – EAV
- Fire flag – EAV
- Bulrush – EAV
- Torpedograss (*Panicum repens*) – EAV
- Southern naiad – SAV
- Muskgrass – SAV
- American lotus – FAV
- Spatterdock – FAV
- Sawgrass – EAV
- White water lily – FAV

Aquatic plant species vary in their nutrient uptake mechanisms (e.g., from water column, soils, or both) and nutrient storage capacities. Understanding these differences could help inform decisions on optimal species assemblages. For example, in nutrient-poor regions of wetlands (e.g., the Everglades), plants remove and sequester P, resulting in a tight P cycle and reduced internal loads (Miao, 2004; Miao and Zou, 2012). Investigations will gather information on aquatic plant species and vegetation types that grow in the front region of STA flow-ways and in low-P environments, take up P from the water or soils, and store P efficiently in their tissues, particularly in belowground components. A study is under way to investigate nutrient reduction efficacy and P uptake of rFAV.

3.1.4 Key Question 4

How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the STAs?

P is retained and released from the wetland system via many biogeochemical pathways, including adsorption, desorption, chemical precipitation reactions, uptake by biota, and sediment accretion (Dunn and Reddy, 2005; Reddy et al., 2005; Kadlec, 2006). P retained by each STA cell is distributed into six primary components: 1) water column, 2) soil, 3) vegetation biomass—belowground and aboveground, 4) floc and litter, 5) microbial biomass, and 6) fauna. The distribution of P among these storage components can vary, depending on various biogeochemical factors; however, soil and floc generally contain the highest mass of P. Storage can be short or long term. Storage within the microbial and vegetation biomass as well as detritus is considered short term, while P assimilated into the soil, including organic and mineral matter, is considered long term (Reddy and DeLaune, 2008). Floc and the surface soil layer in wetlands often is enriched as a result of recent accumulation from internal and external inputs, including sedimentation, litter decomposition, and remobilization of P from subsurface layers to the surface through plant uptake and deposition as detrital material (Reddy and DeLaune, 2008). Each of these storages can influence water column P concentrations through internal loading via various mechanisms such as decomposition of organic matter, resuspension, and flux.

Most water column P near the outflow of well-performing STAs is in the form of DOP and/or PP; therefore, processes of mineralization (biological or photolytic), particulate-settling microbial activity, and resuspension/diffusion can influence these concentrations (**Figure 3-1**). Initial findings indicate that some PP could be in the form of phytoplankton or microbes. Any dissolved inorganic phosphorus (DIP) that is released is removed rapidly by periphyton and SAV. Other processes that affect DIP concentrations are adsorption and desorption with mineral surfaces. In general, reduction of DIP and DOP through adsorption onto particulates and the settling and consolidation of particulates into the soil helps reduce water column P concentrations.

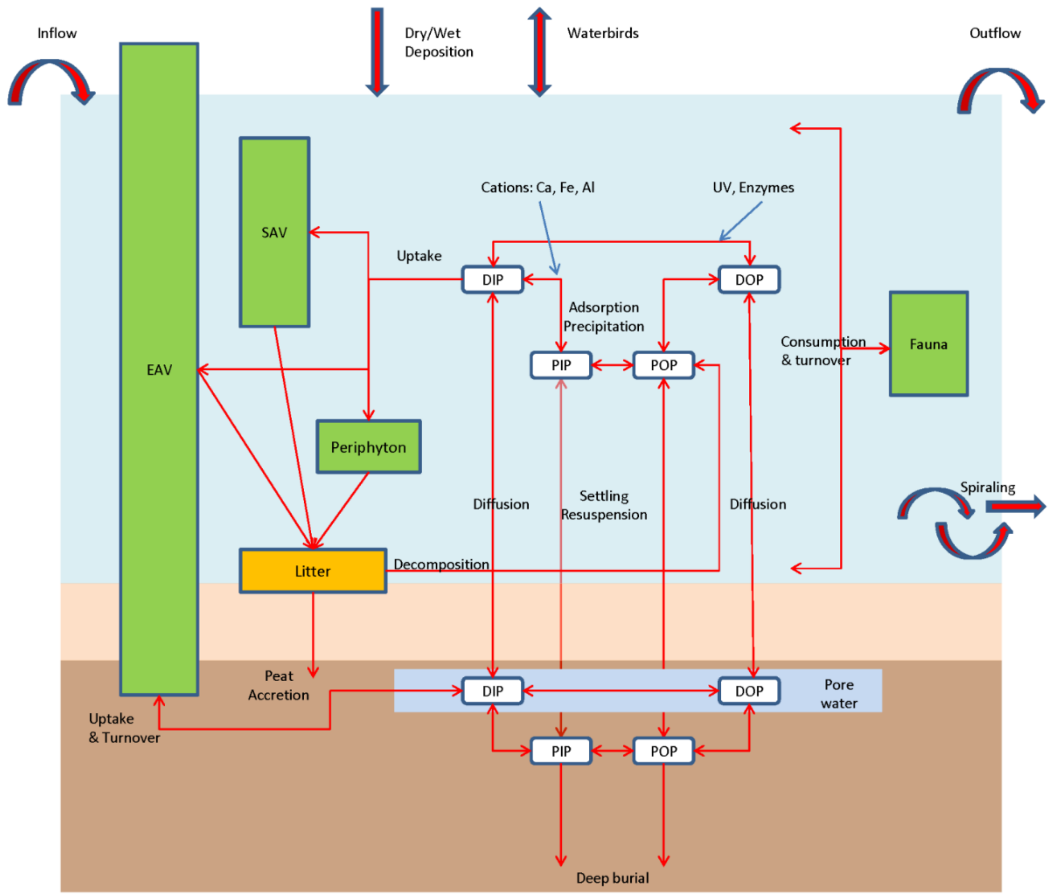


Figure 3-1. Schematic of chemical, physical, and biological processes that can influence changes in P concentrations between the soil and water column.

In properly functioning STAs, TP concentrations decline along the inflow-to-outflow gradient, with the most rapid change in the first third of the flow-way. At some point along the flow-way, typically in the lower SAV cells, the values reach a minimum. Much of the reduction is attributed to particulate settling, uptake of SRP by plants and periphyton, and co-precipitation of P with divalent minerals such as Ca and iron (Fe; **Figure 3-1**). These reduction processes must exceed P release mechanisms (e.g., P flux from the soil to the water column, translocation through the plants, and particulate P flux through sediment resuspension) to achieve net reduction. Where P values no longer change (i.e., no further decline), the processes that remove and release P from/to the water column are assumed to be in dynamic equilibrium.

While the effects of inflow P loading and inflow nutrient concentration on STA performance have been widely studied, very limited information is available on internal loading of P. The contribution of internal loading of P could be significant but is known to vary depending on the location along the flow-way and other biogeochemical factors. Understanding the sources and magnitude of contribution from different components to internal P loading would be useful as a basis to formulate improvement strategies. For example, different management strategies would be needed for increases in water column P due to flux versus increases due to periphyton disintegration or phytoplankton growth. Identifying and quantifying the various forms of P could help determine what factors need to be controlled at various areas along the flow-way (e.g., SRP at the front region and PP in the back region of a flow-way).

Sub-Question: Physicochemical Factors

What are the key physicochemical factors influencing P cycling in very low-P environments?

Key factors influencing P reduction in surface water of wetland systems include the size of the treatment area; vegetation type, coverage, and condition; HLR; PLR; hydraulic retention time; hydraulic efficiency; and soil biogeochemical properties, including redox potential, pH, mineral content (e.g., Fe, Ca, aluminum [Al]), and the soil P concentration (Richardson, 1985; Reddy and DeLaune, 2008; Nungesser and Chimney, 2001). Manipulating some of these factors is key to effective management of the STAs.

Because most P in the water column near the outflows of well-performing STAs is in the form of DOP and/or PP, improved understanding of mineralization (biological or photolytic), particulate settling, microbial activity, and litter and detritus decomposition and resuspension in these areas could help develop management strategies that change the balance of fluxes, reducing TP concentrations in the water column even further. Because some PP in the outflows is attributed to phytoplankton, algal dynamics in the region should be considered. Understanding the solubility of P in the soils, particularly adsorption and desorption with mineral surfaces, may help understand the exchange between the soil and water column. A better understanding of the factors affecting these mechanisms is equally important.

The influence of metallic cations (e.g., Ca, Mg, Fe, Al) has been studied extensively. The role of metallic cations in the STAs, particularly at the very low-P regions, requires further investigation. Ca-related P reduction in an alkaline wetland environment occurs via two pathways: 1) sorption of P onto calcareous soil particles, limestone surfaces, and marl-based detrital material; and 2) co-precipitation with Ca in the water column or porewater (Gumbricht, 1993). Under the right conditions, P will co-precipitate with Ca and Mg in more alkaline systems and with Fe in more acidic systems (Reddy and DeLaune, 2008). The influence of other factors such as redox potential, pH, alkalinity, and sulfate on P cycling under very low-P environments needs to be studied.

The role of microorganisms in the transformation of organic P to inorganic P in the water column and soils is well recognized (Dunn and Reddy, 2005; Reddy et al., 1999). In the water column, organic forms of P generally are divided into: 1) easily decomposable organic forms, and 2) slowly decomposable organic forms, with the most readily available being incorporated into microbial biomass. Reddy et al. (2002) found that approximately 15 to 25 percent of organic P in treatment wetland soils and flocs was microbial. As the life cycle of microbes is short, nutrient turnover is quick and most P uptake likely is returned as labile DOP and PP, leaving only a small fraction permanently buried in the sediments.

Reducing DOP or particulate-bound organic P depends on decomposition or oxidation of organic matter. For P-containing compounds, the byproduct would be inorganic P, which could co-precipitate with minerals, be taken up by microorganisms, or sorb on cationic surfaces such as limerock. The rate of decomposition is influenced by many factors, including redox potential and the nature of organic matter. Photodegradation may be an important factor in P cycling under a very low-P environment. Breakdown of dissolved organic matter can be influenced by light penetrating through the water column (Wetzel, 2002; Sharma et al., 2004). Shallow water, reduced water turbidity, and open areas may induce increased photodegradation. Understanding the role of photodegradation in the STAs may help determine ways to further decrease outflow P concentrations. Current investigations are focused on mineralization processes, microbial enzymatic activity, and photolytic degradation processes. Results will be included in the data integration model development and simulations (**Chapter 4**).

Sub-Question: Operational Changes to Reduce PP and DOP

Are there design or operational changes that can be implemented in the STAs to reduce PP and DOP in the water column?

To identify methods to reduce P in the water column, the forms, storages, and biogeochemical transformations of P in the STAs need to be better understood (**Figure 3-1**). P forms include DIP, PP (inorganic P attached to metallic cations [e.g., Ca, Mg, Fe]), DOP and particle-bound organic P (**Section 3.1.3**). Storages of P in the STAs include the water column, vegetation biomass (aboveground and belowground), phytoplankton, litter (primarily dead SAV and EAV), floc (a mixture of litter and microbial communities), soil, and aquatic fauna (**Section 3.1.6**). Many biogeochemical and physical mechanisms can reduce PP and DOP concentrations in the water column. PP can be reduced through grazing by fauna, incorporation into biological assemblages (e.g., floating periphyton mats), filtering by EAV and SAV, decomposition (mineralization), and sedimentation or settling. DOP can be taken up by periphyton or microbial organisms, and microbial transformation may make this form more readily available for uptake by EAV and SAV, phytoplankton, and bacteria. DOP also can be reduced through photodegradation (Sharma et al., 2004), co-precipitation with minerals, and sorption (e.g., on Fe or Al). Identifying operational or design changes that could facilitate these mechanisms could be beneficial.

Transfer of PP from or to the soil primarily occurs through deposition or resuspension of particulate matter (Reddy et al., 1999). During resuspension of particulates, P can return to the water column and reduce wetland treatment efficiency (Chimney and Pietro, 2006). High flow velocity, storm events, and mechanical disturbance (e.g., occasional harvesting of nuisance vegetation, structure operation, bioturbation) can increase resuspension of particulate matter to the water column. Also, recent findings suggest PP could increase as a result of phytoplankton growth or epiphyton detachment. Identifying the internal sources of PP, quantifying their relative contributions to the TP concentration observed at the outflow, and determining the factors affecting PP changes could provide help to control PP concentrations.

Organic P in aquatic systems can occur in dissolved (DOP) or particulate form and can originate from external or internal sources (e.g., through decomposition of organic matter or flux from floc or soil layers). The DOP fraction is poorly characterized and considered diverse in terms of complexity and lability, ranging from simple organic phosphates such as sugar phosphates to more complex molecules such as phospholipids (Reddy and DeLaune, 2008). DOP usually is measured in water samples that have been passed through a 0.45-micron filter. Particulate-bound organic P typically is associated with detrital matter (e.g., dead and decomposing microbial cells, decomposing biomass from plants and animals, organic material attached to particulates). Transformation of organic P depends on biological activity and is influenced by environmental conditions. Microorganisms play an important role in the mineralization of organic matter and eventual release of P, which can be readily assimilated into microbial biomass. Organic P degradation also can result from abiotic processes, including leaching of soluble organic P from necromass, abiotic hydrolysis of P esters, and photolysis.

Knowledge gaps exist regarding the composition and origin of residual P at STA outflows and the cycling of P, including PP and DOP, as water flows along the STA flow-ways. This information is important to better understand and manage the composition and concentration of P in the STA and distribution canal outflows to meet water quality goals. Particulate matter will be investigated in the next 5 years as part of a few studies. Understanding the cycling, transformations, and transport of organic P along the flow-way is important to reduce residual DOP at STA outflows. Specifically, understanding the sources and release rates of DOP is important. A study to identify and characterize DOP and organic carbon and sources was initiated in the initial 5 years and is expected to continue as part of the next Five-Year Work Plan.

P mineralization is slower under continuous inundation (i.e., flooding) than under oxidized conditions (i.e., dryout). In areas where the soil and accrued material are highly organic, P spikes commonly are observed following dryout periods. This is particularly problematic as the newly accreted P in floc and the surface soil layer in the STAs generally is highly labile, and a large fraction of stored P can be quickly released back into the water column upon rehydration.

The resulting P spike depends on several factors, including the amount of labile organic P in the oxidized soil layer and the microbial and SAV uptake of P. Microbial communities associated with senescing material rapidly assimilate the released P, while excess P can remain in the water column and eventually reach the outflow structures. Due to the higher organic content in accreted material within EAV cells, the effects of dryout/oxidation on P flux generally are greater in these cells (Ivanoff et al., 2013). However, loss of vegetation when an SAV cell dries out also results in P flux and generally high turbidity upon rehydration. After rehydration, the internally generated P can be reabsorbed by the system through sorption, plant and microbial uptake, Ca and Fe binding, and settling. However, when water is discharged shortly after initial rehydration, high P concentrations occur in the flow-way or STA outflow structures. Soil P flux can be accelerated through repeated cycles of dryout and flooding.

Since the completion of the Marsh Dryout Study (White et al., 2004, 2006; Moustafa et al., 2011, 2012), the SFWMD has gained considerable experience with the effects of soil P flux on STA performance during start-up and re-flooding after droughts. Findings from this study, along with operational experience in the STAs, have led to the establishment of minimum water depth targets for the STAs. When water is not available for hydration, maintaining moist soil can minimize P release (Aldous et al., 2005; DeBusk, 2011).

Dryout or brief drawdown periods can benefit EAV through increased new plant growth. Drier condition could stimulate periphyton re-growth and facilitate aggregation of floc and finer soil particles, thereby reducing the potential for resuspension. Field investigations of dryout effects can be undertaken if conditions are appropriate; a flow-way must be taken offline for restoration and/or drought conditions must occur.

3.1.5 Key Question 5

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?

As a result of the gradient between the water column and P-enriched floc and surface soil layers, P can flux from the soil to the water column, elevating water column P concentrations. This process is influenced by various chemical, physical, and biological processes, including diffusion and advection via wind or flow, bioturbation, vegetation-mediated flux, redox conditions, diagenetic processes at surface of sediments, and abiotic and biotic processes in the water column (Reddy and DeLaune, 2008). Greater potential for P flux in enriched soils results from higher equilibrium P concentration values, and greater amounts of labile soil P, and higher P concentration in porewater (McCormick et al., 2002; Reddy and DeLaune, 2008; Wright, 2009; Reddy et al., 2011). If the P concentration in surface water is higher than the mobile P concentration in the soil, then P can be assimilated into the soil. However, if surface water P concentrations are lower than this threshold concentration, P may be released from the soil or sediments**.**

There are limited data describing P flux in the STAs. As part of a 2013 Science Plan study, flux rates were measured in STA-2 Cells 1 and 3, using porewater equilibrators (peepers) and large mesocosms deployed in vegetated and non-vegetated areas along each flow-way. Mescocosm net-flux measurements showed no strong temporal or spatial patterns, although the net loads at the outflow region tended to be smaller. Measurements from porewater equilibrators indicated highest diffusive flux potential near the inflow region of the STA and little to no diffusive flux potential at outflow regions (Villapando and King, 2018). There also were no relationships with short-term antecedent load or soil P conditions, indicating there likely are substantial contributions to net internal fluxes from other soil and/or biotic processes aside from diffusion of soil porewater. Investigations on flux, including factors affecting the observed rates, is continuing as part of the second Five-Year Work Plan. Understanding these factors is critical to formulating recommendations for controlling P flux in the STAs. The STA-3/4 PSTA cell, where muck has been removed, consistently achieved annual outflow concentrations of 13 µg L^{-1} or less, suggesting that removal of flux source at a fraction of a flow-way could be beneficial (Zamorano et al., 2018). Alternatively, the use of soil amendments (e.g., limerock) was investigated as part of another study under the initial Five-Year Work Plan. Soil inversion, which could result in limerock layer at the soil surface, is being investigated as part of the second Five-Year Work Plan.

Sub-Question: Soil Amendment or Soil Management

What is the treatment efficacy, long-term stability, and potential impact of soil amendment management?

The numerous mechanisms and pathways for internal P flux pose a serious challenge to ensuring maximum and sustainable performance of the STAs. Soil management—typically characterized as physical manipulation (soil removal to limestone cap rock, disking, inversion, or capping) or addition of soil amendments—has been used in other areas to reduce P flux. In the Everglades STAs, the benefits of soil removal within a 100-acre PSTA cell in STA-3/4 were evaluated (Zamorano et al., 2018). The annual average discharge concentrations resulting from the study successfully met the WQBEL for 11 years (Water Years 2008 to 2017).

Several studies have tested the efficacy of physical soil manipulation on reducing P concentrations. Removal of the accrued soil layer in STA-1W Cell 1B reduced soil TP concentrations from 1,300 to less than 400 milligrams per kilogram (SFWMD, 2007a). P release (DIP, DOP, and inorganic and organic PP) from the plowed/inverted soils in the littoral zone/nearshore area of Lake Okeechobee was orders of magnitude lower than P release from pre-tilled (undisturbed) soils, although there were no significant ($p > 0.05$) differences in P release from tilled and scraped (topsoil removed) soils (Water and Soil Solutions, LLC, 2009). Muck removal followed by re-vegetation in the front-end cells of the Orlando Easterly Wetland northern flow-way greatly improved the hydraulic performance and P removal effectiveness of the rejuvenated wetland (Wang et al., 2006). Removing the top 30 centimeters of muck from Lake Okeechobee decreased the equilibrium P concentration from 0.03 to 0.01 milligrams per liter, indicating subsurface soils had a greater affinity to retain P. Dredging reduced P flux under oxygenated water column conditions, with P flux in the range of 0.1 to 0.35 milligrams of P per square meter per day (Reddy et al., 2006).

Malecki-Brown et al. (2009) found physical removal of accreted organic soil in combination with alum treatments substantially reduced P flux from a municipal wastewater treatment wetland. Because of the difficulties and costs associated with the removal and disposal of soils from a treatment wetland, alum addition alone may be the most cost-effective and efficient means of sequestering P in aging wetlands experiencing declines of P reduction rates; however, organic soil removal would be a more permanent solution to reducing P flux (Lindstrom and White, 2011).

Many studies have addressed the use of various soil amendments to reduce P flux. The most common soil amendments are Al, Fe, or Ca salts that bind P and effectively reduce water column TP concentrations in several experiments. CH2MHill (2003) tested the ability of three soil amendments (polyaluminum chloride, ferric chloride, and hydrated lime) to reduce P flux from flooded organic soil in a 4-month mesocosm study. None of the amendments completely controlled P flux, but polyaluminum chloride and ferric chloride were more effective than hydrated lime.

Hoge et al. (2003) conducted a field enclosure study involving the application of wastewater treatment residuals (consisting of hydrated lime, gypsum, and alum) to soils, which then were flooded to a depth of 25 centimeters. Data showed alum residuals strongly reduced P flux to the overlying water, but lime and gypsum applications were much less effective. Chimney et al. (2007) reported that broadcasting calcium silicate ($CaSiO_3$) slag on top of soil to create a surface barrier reduced the flux of soil P up to 84 percent compared to an unamended soil control. However, incorporation of the material into the soil was only minimally effective at reducing P release.

Chimney (2015) researched more than 100 soil amendments to control P flux in the STAs. Concerns regarding these amendments include the amount of treatment material necessary to adequately control P flux, length of time the materials will remain effective, and potential toxicity associated with various soil amendments. Therefore, follow-up studies on the role and applicability of soil management will be limited to soil manipulation. A soil inversion study will be conducted in the STA-1W expansion area in January 2019. This study will leverage soil inversion in Cell 7 (to remove copper) and use Cell 8 as a control for comparison.

Sub-Question: Sources, Forms, and Transformation of P

What are the sources, forms, and transformation mechanisms controlling residual P pools within the STAs, and how do they compare to the natural system?

As described in **Section 3.1.4**, P cycling and transformations affect P reduction and the TP measured at outflows. Inorganic forms of P (e.g., SRP) cycle quickly in aquatic ecosystems as they are readily taken up by flora, sorbed with calcareous substrates, or co-precipitated with minerals within an STA. Other P forms (i.e., complex organic P and PP) have longer turnover times and are more resistant to breakdown or are generated as part of the P biogeochemical cycle. In general, when the STAs are performing well, most SRP is rapidly reduced to below detection levels, leaving PP and DOP as the predominant P forms in outflow water. However, there are periods in well-performing STAs (e.g., following stagnant conditions, during high-flow storm events) when higher concentrations of SRP is detected at the outflow structures. It is important to determine if this SRP is being produced near the outflow or is being moved through the STA without substantial cycling. DOP and PP are removed in the STAs and can be produced and recycled in the STAs as well. Information is limited on whether these P forms are present in the effluent because they are stable (refractory), because they are regenerated internally, or a combination of both processes. This is one of the investigations in the Evaluate P Sources, Forms, and Transformation Processes in the STAs study, which is continuing as part of the Five-Year Work Plan. The investigation is being expanded to use biomarkers to track the source(s) of DOP and PP, and further study on periphyton and phytoplankton growth and senescence will be conducted.

Sub-Question: Role of Vegetation in Low-P Environments

What is the role of vegetation in modifying P availability in low-P environments, including the transformation of refractory forms of P?

Vegetation is a major biological mechanism of reducing nutrient concentrations in the STAs. More information on the role and processes associated with various vegetation types is provided in **Section 3.1.3**. Understanding and quantifying these mechanisms, particularly in low-P environments, is critical to optimize P reduction. Earlier studies in the STAs and similar systems evaluated the effects of various types of aquatic vegetation on P availability. The effects could be direct (P uptake) or indirect (e.g., increased pH due to photosynthetic activity, which facilitates co-precipitation of P with Ca). *In situ* chamber results suggested P flux is reduced when EAV or SAV is present (Villapando and King, 2018). Previous mesocosm studies showed the presence of SAV in limerock cap experiments resulted in higher P concentrations in the water column compared to mesocoms without SAV, suggesting SAV's role in mining P from the soil layer (DB Environmental, Inc., 2018). Comparison of areas in the STAs dominated by rFAV or SAV showed higher TP concentrations in the rFAV regions, suggesting translocation from the plant roots to the water column or shading resulting in less biomass of SAV and periphyton uptake, which allows for increased P flux from the soil into the water column (DB Environmental, Inc., 2017).

Reddy et al. (1999) indicated that aboveground plant biomass returns P to the water after dieback via leaching and decomposition, and deposits refractory residuals on the soil surface as well as redistributing nutrients to belowground portions, as necessary for storage. However, dead roots and rhizomes decompose belowground, thereby adding refractory compounds to the soil and leachates to the porewater. As such, the aboveground portion of the macrophyte cycle returns P to the water, while the belowground biomass returns P to the soil. Decay and translocation processes release most P to the water column, with the residual accreting as new soil. DeBusk et al. (2004) indicated that low water velocities and dense stands of SAV and EAV facilitate settling of PP. Macrophyte uptake and translocation can be an important mechanism linking soil and water column TP concentrations in marsh ecosystems—this process is known as P mining (Noe and Childers, 2007). However, this upward transfer is countered by two opposing processes: 1) the transpiration flux, or downward movement of water and associated P, resulting from plant transpiration; and 2) translocation of P from senescing leaves to the rhizomes (Kadlec and Wallace, 2009). Because of the competing processes among plant uptake, detrital decomposition, and transpiration flux in the root zone, a vertically decreasing concentration of soil TP and porewater P in the soil profile may exist (Kadlec and Wallace, 2009). SAV decomposition, particularly during low-water conditions, may be responsible for the high flux of PP and SRP. Additional information is needed on the generation and breakdown of DOP in the STAs, particularly near outflows.

A benthic periphyton community can obtain nutrients directly from the water column or via diffusion from the soil. Therefore, benthic periphyton communities influence the net exchange of nutrients across the soil-water interface (Hansson, 1989; Newman et al., 2004). Periphyton reduces P concentrations in the water column through several mechanisms, including direct uptake and storage as cellular organic P, metal-phosphate deposition, co-precipitation with Ca and Mg, and adsorption to inorganic compounds such as calcium carbonate (Hagerthey et al., 2011). Periphyton is closely involved in wetland biogeochemical cycling, which allows for long-term storage of nutrients in soils. Periphyton assemblages can play several roles that increase retention of nutrients, including removing nutrients from the water column; slowing water exchange across the soil-water interface, thereby decreasing advective transport of P away from soils; intercepting P diffusing from soils or senescent macrophytes that cause biochemical conditions that favor P deposition; and trapping particulate material from the water column (Dodds, 2003). Obtaining additional information on periphyton, particularly their role in long-term P storage, is important to improve STA performance.

Investigations on the role of vegetation in P cycling in low-P environments will continue. Translocation and periphyton uptake will be evaluated separately in two planned studies; the first on vertical advection and the second to quantify uptake and release of P by periphyton. Additional studies to better understand the nature of organic carbon and P forms in low P environments of the STAs are under way.

Sub-Question: Water Level Drawdown

Do water level drawdowns improve soil consolidation and compaction?

Within the STAs, accreted soils in EAV-dominated cells are highly organic, while accreted soils in SAV-dominated cells are primarily amorphous marl. Many EAV cells experience low-water conditions during the winter, with some cells experiencing dryout. As a vegetation management strategy, SAV cells generally are kept hydrated when water is available. Drawdowns have been conducted in selected cells for vegetation rehabilitation purposes. In STA-1W, cells were dried out to accommodate major rehabilitation work, including earthwork. Very little information is available regarding the effects of water level drawdown on physical and chemical characteristics of soil. Any investigation related to drawdown would involve taking a flow-way offline. An opportunistic study could be developed to evaluate soil compaction after drawdowns due to construction, drought, or vegetation re-establishment. Consolidation and aggregation presumably would result in a more stable rooting zone that is less susceptible to disturbance through hydrodynamics and bioturbation. Although P flux from the soil may increase during the initial re-flooding, studies should investigate the long-term benefits such as soil consolidation and improved P reduction performance.

3.1.6 Key Question 6

What is the influence of wildlife and fisheries on the reduction of P in the STAs?

The role of wildlife and fisheries in P cycling and reduction in the STAs has not been investigated prior to implementation of the 2013 Science Plan. P interactions between fauna and the water column in STAs are relatively complex (**Figure 3-2**). For treatment wetlands, Kadlec and Wallace (2009) emphasized that birds and other grazing animals are important components of the P cycle through feeding and excretion and through transporting P during daily and seasonal movements. Kadlec and Wallace (2009) indicated fecal production rates by bird flocks in treatment wetlands "may influence the ability of treatment wetlands to achieve ultra-low P concentrations but will not affect treatment at the secondary or primary level." Frederick and Powell (1994) estimated that even the reduced number of birds present in the Everglades during their study could produce sizeable P loading in colony locations, and the loads could be many times greater than P inputs from the atmosphere. Like Kadlec and Wallace (2009), they qualified these high numbers by noting that birds are not important agents of P loading at the scale of the entire Everglades.

Overall, these examples are conservative when viewed in the context of biologically productive STAs because they only considered bird effects on P cycling. Recent surveys of the STAs documented large flocks of American Coots (*Fulica americana*) and wading birds that use the SAV cells at certain times of the year. In addition, large numbers of fish nests (tilapia) were observed in these areas. Based on the density of these fish, they can have a notable effect on the internal P cycling of this region. As reviewed by Vanni (2002), birds, fish, and macro-crustaceans (e.g., crayfish, grass shrimp) can alter several pathways leading to higher or lower TP concentrations in the water column of aquatic ecosystems (**Figure 3-2**). The investigation of fauna is being expanded as part of the second Five-Year Work Plan (**Appendix A**).

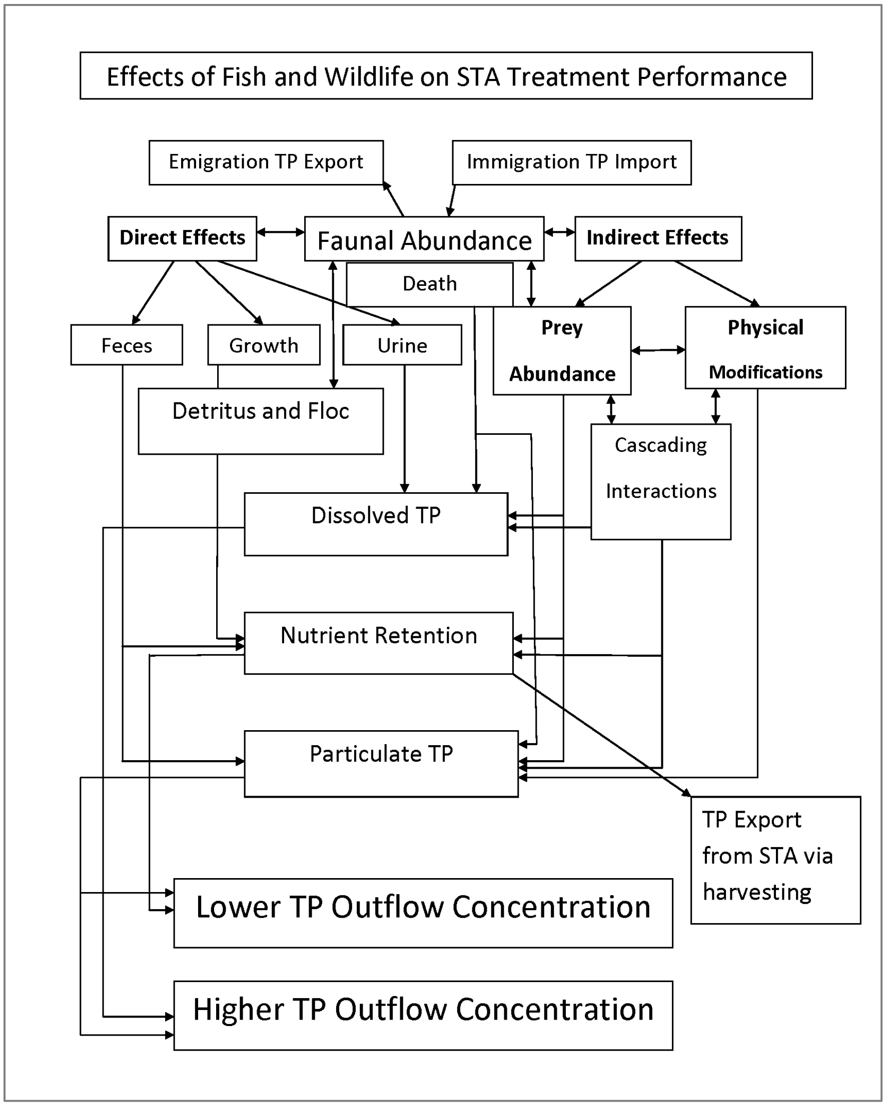


Figure 3-2. Conceptual diagram of interactions between fauna and STA performance and outflow P concentrations (Modified from: Vanni, 2002).

Sub-Question: Wildlife Effects

What are direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (i.e., are they net sinks or sources)?

In STA cells near outflows, fauna could be major factors in outflow TP levels when concentrations are very low. The STAs host many animal consumers, most conspicuously avifauna and alligators (*Alligator mississippiensis*). STAs attract many species of migratory birds, which arrive in large numbers and stay for months at a time during fall and winter (Gawlik and Beck, 2010). At the scale of an entire STA, it is unknown whether wildlife interactions will noticeably affect outflow TP concentrations, though they locally influence water column P dynamics. Gawlik and Beck (2010) placed such observations in perspective. They found bird densities in the STAs to be 35 times greater than that found in marshes of WCA-3A averaged over the entire year, but 50 to 120 times greater during fall and winter. Wetland fishes also contribute substantial internal P loading and support high algal growth rates through strong bottom-up influences (Zimmer et al., 2006). Fish can initiate cascading trophic interactions across wetlands like the STAs. Direct and indirect effects (**Figure 3-2**) associated with faunal predation, grazing, and physical modification of the environment are worthy of further study as they cascade through the marshes near STA outflows and could alter outflow TP concentrations. The current faunal study will evaluate this sub-question and associated questions using field surveys and mesocosm experiments.

Based on **Figure 3-2**, this question will focus on the following variables:

- Effects of fish and wildlife on cycling of P and other nutrients within the system;
- Primary diets of waterfowl and submerged aquatic wildlife in the STAs;
- Rates of TP cycling from wildlife, fish, macro-crustaceans, and insects in the STAs;
- Contribution of faunal recycling to ambient P turnover;
- Form and availability of excreted TP for the dominant faunal components;
- Effect of SAV (e.g., hydrilla) grazing on STA functionality; and
- Effects of herbivory on SAV growth, health, biomass, and TP retention.

Birds

Many avian surveys show the STAs support a relatively diverse and abundant community of birds (Chimney and Gawlik, 2007; Gawlik and Beck, 2010; Evans et al., 2018). More than 200 bird species have been identified in STA-5 (currently a part of STA-5/6) alone (eBird, 2012), and the STAs support more than twice the density of birds in the EAA. Many bird species forage on SAV (e.g., hydrilla), and approximately 90 percent of birds within the STAs are found in the SAV cells. By the time spring migration occurs, SAV biomass often is greatly reduced; however, the extent to which this loss is due to herbivory by waterfowl or other animals (e.g., large fishes) is unknown.

Fish-eating birds, especially wading birds (e.g., herons, ibises, storks), are common in the STAs. Breeding wading birds are potential net exporters of TP from the STAs. Wading birds transfer TP from aquatic habitats to terrestrial breeding colonies and roost sites, largely through feeding their offspring aquatic prey animals and through defecation. The export, import, and recycling of feces may play an important role in P dynamics and STA outflow P concentrations. Initial observations and examples from literature (e.g., Post et al., 1998; Sekercioglu, 2006) provide strong justification to gather more definitive information regarding avifauna influences on STA performance and TP export or import.

Birds protected by the Migratory Bird Treaty Act or the Endangered Species Act, such as Black-necked Stilts (*Himantopus mexicanus*), establish a direct link between avian presence in the STAs and operational limitations that can influence STA performance. These birds have nested on the ground within drying portions of STA cells. Operational measures implemented to minimize the flooding of nests as part of the Avian Protection Plan (Pandion Systems, Inc. 2008) could affect the overall functionality of the treatment wetlands.

Fish

The STAs provide excellent habitat conditions for an abundant and diverse fish community. Evans et al. (2018) documented 21 species of small fishes (<8 centimeters standard length) in STA-2, and 19 to 20 species of large-bodied fishes (≥8 centimeters standard length) in STA-2, STA-1E, and STA-1W. Mean small-fish density (± standard error) ranged from 25.4 ± 3.6 to 42.4 ± 5.0 individuals per square meter, depending on the season. These densities were 2.3 to 11.3 times higher than those observed in other regions of the Everglades during similar times. The mean catch-per-unit-effort of large-bodied fishes in STA-1W and STA-1E were significantly greater ($p < 0.05$) than those from the Everglades. STA fish are larger and have higher P body content than fish found in the unenriched marshes of the Everglades. The high density of fishes in the STAs suggests they could have substantial effects on water column P and nitrogen concentrations via bioturbation (Zimmer et al., 2001, 2006), excretion (Zimmer et al., 2006), grazing, and predation.

Alligators

Alligators are abundant in the STAs, but there have been no quantitative studies of their abundance or their effect on STA performance. Their body mass (approximately 50 kilograms) is huge relative to other organisms in the STAs. When concentrated near outflows, alligators could affect P recycling, and their role in physical disturbance of the soils could influence water column P concentrations substantially. As a result, when working toward very low outflow P concentrations, information on direct and indirect effects of alligators on water column P concentrations would be valuable, particularly near outflows. However, these large animals store more P in their body tissues than smaller animals, and because they are long-lived (beyond 50 years), they might function as a nutrient sink. Understanding the role of alligators in the P mass balance in the STAs would help guide future studies and management strategies.

Invertebrates

The STAs, as eutrophic to mesotrophic wetlands, provide the food and habitat resources needed to support relatively high densities of macroinvertebrates. Initial surveys indicate high densities of macroinvertebrates and high species richness, which could lead to notable interactions as consumers and recyclers of P.

Sub-Question: Wildlife Management

What options are there for mitigating or reducing the impacts of fish and wildlife on STA performance through wildlife management or changes in operations?

Faunal consumers can cause top-down (i.e., predation, herbivory) and bottom-up (i.e., excretion) interactions. Disentangling the consequences of community-level interactions occurring simultaneously in an STA would be difficult, but studies support working in that direction (Wetzel et al., 2005). Overall, the challenge is to decide what ecological interactions may be important and conduct the studies necessary to make decisions on potential management and operational means to lower outflow P concentrations through cascading biological interactions. When birds like Caspian Terns (*Hydroprogne caspia*), Black Skimmers (*Rynchops niger*), or White Pelicans (*Pelecanus erythrorhynchos*) gather in specific areas, they may generate nutrient hotspots. Near outflows, such nutrient hotspots could substantially increase TP concentrations, at least for part of the water year (e.g., waterfowl grazing and defecation plus reduction of SAV surface area for periphyton). Quantitative estimates of faunal densities and interactions are needed to ascertain if the hotspots are TP sources or sinks in the STAs. Reliable wildlife information is valuable for monitoring ecosystem performance as well as encouraging public understanding and support for the STAs and Everglades management (Gawlik, 2005).

Landscape-level approaches within and outside the STAs could be considered as part of future management options. There is relevant literature on the intersection of population, community, and ecosystem science involving landscape dynamics, natural or man-made, and ecosystem responses. Concepts from these studies can be pursued in the STAs. For example, selective clearing in an STA could change species distributions and abundance to favor lower TP concentrations. Reshaping internal canals and creating transecting channels may allow modification of fish predation patterns and cascading interactions with P recycling and retention. Altering landscapes outside the STAs may attract waterfowl away from the STAs (daily or seasonally) and thereby alter the P mass balance.

3.2 OTHER AREAS OF INVESTIGATION

Aside from the research studies discussed earlier, other investigation efforts have been underway that support the studies herein: 1) water and P budget improvements, and 2) evaluation of water quality sampling methods. The first two areas of investigation are meant to improve the accuracy and precision of budgets and water quality data. The improved data will support modeling efforts to better understand STA performance.

3.2.1 STA Water and P Budget Improvements

An accurate water budget for an STA (or individual cell) is necessary to develop a P budget and understand P treatment performance. Water budgets for the STAs include inflows from structures, rainfall, and seepage in as well as outflows from structure discharge, seepage out, and evapotranspiration (ET). To complete the water budget, changes in storage and residual (error) must be determined. The STA Water Budget Tool is used to compute water budgets for entire STAs and individual STA cells. Water budgets can be computed on a daily, monthly, seasonal, annual, or multiyear basis. For STA water budget calculations, inflow, outflow, ET, rainfall, and stage data are obtained from the District's hydrometeorologic database (DBHYDRO), and seepage through levees is estimated with seepage coefficients and water level differences. Water control structure flows are the largest component of STA water budgets, accounting for approximately 70 to 80 percent of the annual water budget during an average year, while rainfall and ET are 10 and 12 percent, respectively (Abtew et al., 2016). In dry years, especially during droughts when inflow and outflow structures typically are closed, seepage, ET, and rainfall account for larger percentages. Water budgets for entire STAs are developed using the inflow and outflow structures referenced in the operating permits, known as the compliance monitoring sites. Flow estimates for the compliance monitoring sites are maintained in Preferred DBKEYs, which are subject to the highest level of quality assurance (QA) that can be provided by SFWMD data management staff. While most STA inflow and outflow structures have Preferred DBKEYs, this is not the case for most of the internal structures.

Annual water budgets for each STA typically have less than a 10 percent error, whereas individual cell water budget errors can be much larger (40 to 50 percent; Abtew et al., 2013). The primary sources of error are estimates of structure inflows and outflows as well as seepage. Flow-way or cell water budgets can have large error terms because flow-way inflow and outflow structures and cell-to-cell structures typically are culverts, which are difficult to estimate for flow, particularly when operating under the low head difference conditions prevalent in the STAs. When the head differential between upstream and downstream sections of a water control structure is very small (typically less than 0.05 feet), the discharge estimate is highly sensitive to errors in headwater and tailwater elevations. In such cases, small errors in elevations result in large errors in estimated discharges. Unfortunately, by design, the STA culverts typically operate under a low head difference regime, and these head differences are less than the headwater and tailwater stage sensors resolution (approximately 0.03 feet).

Improvements to structure flow data (in particular, internal culverts that operate under low head differences) are being prioritized, taking into account resource availability and the needs of the Science Plan studies. In some cases, further improvements in cell water budgets may require structural retrofits, operational changes, enhanced monitoring, equipment installation, field investigation (e.g., surveying), as well as development and maintenance of additional DBKEYs as needed and as resources permit. To improve STA water budgets, errors in all water budget components should be reduced to the maximum extent practicable.

Seepage often is the largest unquantifiable term in the water budget. While it can be estimated, seepage frequently is co-mingled with the error term. Modeling tools exist for estimating seepage flows (e.g., SEEP2D seepage analysis program) associated with STA cells. For STA cells with large error terms in the water budget, in addition to making all possible improvements to the other water budget terms, the seepage estimates should be evaluated for potential improvement using appropriate methods and tools. In some cases, it may be necessary to collect field data to more accurately characterize the seepage component of some STA cells. Because installation of seepage monitoring facilities (e.g., wells with monitoring equipment) can be expensive and time-consuming, such efforts need to be further evaluated in relation to the Science Plan's goals.

The rainfall component of STA water budgets is estimated from rain gauges in the STA or the nearest gauge in the surrounding area. Raindar (NEXRAD rainfall) is an areal, radar-based rainfall estimate adjusted with point-based gauge observations. Raindar data can be used to fill gaps in rain gauge data, replace irregular observations, or develop better areal estimates of rainfall. Huebner et al. (2007) showed that NEXRAD rainfall estimates were consistent with rainfall measurements at one or two points, and provided better spatial resolution to provide more accurate rainfall estimates over the STAs.

ET is one of the better quantified components in the STA water budgets. The model for ET computation was developed from lysimeter experiments associated with the Everglades Nutrient Removal Project (Abtew and Obeysekera, 1995). This model has been published in many peer-reviewed journals and books and is applied in several countries (Abtew and Melesse, 2013). ET data for the STAs are derived from a model that uses input data from the closest weather station. DBHYDRO contains data for potential ET.

A test case water budget improvement was performed in STA-3/4 Cells 3A and 3B (Polatel et al., 2014). Annual water budgets for the two cells were greatly improved with revised flow data for the mid-levee culverts; residuals were reduced from as high as 100 percent to 8 percent or lower. 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 using weighted average flow-way inflows and outflows (instead of flow data at cell inflow and outflow structures).

Building on the results of the test case, more detailed flow data improvement methods were used for selected treatment cells in STA-2 and STA-3/4 to generate improved period of record water and P budgets. Period of record water and P budget analysis was completed for STA-2 Flow-ways 1, 2, and 3, and a summary is included in Appendix 5C-6 of the 2018 SFER (Zhao and Piccone, 2018a). A period of record water and P budget analysis is being conducted for STA-3/4 (all cells), and the results will be included in the 2019 SFER. Additional water and P budget analyses are planned for other cells and flow-ways, including those that would be needed for new studies planned for 2018-2023 implementation.

3.2.2 Evaluation of Water Quality Sampling Methods

STA performance and compliance calculations are based on flow and TP concentration data collected at inflow and outflow structures. Water quality measurements generally are collected using 1) grab samples, which are singular collections of water from a specified location, depth, and time; and 2) flow-proportional composite samples, in which a programmable pump collects a series of samples from the same specified location and depth, but with multiple events over time that have been initiated by defined and measured flow volumes. A third measurement of TP, time-proportional composite samples, is a variation on the composite when flow data are not available. With this monitoring, a programmable pump collects a series of samples from the same specified location and depth, but with multiple events over time that have been initiated by a defined periodicity. Using these data in combination with structure flows allows for the calculation of TP flow-weighted mean concentrations to determine STA performance and WQBEL compliance.

Major differences in grab and composite samples can be found in many of the data sets. Often, composite data show higher TP concentrations than grab samples for the same sampling period (MSA, 2008). Grab samples are comparable to several daily composited samples but not to a smaller subset of composites, which deviate from the others due to strong flows, accumulation of debris, and equipment problems. Grab sample collection typically avoids debris accumulations, which are not considered representative of the water body as a whole. Thus, the observed differences between grab and composite samples may be explained by brief, localized events that affect the composite results. Further analyses of annual flow-weighted means of STA discharge data, comparing composite and grab sample data sets, showed relatively small differences over long-term (annual) averages, usually of less than 2 $\mu g\ L^{-1}$, always in favor of the autosampler. This suggests that while the autosampler results tend to be slightly higher, differences are very small; therefore, further study is not recommended at this time.

4. INTEGRAL ROLE OF MODELING

Modeling tools are an integral part of the Science Plan, particularly for project planning and data synthesis. For planning purposes, a model can be used to determine: 1) what is known (e.g., the information incorporated into the model), 2) what is not known (e.g., the gaps and uncertainties, equation values needed for the model framework), and 3) what should be known (e.g., the effect of changing specific equation values on the change in outflow discharge TP).

Models have been and will be used to

- support development of study designs, including determining monitoring/measurement needs;
- evaluate and analyze existing data for information or knowledge;
- test hypotheses as an inexpensive way to scale the scope of experiments;
- isolate processes and explore scenarios that cannot be cost-effectively tested in field experiments;
- facilitate rapid assessment of alternatives; and
- optimize flow distribution among STA flow paths to maximize P reduction.

4.1 STRATEGY FOR MODEL APPLICATION

As with much of the Science Plan, the strategy for model application will evolve over time as needs change and new information is gathered. Currently, the major questions have been defined and most studies have been identified. Modeling tools and strategies are being developed to address research questions.

The general steps of model application for the studies include the following:

- Identify specific problems, questions, and hypotheses;
- Develop a conceptual model;
- Select modeling or analysis tools;
- Design the study and identify specific scopes to acquire data;
- Gather information needed to build and implement models;
- Apply information to selected models, including parameterization, calibration, and validation/verification; and
- Apply the model to explore identified problems, questions, and hypotheses with respect to STA performance.

Each study plan may incorporate a modeling and analysis section or integrate the modeling and analysis in the description of the study design. Data integration and synthesis are expected to span to multiple studies and other available STA information to best address problems, specific questions, and hypotheses. Each study in the 2018 Science Plan will be assessed for its analysis needs, related data, and opportunities to leverage the study configuration and data collection to model all or parts of the chemical/physical processes in the STA.

The proposed strategy will leverage available tools and develop, implement, and apply new tools as needed. The tools applied in the Science Plan are expected to range from simple analytical models to complex, physically based numerical models covering multiple disciplines, including hydraulics and hydrology, water quality, and ecology. Overall, the objective is to properly match the tool and complexity to the analysis necessary to address the identified issue or question. Opportunities to consolidate tools and knowledge gained from each implementation in a systemwide analysis and prediction tool will be explored. To date, established models have played a key role in the Restoration Strategies Program (**Table 4-1**).

Hydraulic and hydrologic models have been used to quantify flows and system responses to varying climate, operations, and management options. Simple and moderately complex water quality models and hydrodynamic models have been used to evaluate STA performance resulting from various hydrologic regimes and management options. For the 2018 Science Plan, the existing suite of tools, as well as other tools necessary to achieve specific defined modeling objectives, will be employed, as applicable, to each study design (**Appendix A**). Data integration frameworks are being developed and tested from top-down (highly integrated and simple) and bottom-up (detailed and process oriented) approaches within the Data Analysis, Integration, and Synthesis Plan (SFWMD et al., 2018). The modeling strategies will be revisited periodically and may evolve as new information is generated.

Table 4-1. Models used in support of the Restoration Strategies Science Plan.

Model Name	Description	Reference
RSM-BN	Regional Simulation Model (Basin). A hydraulic model that determines basin runoff and flow. Used for development and design of STAs and FEBs.	SFWMD (2005a,b)
RSM (TVDLF)	Regional Simulation Model (total variation diminishing Lax-Friedrichs). A 2-dimensional simulation model that evaluates the flow patterns within STA cells. Used to develop tools to manage flows through structures and to estimate water levels in near real time.	Lal (2017)
iModel	Inverse Model. An optimization tool that can be used to inform decision-making for FEBs/STAs by approximating potential TP outflow under alternative operational flow routing regimes.	Ali (2018)
DMSTA	Dynamic Model for Everglades Stormwater Treatment Areas. A mass balance model of P storage and cycling in STAs. Used for design of STAs.	Walker and Kadlec (2011)
LP-WEM	Low Phosphorus Wetland Model. A simple model that simulates low-P conditions within an STA flow-way. Used to evaluate P concentrations and flow along the hydrologic gradient of the STA.	Juston (2017)
STA Spiraling Concept Model	A moderately complex model that incorporates P dynamics along the STA flow-way, including short-term and long-term P release and uptake within the soil, vegetation, microbial, and water components. Currently in development to assist the Data Analysis, Integration, and Synthesis Plan data integration plan (SFWMD et al., 2018).	University of Florida (2018)

4.2 DATA INTEGRATION AND SYNTHESIS PLAN

Integral to modeling efforts is the incorporation of data collected since the inception of the first STA in 1994 and more recently with implementation of the 2013 Science Plan studies. Data collected from these studies include: 1) hydraulics and hydrology; 2) water chemistry; 3) soil, floc, and litter chemistry; 4) soil and litter biogeochemistry; 5) particle dynamics; 6) microbial characteristics; and 7) fauna. An effective integration and synthesis framework is necessary to process and analyze the vast amount of data collected from the studies, along with historical data and observations. The Data Integration and Synthesis Plan will examine and interpret trends, relationships, and causation; connect research findings to STA management and operational strategies; and identify additional information gaps and uncertainties.

Integration framework and modeling tools were created under the P cycling study (one of the studies conducted in the initial 5 years) to synthesize and analyze data from the P cycling study, STA-3/4 PSTA study, and relevant historical data. Conceptual models have been developed to represent bottom-up and top-down approaches (**Figures 3-3** and **3-4**). The bottom-up approach will incorporate data related to spatial spiraling and temporal cycling within the water column, floc, and soil layers. This approach can be used to explore findings and patterns observed through the top-down approach. The top-down approach uses data-mining techniques and focuses on developing and discovering relationships using statistical models and time-series analysis, where the discovery process is guided by a simple conceptual model framework that can be increased in detail as observations and analysis develop. The top-down approach and mining/exploration of existing data helps identify gaps in the conceptual frameworks, which are important tools for data analysis, operations, and management. Development and enhancement of these frameworks and tools will continue over the next 5 years of implementation and will be enhanced as additional data are collected from other studies.

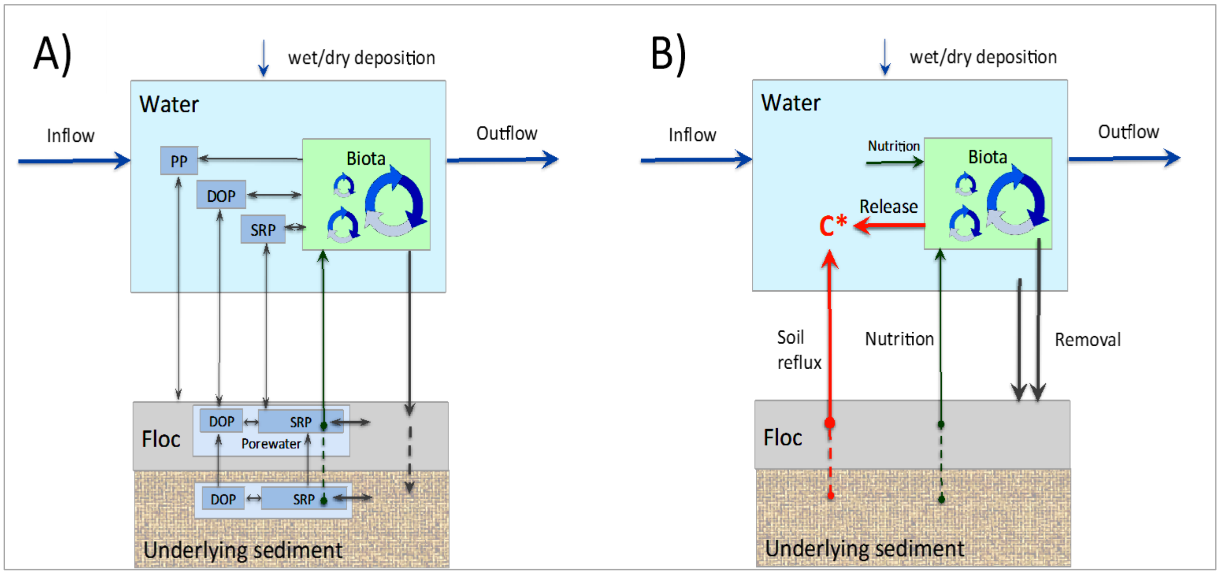


Figure 3-3. Aggregated (A) and highly aggregated (B) conceptual diagrams of P cycling in STA systems. Lowest achievable TP concentrations from the STAs (C*) likely are limited by internal loading from soil (e.g., diffusive fluxes, storages; indicated in red) and biotic sources (e.g., SAV biomass turnover, phytoplankton production; indicated in green). The soil matrix is shown partitioned into upper and lower layers.

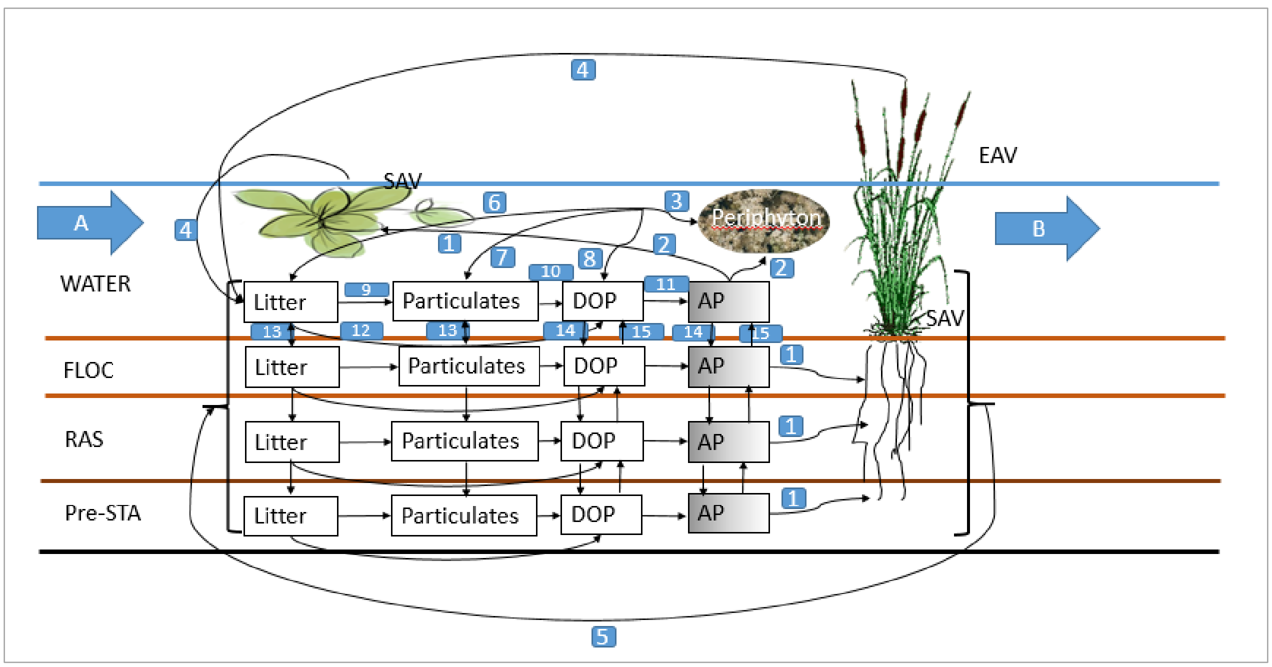


Figure 3-4. Conceptual model with state variables and fluxes to be incorporated into a numerical framework. The figure depicts a length segment within an STA cell. The state variables are operating in four domains: water, floc, recently accreted soil (RAS), and pre-STA soil.

Note: Thick arrows (A, B) – upstream and downstream P at a specific flow-way segment, respectively; thin arrows – P transformations. Numbers for respective fluxes: 1) uptake of available P (AP) by vegetation; 2) periphyton P uptake from the water domain; 3) incorporation of plant and other organic materials into periphyton; 4) litter fall and plant mortality; 5) root mortality; 6, 7, 8) disintegration of periphyton; 9) litter fragmentation; 10) decomposition of organic matter; 11) mineralization of organic matter; 12) leaching from litter; 13) sedimentation and resuspension of litter and particulate (fragmented) organic matter; 14) integration of available P into floc, recently accreted soil, and pre-STA soil domains via evaporation pumping; and 15) diffusion of AP across domains. The gradient fill for AP includes the partitioning of DIP into sorbed and desorbed species, where the sorption potential changes across domain

4.3 STANDARDS AND BEST PRACTICES

The SFWMD requires that modeling work implemented by staff, consultants, or others as part of this 2018 Science Plan follow industry best practices appropriate for the scale and complexity of the model. The Methodology for Model Implementation and Application (SFWMD, 2010) describes the SFWMD's recommended modeling best practices and provides guidelines for consideration. ASTM International (formerly known as the American Society for Testing and Materials) also publishes modeling standards and best practices. Modeling implemented under the Science Plan is anticipated to incorporate stages of the modeling life cycle, including conceptualization and design, scoping and tool selection, implementation, documentation, peer review, and archiving.

5. ADAPTIVE MANAGEMENT

The implementation of this 2018 Science Plan follows an adaptive management approach to allow the Restoration Strategies Program and associated efforts to move forward, even with uncertainty, by ensuring actions are evaluated against goals and objectives and altered to optimize outcomes, as necessary. Additionally, operation and management of the STAs continue during the process of Science Plan implementation, and any new information is considered, in terms of research focus and in implementing any immediate recommendations in managing or operating the STAs. Despite extensive data collection and previous research in the STAs, operational and ecological uncertainties remain regarding optimizing and sustaining desired performance. In some cases, there is sufficient scientific information to move forward with recommendations that will help meet the goals and objectives of the Restoration Strategies Program (e.g., attenuating peak stormwater flows by using FEBs to optimize P reduction). In other cases, available information is not sufficient to formulate recommendations on the design, operation, or management of the STAs (e.g., reducing tussock formation, sustaining healthy SAV communities). A robust and strategic STA science program will help reduce uncertainties and lead to scientifically based decisions.

5.1 DEFINING ADAPTIVE MANAGEMENT

Adaptive management is a cycle of investigation, action, evaluation, and adjustment that links science and actions (**Figure 5-1**). It allows for scientifically robust, iterative decision-making in the face of uncertainty that involves evaluating results of actions and adjusting actions based on increased knowledge, with the objective to improve STA performance over time. Adaptive management is used to manage a system while learning about the system (Walters and Holling, 1990). Because adaptive management is based on a learning process, it improves long-term management outcomes. The challenge of the adaptive management approach is to find the balance between investigation to improve future management and using current knowledge to manage for the best short-term outcome.

The following paragraph, presented by the National Research Council (2004), provides the conceptual basis for adaptive management used in developing the U.S. Army Corps of Engineers technical guide (U.S. Army Corps of Engineers and SFWMD, 2011):

> *Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits.*

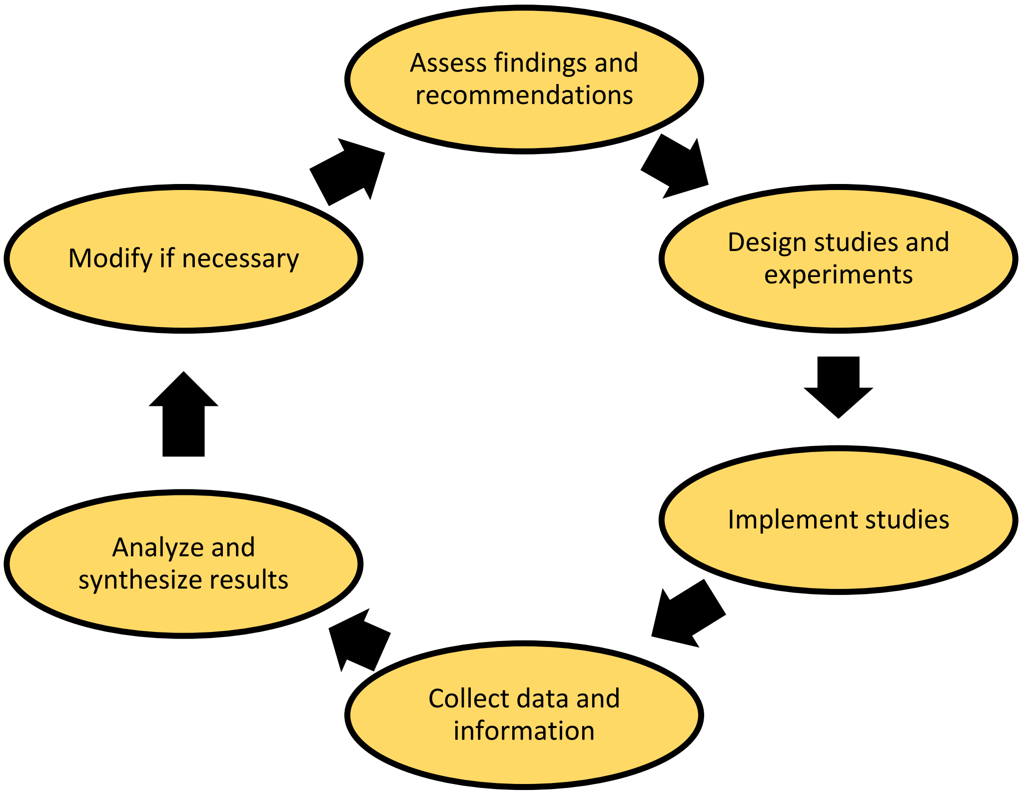


Figure 5-1. Key elements of the step-wise adaptive management process as it applies to the Science Plan implementation.

5.2 APPLYING ADAPTIVE MANAGEMENT TO SCIENCE PLAN

Adaptive management is used to plan, design, and implement science/research projects; identify uncertainties; facilitate progress; and communicate findings to management and stakeholders. The adaptive management process incorporates robustness and flexibility into program/project planning and implementation, and by testing hypotheses, links science to decision-making and adjusts implementation, as necessary, to achieve the Science Plan objectives.

Adaptive management during implementation of the Restoration Strategies Program includes the following steps:

- Identifying key questions regarding the optimal approach to achieve water quality goals;
- Designing studies to address the key questions;
- Incorporating new data and other relevant information into decision-making to improve project design and execution by exploring alternative actions with associated risks and uncertainties;
- Measuring and evaluating outcomes explicitly and objectively; and
- Adjusting actions based on the evaluation of outcomes.

Adaptive management provides a credible means by which scientists can inform management and decision-makers to ensure alternative actions are evaluated against the objectives of the program and adapted to optimize outcomes. Information gained from the 2018 Science Plan studies will be incorporated into the design, construction, and operations of the water quality features, and in short- and long-term management of the STAs. One example is the recent decision to invert soil in a portion of the STA-1W

Expansion Area to control P flux. Options were evaluated, based on prior knowledge and short-term experimentation, but further assessment is planned to evaluate long-term benefits. This inversion is expected to lower outflow TP concentrations.

5.3 ASSESSING PERFORMANCE

Implementation of adaptive management is an iterative process. As studies are implemented, results are evaluated and discussed with the Science Plan team and Technical Representatives. Modifications to the study plans, experimental design, and data analysis procedures may be necessary to reach the objectives of the study or the overall goal of the Science Plan. Forums and workshops allow for rapid dissemination of information and prompt assessment of the potential need for specific steps to take if mid-course corrections are necessary or if additional studies are needed to address relevant issues. This feedback loop ensures the most relevant and promising studies move forward. In a parallel effort, technical staff coordinate closely with stakeholders and construction and engineering teams to ensure relevant information from the study plans is considered and incorporated into the design, operation, and management activities for the STAs and associated features. Performance data for each STA will continue to be assessed, and new studies will be created to address remaining uncertainties, as needed, within the Restoration Strategies Program timelines.

6. REVIEW PROCESS

There are various review processes in place for the development of the Restoration Strategies Science Plan and study plans, as well as for the review of reports and manuscripts. Review allows a diverse group of SFWMD managers, internal and external technical experts, and other stakeholders to discuss scientific ideas, assist with project formulation, critique data analysis, validate study findings, and improve the quality of research plans, experimental designs, and publications.

6.1 SCIENCE PLAN

The 2013 Science Plan, including proposals for the initial nine studies, was reviewed extensively through several venues. This included reviews by the Science Plan Team, discussions with and review by the Technical Representatives, and solicitation for comments at public meetings (e.g., Long-Term Plan communication meetings, Water Resources Analysis Coalition meetings, SFWMD Governing Board meetings) and from the SFER peer-review panel. This 2018 Science Plan followed a similar process. Key questions and study areas were reviewed in workshops and discussions among SFWMD scientists. During this process, questions were retained, revised, or archived, while new questions and study areas were formulated. Additionally, drafts of the 2018 Science Plan and study concepts were reviewed. The Technical Representatives and select external technical experts were given an opportunity to review and comment on the draft Science Plan through workshops and electronic communications.

6.2 STUDY PROPOSALS

The following criteria are used to evaluate each Science Plan study proposal:

- **Hypothesis and Study Objectives**: Does the proposed study clearly lay out the rationale for its implementation? Is the hypothesis (hypotheses) scientifically sound? Do the experimental design and associated data analyses address the hypothesis (hypotheses)? Do the study objectives link anticipated study results to potential STA management strategies and, where practicable, influence the approach to STA and FEB design?

- **Study Relevance and Feasibility**: Is the proposed study likely to provide information that leads to management strategies improving STA treatment performance? Can information gained from the proposed study realistically be implemented at the scale of the STAs and, if implemented, be sustainable over the long term? Will findings from the proposed study enable the STAs to achieve the WQBEL objective?

- **Background Information**: Has a preliminary literature review and/or evaluation of any existing data been performed? A summary of key findings from these efforts should be part of the justification for conducting the proposed study.

- **Proposed Study Approach**:

    - **Testability**: Is the proposed study technically sound? Can it realistically be conducted to address the hypothesis and provide reliable results? Will this effort provide results that are defensible? What will be the uncertainty associated with the results?
    - **Study Design**: Does the proposed study design adequately address the study questions? Are all critical activities and milestones (e.g., STOP/GO decision points) clearly defined?

- **Timeliness**: Is the proposed study a short-term or long-term endeavor? Can the study be completed in time to support STA management decisions, and is it in the critical path of other Science Plan studies?

Based on the outcome of management review of the study proposals, a study may be approved and authorized to proceed after a detailed study plan is developed, or revisions to the study proposal may be required prior to receiving authorization to proceed.

6.3 STUDY PLANS

Once a study proposal has been approved, a draft study plan is prepared and submitted for review by SFWMD technical experts. Input from the Technical Representatives is solicited via workshops and electronic distribution of the draft study plan. Input from contractors may be requested via established contract tasks. The reviews are meant to ensure the draft study plan, including the experimental design, is technically sound and feasible. Draft study plans are evaluated against the following criteria:

- Completeness and clarity of writing;
- Technical rigor and feasibility of the experimental or study design;
- Data management and quality assurance/quality control (QA/QC) procedures;
- Budget and resource requirements;
- Activities and milestones; and
- If appropriate, STOP/GO criteria are specified.

6.4 REPORTS AND PUBLICATIONS

There are three categories of Science Plan study reports and publications:

1. Project reports, usually submitted by contractors;
2. Technical publications; and
3. Manuscripts intended for publication in science/engineering journals.

Interim project reports (e.g., from contractors) are reviewed by the project manager and other scientists. All publications undergo a standard internal review process, which includes review by management and by two or more peers (SFWMD, 2014a). Findings and publications are discussed with management, who provides the final approval for publication.

Reports on progress and findings from Science Plan studies have been included in Chapter 5C, Volume I of the annual SFER since 2015. Internal and external peer reviews of the chapter are conducted prior to its publication.

6.5 ADDITIONAL INDEPENDENT PEER REVIEW

When needed for vital projects or complex topics, external experts are used to provide technical review, resolve critical questions, or give guidance on pivotal issues.

7. QUALITY ASSURANCE AND QUALITY CONTROL

Collectively, the QA/QC requirements specified in project plans and process-specific standard operating procedures (SOPs) are in place to ensure documented quality of environmental monitoring and ecological studies. These requirements provide a structured and documented management system to sustain the quality and traceability of work performed by or for the SFWMD throughout all projects, including those under the Science Plan.

Due to the legal basis for Science Plan studies and the potential application of findings, research under the Science Plan is required to meet the applicable requirements of Chapter 62-160, F.A.C., known as the QA Rule. The rule, overseen by the FDEP, applies to most aspects of the Science Plan studies: field activities (e.g., sample collection, sample preservation, field measurements, site evaluation); sample handling, storage, and shipment; laboratory activities (e.g., sample receipt, analysis, data verification, data validation); data review, summaries, or presentation activities; and all activities that affect data quality, such as providing sample containers, instrument calibration services, or reagents and standards (not including commercial vendors). A rigorous QA/QC program ensures compliance with the QA Rule and provides assurance of the repeatability and quality of information generated using non-standard or non-routine procedures. The FDEP may require review of project plans and may audit studies to ensure adherence to the QA Rule on a case-by-case basis.

QA/QC is routinely incorporated into the SFWMD's data collection, processing, management, and reporting, as specified in the Quality Management Plan (SFWMD, 2014b). Specific requirements are detailed in the Field Sampling Quality Manual (SFWMD, 2017f), Chemistry Laboratory Quality Manual (SFWMD, 2018b), and Enterprise Scientific Data Management Policies and Procedures (SFWMD, 2007b, 2012c,d). Any additional procedures not included in accordance with the approved quality manuals need to be documented within the study work plan or in a separate SOP document. Data quality objectives (DQOs) are specified in individual study plans. As applicable, the DQOs defined in the Field Sampling Quality Manual (SFWMD, 2017f) or the Chemistry Laboratory Quality Manual (SFWMD, 2018b) can be referenced in the study plan, but additional study-specific DQOs must be detailed.

Research-oriented, non-standard methods can be reviewed and accepted as described in Rule 62-160.600, F.A.C. When the research focus is beyond the FDEP's jurisdiction, general QA practices apply to provide thorough documentation to support repeatability and defensibility of all resulting data. In addition, all laboratories used for the Science Plan studies must be certified for the methods being used. Exceptions to certification must be detailed in the study plan and/or contract Statement of Work (FDEP, 2014). Laboratory data must be reported using applicable data qualifier codes defined in the QA Rule and following the SFWMD-specified format for permanently loading to District databases. Data are validated against the established DQOs, and applicable qualifier codes are used if data do not meet any of these objectives. Records shall be retained for a minimum of 5 years after the completion of the study (SFWMD, 2014b). Individual studies, such as those under the Science Plan, must define DQOs and additional requirements through the study plans and SOPs.

7.1 QUALITY SYSTEM DOCUMENTS

According to the QA Rule and the quality system requirements discussed earlier, all data collection activities for the environmental monitoring programs and scientific research studies outlined in the Science Plan must be scientifically valid and defensible. DQOs must be clearly defined and verified, and data quality assessment should be performed annually for each project. Research data should be of acceptable completeness, representativeness, and comparability and of known and documented quality. The reported data should include required reporting attributes and, where applicable, documented QC (precision and accuracy) data and appropriate data qualifiers in accordance with the QA Rule.

The Field Sampling Quality Manual (SFWMD, 2017f) and associated SOPs define the minimum field sample collection and measurement protocols needed to meet the requirements of Chapter 62-160, F.A.C. These protocols apply to the collection of surface water, groundwater, atmospheric deposition, soil, and biological samples collected by SFWMD staff when conducting environmental monitoring and scientific research projects.

The Chemistry Laboratory Quality Manual (SFWMD, 2018b) defines the QA program for the SFWMD's analytical chemistry laboratory that will be used for the 2018 Science Plan projects. The manual complies with the National Environmental Laboratory Accreditation Conference (NELAC) Institute's (2016) Laboratory Accreditation Standards and defines QA requirements and minimum standards of compliance for laboratory QC procedures that apply to the analyses of surface water, groundwater, estuarine water, rain water, and biological tissue samples. Overall project organization and responsibilities for QA are detailed in the Quality Management Plan (SFWMD, 2014b).

Any contractors performing sampling and analysis for any of the studies must have their own field and laboratory quality manuals that meet the requirements of Chapter 62-160, F.A.C. Overall project organization and responsibilities for QA must be detailed in the contractor's field and laboratory quality manuals and in the Statement of Work to ensure data repeatability and defensibility. A copy of these manuals must be submitted to the SFWMD's study lead prior to initiation of any work. When deviation from these documents is necessary, the nature of the deviation and the resulting procedure must be fully documented. Contractors must seek FDEP approval by following the procedure outlined by the QA Rule prior to using any non-standard procedures. Contractors also most seek approval from the SFWMD's study lead and an authorized QA expert for a design that is different from what was specified in the study plan. Only properly trained personnel shall be approved to perform sampling, field measurements, or laboratory analyses for the Science Plan studies. This must be enforced by the SFWMD's study lead and documented by the authorized QA coordinator to ensure all staff are working within the same criteria.

7.2 QUALITY ASSURANCE OVERSIGHT

The SFWMD has an established QA program, including oversight, which is applicable for most of the data collection activities for the 2018 Science Plan. At the District level, a cross-functional QA team will oversee efforts in achieving organizational QA objectives.

For field sampling and measurements at the structures, a designated QA supervisor oversees the development of and compliance with the field requirements specified in the Quality Management Plan (SFWMD, 2014b) and the Field Sampling Quality Manual (SFWMD, 2017f). For samples analyzed by the SFWMD laboratory, the Chemistry Laboratory QA Officer oversees development of the Chemistry Laboratory Quality Manual (SFWMD, 2018b), SOPs, and compliance with the laboratory quality system. The study lead is responsible for implementing QA/QC protocols and coordinating any corrective actions for individual studies to ensure data are of acceptable quality.

7.3 DATA REVIEW

There are several steps to an effective data review process. The first level of review occurs at the time of measurement in the field or laboratory, and the individual or team generating the results are responsible for this level of review (data verification). This review generally involves verification against standard procedures such as preservation, holding time, calibration and instrument performance, QC, and documentation. Additional review is performed by the laboratory supervisor or, in some cases, the QA

Officer. Data generated by contractors must include a summary of the data review and be submitted to the SFWMD as part of the data deliverables. The second step in the data review process is data validation, which checks data against established DQOs and determines data usability. This process generally is performed by designated data validators. For example, data generated by the SFWMD undergo routine data validation (SFWMD, 2015, 2017g,h). For experimental data, the review process is more complex and should include steps to determine if data collection was done properly, calculations were correct, replicates are within acceptable ranges, and values are within the expected range.

Data are further assessed by the study lead or data users for usability purposes. For contractor-generated data, this step is done prior to loading data into a District database. Standard data qualifiers are applied to data that do not fully meet the DQOs. Data quality patterns are examined so corrective actions can be implemented. Other metrics must be used when possible to evaluate performance, such as project completeness, and laboratory proficiency test results for continuing certification. Qualified data may be used for the intended study or experiments, unless data are deemed erroneous or questionable. Further demonstration of the quality of results may be required.

7.4 PERFORMANCE ASSESSMENTS

Any collection and laboratory analyses done by SFWMD staff or contractors are subject to periodic on-site quality assessments by District personnel or designated contractors to ensure work is being done according to the quality system documents. Audit findings will be discussed with the specific group audited, the study lead, and the District's cross-functional QA team. The audited group will be required to respond with a plan of corrective action, if needed. Follow-up assessments may be conducted to verify satisfactory implementation of the corrective actions.

8. DATA MANAGEMENT

Implementation of studies under the Science Plan is expected to generate a vast amount of data and information from the field, the SFWMD laboratory, and contractors. All data and information must be stored in the proper repository, in accordance with the SFWMD's Scientific Data Management Policy (SFWMD, 2007b) and SOPs for data management (SFWMD 2012c,d). The policy elements are supported by QA/QC manuals, including SOPs for field sampling, laboratory analyses, data review, and data management. Data management SOPs define roles and responsibilities for project staff and guide the complete data lifecycle from establishment of a study through its data distribution. SFWMD data stewards must be engaged early in the planning process to establish study-level metadata and a system of record. This ensures conformance to data conventions, deliverable data formats, and metadata requirements to facilitate data acquisition and improve the synthesis and assessment that occur later in the lifecycle.

Standardized metadata are necessary to achieve these objectives and support data structure heterogeneity. Water quality monitoring metadata follow requirements defined by the FDEP (2014; Rule 62-160.240, F.A.C.). Hydrologic monitoring metadata are based on U.S. Geological Survey practices. Ecological monitoring and research metadata conform to the Ecological Metadata Language standard.

8.1 DATA REPOSITORIES

The SFWMD maintains a scientific data management system consisting of three databases: DBHYDRO, Metacat/Morpho, and ERDP. DBHYDRO (http://www.sfwmd.gov/dbhydro) is primarily for water quality and hydrologic monitoring data, whereas Metacat/Morpho and ERDP are primarily for metadata and ecological monitoring and research data (**Table 8-1**; **Figure 8-1**).

Table 8-1. Restoration Strategies Science Plan data type and process for storage.

Data Type	Process and Database
Water Quality	Data generated in the field and in the laboratory are verified and validated by following a standard review process then archived in DBHYDRO. Data not meeting all quality criteria are assigned standard qualifier codes. When applicable, data from outside contractors should be delivered in Adapt format for validation and loading to the DBHYDRO database.
Hydrologic	Stage and rainfall data from STA structures are remotely acquired via telemetry. Localized measurements are included in some field studies (e.g., using pressure transducers, velocity meters, or measuring sticks). Data, including calculated flow data, are reviewed according to SOPs, which could vary depending on the criticality of the hydrologic information. Critical information (e.g., for permit reporting) undergoes additional QA and is stored as preferred data. All structure data are archived in DBHYDRO, while study measurements are stored in ERDP or Metacat/Morpho databases.
Ecological Research	Other ecological measurements or experimental data are validated by research team technical leads and stored in the Metacat/Morpho and ERDP databases.

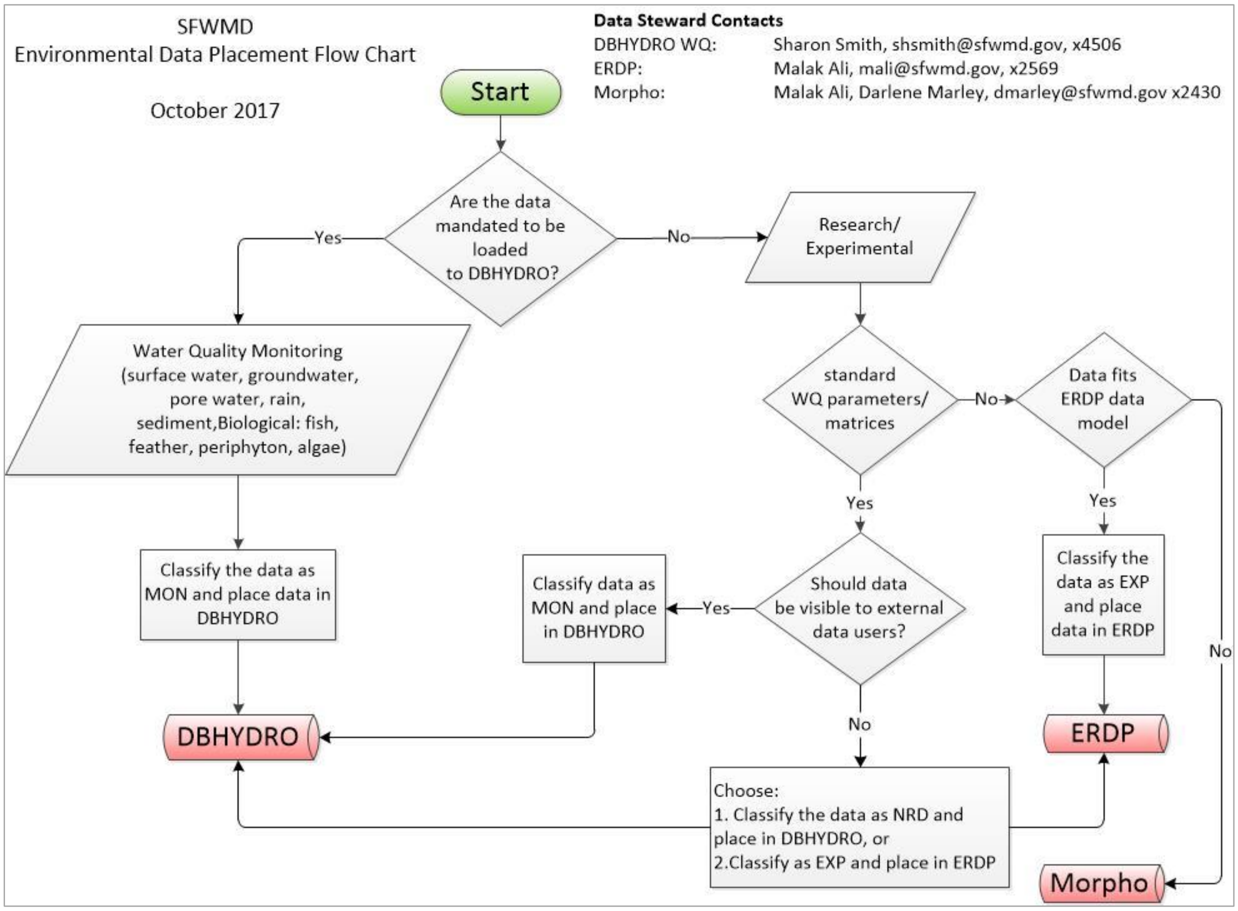


Figure 8-1. The process to determine where a given set of data will reside within the three SFWMD databases.

8.2 FIELD DOCUMENTATION

Field documentation is an important part of data management. All personnel responsible for collecting environmental samples and field measurements for Science Plan projects must collect and log the required information for field documentation. When applicable, routine water quality monitoring field data are recorded on a field laptop using Horizon Field Data Manager, an Excel-based platform for field data entry. For vegetation surveys, data are recorded using a tablet with data collection software compatible with ArcGIS®. For projects where a computer or tablet is not available or practical, data can be recorded on paper using a survey form or write-in-rain booklet. For data recorded on Rite in the Rain® copy paper, a table format with the parameters to be measured should be created ahead to optimize time in the field. Any supporting photographs taken during data collection must include time and location information in the photograph's title or metadata and must be uploaded to the appropriate project folder on the SFWMD's servers. At a minimum, electronic or paper documentation must include the following:

- Date and time;
- Log file name;
- Personnel and roles;
- Project name;
- Tasks;
- Location;

- Weather conditions;
- Description of surrounding area;
- Depth of sample collection; and
- Any field measurements (e.g., water depth, turbidity).

Deployed sonde data stored in ERDP must go through a QA/QC process and have accompanying pre- and post-deployment calibration and verification information. Levelogger® data must include well construction information. Installation of Levelogger® stations in the field should include detailed information on the initial setup, especially the deployment depth, which will be important for future calculations. Data obtained using Collector for ArcGIS® must be verified for accuracy within 2 weeks of being stored in a geodatabase. Properly collected metadata, along with measurement data, will play a role in the integration, synthesis, and interpretation of information.

8.3 LABORATORY DOCUMENTATION

Data from laboratories must include the sample metadata (e.g., date and time sampled, date and time measured/analyzed, comments), analytical results, data validation and qualification codes (i.e., qualifiers) (SFWMD 2015, 2017g), and deviations from analytical procedures approved in the Five-Year Work Plan. Variation from the SFWMD data qualification codes, or the conditions under which they are applied, must be specified in the study plan. Laboratory documentation will be reviewed by the data steward and project manager in accordance with the data management SOP (SFWMD, 2012d).

9. GLOSSARY

Accretion: Increase in size because of accumulation. Soil accretion results in accumulation of particles and plant material.

Acre-foot or acre-feet (ac-ft): Volume of liquid required to cover 1 acre to a depth of 1 foot, commonly used to express large amounts of water (1 acre-foot = 43,560 cubic feet).

Adaptive management: The application of scientific information and explicit feedback mechanisms to refine and improve future management decisions.

Advanced Treatment Technologies (ATT) Research Program: A comprehensive research program conducted from 1997–2002, which focused on testing and demonstrating potential technologies that could be used in conjunction with cattail-dominated STAs to meet water quality standards in discharges to the Everglades Protection Area. the technologies investigated included submerged aquatic vegetation treatment system, periphyton-based stormwater treatment area, chemical treatment–direct filtration, chemical treatment–high rate sedimentation, chemical treatment–dissolved air flotation/filtration, chemical treatment–microfiltration/ultrafiltration, low intensity chemical dosing, and managed wetlands.

Advection (Advective): A transport mechanism of a substance or conserved property by a fluid due to the fluid's bulk motion.

Aerial imagery: High-resolution photographs taken by plane. In the STAs, aerial imagery is used to map and estimate emergent vegetation coverage.

Alkalinity: Capability of water to neutralize an acid.

Baseline period: Specified length of time during which collected data are used for comparisons with subsequent data.

Basin-Specific Feasibility Studies: As an important step toward development of the Long-Term Compliance Permit application required under the Everglades Forever Act, the SFWMD completed Basin-Specific Feasibility Studies for thirteen Everglades Protection Area (EPA) tributary basins (Burns & McDonnell, 2002).

Benthic: Relating to the bottom region of a water body (e.g., ocean or lake), which includes the soil surface and some sub-surface layers.

Best Management Practices: Land, agricultural, industrial, and waste management techniques that reduce pollutant export from a specified area.

Biogeochemistry: Study of the chemical, physical, geological, and biological processes and reactions that govern the composition of the natural environment (including the biosphere, hydrosphere, pedosphere, atmosphere, and lithosphere), and the cycles of matter and energy that transport the Earth’s chemical components in time and space.

Biomass: Amount of living material in a sample, population, or area, usually measured as dry weight.

Bioturbation: Disturbances caused by living organisms.

Bulk density: Mass of soil per unit volume.

Chemical treatment/solid separation technology: A technology evaluated under the ATT Research Program, which assessed the effectiveness of various chemical amendments (i.e., aluminum or iron salts with polymers, including ferric chloride, polyferric sulfate, polyaluminum chloride, aluminum sulfate, anionic, cationic and nonionic polymers) followed by various solids separation methods (direct filtration, high-rate sedimentation, dissolved-air flotation, microfiltration) to remove P from the surface water. An evaluation of the residual solids was also a component of this effort.

Compliance monitoring: Sampling and analytical activities to monitor parameters specified in a permit or other official mandate.

Constructed wetlands: Man-made wetlands created by surrounding areas with earthen levees or berms to contain areas inundated by water. Water movement through the wetlands is usually controlled by water control structures, such as pump stations or culverts.

DBHYDRO: The District's environmental database that contains water quality and hydrological data.

DBKEY: A unique identifier for a data set (or time series) assigned by the District's DBHYDRO database. Each unique combination of station, data type, frequency, statistic type, recorder, operation number, and agency results in a unique DBKEY.

Decomposition: Action of microorganisms breaking down organic compounds into simpler ones, resulting in the release of energy.

Diel: related to the daily (24-hour) cycle, primarily related to animal and plant physiology

Diffusion: Transport of mass of material in response to a chemical concentration gradient.

Discharge: Release water from a facility via a water control structure see outflow.

Dissolved inorganic phosphorus: A form of P associated in a water sample that has been passed through a 0.45-micrometer membrane filter, primarily in the form of phosphate (PO_4).

Dissolved organic phosphorus (DOP): A form of P associated with organic matter in a water sample that has been passed through a 0.45-micrometer membrane filter; usually calculated as DOP = total dissolved P – soluble reactive P.

Diurnal: Recurring every day or having a daily cycle (e.g., diurnal animals are active during the day rather than at night; diurnal flowers open during the day and close at night).

Drawdown: Lowering of the water level in a reservoir or other body of water.

Drought: Extended period of low rainfall, below-normal streamflow, and depleted surface and subsurface storage.

Dryout: Condition in which the water level within the STA cells falls below the average ground elevation.

Ecosystem: Biological communities together with their environment, functioning as a unit.

Effective treatment area: Area within an STA that is inundated under normal operational conditions that functions to remove P from the receiving water. The effective treatment area usually does not include levees or water control structures.

Emergent aquatic vegetation (EAV): Wetland plants that extend above the water surface (e.g., cattail, bulrush, sawgrass).

Enzyme activity: Catalysis or breakdown of organic molecules by organisms. Enzyme activity is measured and reported in terms of the amount of substrate converted to product per unit time under specific reaction conditions.

Epiphytic periphyton (epiphyton): Type of periphyton that grows on submerged portion of plants.

Equilibrium phosphorus concentration: The critical concentration of P when net P adsorption equals zero, i.e., adsorption equals desorption and the system is at equilibrium. At this point, the soil exhibits maximum capacity for buffering P in soil pore water (Reddy and DeLaune, 2008).

Eutrophication: Enrichment of aquatic environments with nutrients like P and nitrogen, typically from mineral and organic runoff originating in the surrounding watershed. This enrichment results in increased growth of plants and algae that may reduce dissolved oxygen content in the water and can result in die-off of other organisms.

Everglades Construction Project (ECP): The ECP is a requirement of the 1994 Everglades Forever Act and the foundation of a large ecosystem restoration program, composed of various interrelated construction projects between Lake Okeechobee and the Everglades, including the construction of the Everglades Stormwater Treatment Areas (STAs).

Everglades Forever Act (EFA): A 1994 Florida law [Section 373.4592, Florida Statutes], amended in 2003 and 2013, to promote Everglades restoration and protection. This will be achieved through comprehensive and innovative solutions to issues of water quality, water quantity, hydroperiod, and invasion of nonindigenous species to the Everglades ecosystem. The EFA establishes the plan, the enforceable schedule, and the funding for the various components of the Everglades Program.

Everglades Forever Act (EFA) permit: Stormwater Treatment Area permit issued in accordance with the Everglades Forever Act [Section 373.4592, Florida Statutes], authorizing construction, operation, and maintenance activities for the STAs.

Everglades Protection Area (EPA): As defined in the Everglades Forever Act, the EPA includes Water Conservation Area (WCA) 1 (Arthur R. Marshall Loxahatchee National Wildlife Refuge), WCA 2A, WCA 2B, WCA 3A, WCA3B, and Everglades National Park.

ERDP: Everglades Research Database (Production) is a relational database management system used to store results and facilitate data analysis for certain categories of research data.

Everglades Stormwater Treatment Areas (STAs): Large freshwater treatment wetlands situated south of Lake Okeechobee, constructed to reduce TP concentration from runoff water prior to entering the Everglades Protection Area. Currently, the Everglades STAs (STA-1 West, STA-1East, STA-2, STA-3/4, and STA-5/6) cover approximately 68,000 acres, including 57,000 acres of effective treatment area.

Fauna: All animal life associated with a given habitat.

Fiscal Year (FY): Period from October 1 through September 30, during which the SFWMD's annual budget is developed and implemented.

Floating aquatic vegetation (FAV): Wetland plants that have portions floating near or at the water surface (e.g., water lettuce, water hyacinth, water lily).

Floc: A fluffy mass of materials formed in wetlands through settling, precipitation, or aggregation of suspended particles and decomposing plants and detritus; this may be comprised of inorganic and organic material.

Flocculation: A chemical process in which dispersed particles in water combine to form larger particulate clusters (flocs) that typically settle out of solution.

Flora: All plant life associated with a given habitat.

Flow Equalization Basin (FEB): Impoundment areas that serve to store or distribute water to the STAs to modulate treatment area inflows for vegetation health, optimal water depths, and P reduction efficiency.

Flow path: Planning-level delineation of source basins that are tributary to the existing STAs developed during preparation of the Restoration Strategies Regional Water Quality Plan. The Eastern Flow Path contains STA-1E and STA-1W, the Central Flow Path contains STA-2 (including Compartment B) and STA-3/4, and the Western Flow Path contains STA-5/6 (including Compartment C).

Flow-way: Area within an STA that consists of one or more treatment cells, separated with levees and has one or more inflow and outflow structures.

Flow-weighted mean concentration: Average concentration of a substance in water, corrected for volume of water flow at the time of sampling. Samples taken when flow is high are given greater weight in the average. Flow-weighted mean concentrations are used to calculate mass loading at a particular location.

Hydraulic loading rate (HLR): Amount of water received by the STA divided by the amount of effective treatment area, typically expressed as centimeters per day.

Hydraulic residence (or retention) time: Length of time that water resides in a specified area, usually measured as days. Hydraulic residence (or retention) time is estimated by dividing the average depth by HLR (inflow volume divided by effective treatment area acreage).

Hydraulic(s): Pertaining to the movement (flow) or effects (pressure) of liquids such as water.

Hydrology: Scientific study of the properties, distribution, and effects of water on the Earth's surface, in the soil and underlying rocks, and in the atmosphere.

Hydropattern: Water depth, duration, timing, and distribution of fresh water in a specified area. A consistent hydropattern is critical for maintaining various ecological communities in wetlands and other ecosystems.

Hydroperiod: Duration and frequency of inundation in a wetland area.

Inflow: Movement of water into a facility or area. In the Stormwater Treatment Areas, inflow is water flow at the beginning or top of a cell, flow-way, or STA. Inflow may also refer to the structure or location where untreated water enters a cell, flow-way, or STA.

Inoculation: The act of introducing a biological organism into a suitable situation for growth. In the STAs, inoculation is used as a management tool to accelerate SAV recruitment in areas converted from EAV to SAV or in SAV cells undergoing rehabilitation.

Inorganic: Composed of minerals rather than material from living organisms.

Labile: Readily or continually undergoing chemical, physical, or biological change or breakdown.

Litter: Plant material that is suspended in the water column or deposited on the soil surface.

Loading (hydraulic or mass loading): Amount of a substance carried into a specified area expressed as mass per unit of time. Total P loading is typically reported in metric tons per year.

Long-Term Plan: The 2003 Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area Tributary Basins and subsequent revisions contains a suite of projects, ranging from STA structural enhancements, STA expansions, STA optimization research, STA compliance and operational monitoring (hydraulic and water quality), STA downstream monitoring and research, STA water quality and hydrodynamic modeling, and Best Management Practices/source controls programs.

Low-intensity chemical dosing: A technology investigated as part of the ATT Research Program, which assessed the effectiveness of adding small doses of aluminum or iron salts directly into the water column, without the use of rapid mixing, flocculation, or settling basins to reduce P from surface waters.

Macrophytes: Visible (non-microscopic) plants found in aquatic environments.

Managed wetlands: A technology investigated as part of the ATT Research Program, which assessed the effectiveness of coupling chemical treatment with wetlands. The inflow stormwater was mixed with doses of aluminum or iron salts and polymers, followed by high-rate sedimentation or settling ponds, followed by wetlands to reduce P from surface waters.

Marl: A naturally occurring fine crumbly mixture of clay and limestone, often containing shell fragments and sometimes other minerals.

Marsh: Area of soft, wet, low-lying land, characterized by grassy vegetation and often forming a transition zone between water and land.

Mesocosm: Experimental units or enclosures larger than microcosms but smaller than macrocosms that are used to provide a limited amount of the natural environment under controlled conditions.

Metacat: A general purpose repository for data and metadata (descriptions of data) that helps scientists find, understand and use the data sets they manage or that have been created by others.

Mineralization: Decomposition or oxidation of the chemical compounds in organic matter releasing the nutrients contained in those compounds into soluble inorganic forms that may be plant accessible.

Morpho: a desktop tool to facilitate the creation, storage, and retrieval of metadata. Morpho interfaces with Metacat, allowing users to upload, download, store, query and view relevant metadata and data. Users can authorize the public or only selected colleagues to view their data files.

Muck: Dark, organic soil derived from well-decomposed plant biomass.

National Pollutant Discharge Elimination System (NPDES) permit: A wastewater facility permit required under the Clean Water Act that authorizes discharge to waters of the United States. The permit specifies limits on what can be discharged, monitoring and reporting requirements, and other provisions to ensure that the discharge does not impact water quality or human health. For the STAs, an NPDES permit was issued under the provision of Chapter 403, Florida Statutes, and applicable rules of the Florida Administrative Code.

NEXRAD: A system of Doppler radars that tracks precipitation and wind.

Nutrients: Organic or inorganic compounds essential for survival of an organism. In aquatic environments, nitrogen and P are key nutrients that affect the growth rate of plants.

Oligotrophic: Aquatic environment depleted of nutrients, resulting in low plant productivity.

Operations plan: Document that guides operation of the STAs under various scenarios such as normal operation, pre-storm, extreme flow, and drought operations and includes descriptions about the facility and water control structures.

Optimization: Action or goal to improve the effectiveness and/or efficiency of a method, process, or mechanism.

Organic: Relating to, derived from, or characteristic of living things.

Outflow: Movement of water out of an area, discharge. In the Stormwater Treatment Areas, outflow occurs at the end of a cell, flow-way, or STA. Outflow may also refer to the structure where treated water exists a cell, flow-way, or STA.

Parameter: Variable or constant representing a characteristic of interest. For example, pH is a water quality parameter. Use of this term is highly subjective and varies greatly across disciplines.

Particle impaction: occurs when particles in the water column hit a surface (in STAs, typically plants, soil, or rock) and stick to that surface rather than being swept around by the current.

Particle interception: occurs when particles in the water column contact and stick to a boundary (such as a plant stem) as they pass by in the current.

Particulate: Relating to or in the form of minute separate particles.

Particulate Phosphorus (PP): Particulate-bound P, not passing through a 0.45-micrometer filter, that can include both organic and inorganic forms; usually a calculated value: PP = TP – total soluble P.

Peat: Soils that contain partially decayed plant material. Peat is formed under anaerobic conditions found in inundated wetlands, is rich in humus and known as a histosol.

Periphyton: The biological community of microscopic plants and animals attached to surfaces in aquatic environments, including bacteria, fungi, and algae—the primary component in these assemblages.

Periphytometers: Floating apparatus with artificial substrates attached that are deployed for a set time to allow for periphyton growth. The artificial substrates may be glass or acrylic slides or dowels.

Periphyton-based Stormwater Treatment Area (PSTA): Wetland areas where periphyton assemblages are a major component. Soil may be scraped away to reduce the amount of P released into the water column from the soil or porewater. Emergent or submerged aquatic vegetation are also typically present.

pH: Dimensionless quantity that ranges from 1 to 14. It is measured on a scale that is a negative logarithmic representation of the quantity of hydrogen ions in the solution. A value below 7 is considered acidic, above 7 is alkaline

Phosphate diesters: Orthophosphate esters that include nucleic acids, phospholipids, and aromatic compounds.

Phosphate monoesters: Orthophosphate esters that include sugar phosphates (e.g., glucose-6-phosphates and phosphophenols, which are intermediates of metabolic pathways), phosphoproteins, mononucleotides, and inositol hexaphosphates.

Phosphorus (P): Element that is essential for life. In freshwater aquatic environments, P is often in short supply; increased levels can promote the growth of algae and other plants. The Everglades STAs were constructed to remove excess P from surface waters before they enter into the Everglades Protection Areas.

Phosphorus co-precipitation: The formation of amorphous particles as P reacts with metallic cations such as Ca, Mg, Fe, and Al. This is an important P reduction mechanism in aquatic environments.

Phosphorus cycling: The transformation and exchange of P, mediated by biological, chemical, and physical processes, from the environment through one or more organisms and back to the environment.

Phosphorus flux: The movement of P between soil and overlying water column and from one physical or chemical state to another. The dimensions of flux are $M\ L^{-2}\ T^{-1}$, where M is mass of material transferred by flux, L is the distance or length, and T is the time. The processes associated with flux are advection (movement of P with water flow), diffusion (movement between the soil and water column), and dispersion. Diffusive and advective flux between soil and overlying water and elemental uptake by rooted wetland vegetation are the major transport mechanism in which nutrients, metals, and toxic organic compounds are removed from soil and water column. Flux can be between the solid phase and porewater of soils.

Phosphorus loading rate (PLR): Amount of TP received by the STA divided by the amount of effective treatment area. Phosphorus loading rate is usually expressed as grams of TP per year.

Photolytic degradation: The breakdown of compounds by light.

Porewater: Water contained within the spaces between particles within soils.

Porewater equilibrator: A device that samples a vertical profile of water found in soil pores for soluble constituents such as pH and dissolved nutrients. The Porewater equilibrated is divided into small chambers that are filled with deionized water then covered with a membrane filter and protective cover. The device is inserted into the soil layer for a period of time, then removed from the soil, and the water samples in the chambers are processed for laboratory analysis

Precision: Degree of reproducibility of a measurement. Low precision yields high scatter in data.

Process Development and Engineering (PDE): A central element in the overall strategy in the Long-Term Plan that was included in recognition that achieving the water quality goals involves an adaptive management approach, using the best available information to develop and expeditiously implement incremental improvement measures in a cost-effective manner. PDE activities included enhanced control and monitoring of the STAs, refinements to STA water quality modeling tools; investigations into the effectiveness of submerge aquatic vegetation and periphyton; improvement of the reliability of STA inflow forecasts; and long-term and short-term surveys and monitoring (routine and event-driven water quality and spatial soil sampling and analysis, topographic surveys, and vegetation surveys).

Quality assurance (QA): The system of management activities and quality control procedures implemented to produce and evaluate data according to pre-established data quality objectives.

Quality control (QC): The overall system of technical activities that measures the attributes and performance of a process, product, or service against defined standards to verify that they meet the established data quality objectives.

Redox potential: Measure of the oxidation-reduction potential (electron activity) of components in the soil, as measured using platinum electrodes.

Refractory (or recalcitrant): Resistant to chemical, physical, or biological change or breakdown.

Rooted Floating Aquatic Vegetation (rFAV): Floating wetland plants that have extensive belowground rhizomes.

Recently Accreted Soil: Particulate organic material along with inorganic soils that has accumulated between the floc and pre-STA soil layers since the STA became operational.

Restoration Strategies Technical Representative Principals: The executives of each agency involved in the Restoration Strategies Program (e.g., SFWMD, U.S. Army Corps of Engineers, FDEP)

Seepage: Water moving into or out of the wetland through the ground, levees, or areas surrounding the water control structures.

Slough: Depression associated with swamps and marshlands as part of a bayou, inlet, or backwater; it contains areas of slightly deeper water and a slow current, and can be thought of as the broad, shallow rivers of the Everglades.

Soil amendment: Addition or alteration used to improve the ability of soil to capture and bind pollutants (e.g., soil amendments for P treatment include lime, coagulants, and carbon sources).

Soil management: Process of managing soil to achieve desired P reduction results. Management includes but is not limited to preventing dryout conditions, removing soils high in nutrient concentrations, adding amendments, and tilling.

Soluble reactive phosphorus (SRP): The dissolved form of P measured in a water sample after being filtered through a 0.45-micrometer membrane filter; generally represents the most readily available form of phosphorus. Similar to DIP but includes inorganic and sometimes simple dissolved organic P compounds.

Sorption: Taking in or holding of something, either by absorption or adsorption.

Species diversity: Index that incorporated the number of species in an area as well as relative abundance, such as number of individuals or biomass.

Species richness: Number of species occurring in a particular area for a specified sampling period.

Stage: Height of a water surface above an established reference point (datum or elevation). This vertical control measurement is usually expressed as feet National Geodetic Vertical Datum of 1929 or feet North American Vertical Datum of 1988.

Structure: Man-made pump stations, reservoirs, canals, and levees. Region-wide water management is accomplished by the agency's operation and maintenance of over 2,800 miles of canals and levees, over 1,300 water control structures, and 69 pump stations.

Submerged aquatic vegetation (SAV): Wetland plants that exist below the water surface (e.g., hydrilla, Chara, southern naiad).

Sustainability: In relation to the STAs, sustainability is the maintenance of P reduction efficiency and vegetation communities over time.

Total carbon: Total amount of carbon in a system or in an environmental sample, including both inorganic and organic forms of carbon.

Total nitrogen: Total amount of nitrogen in a system or in an environmental sample, includes both inorganic and organic forms of nitrogen.

Total phosphorus (TP): Total amount of P in a system or in an environmental sample, includes both organic and inorganic forms of P.

Total soluble phosphorus: Total P in water sample filtered through a 0.45-micrometer membrane filter and analyzed after sample digestion process; may include soluble reactive P and DOP.

Transect: A traverse path through an area along which ecological measurements are made.

Transpiration: To lose water vapor from a plant surface, especially through leaf stomata.

Translocation: The movement of soluble materials within plants (i.e., the movement of food materials from leaves to the roots or the movement of dissolved minerals upwards from the roots to the leaves).

Tussocks: A floating mass of live and dead vegetation.

Treatment cell: Area within the STA that functions to remove phosphorus from the receiving water; treatment cells are demarcated by levees.

Turbidity: The measure of light scattered by particles in solution and reported in nephelometric turbidity units, or NTUs.

Vegetation conversion: Process of changing the dominant vegetation within a treatment cell through herbicide application of undesired plants, water depth manipulation, or inoculations. In the Everglades STAs, large-scale vegetation conversions have occurred to convert areas dominated by emergent aquatic vegetation to submerged aquatic vegetation.

Vegetation resistance: Friction created by plants as water moves through the STA. The amount of vegetation resistance is determined by plant species, height, and density.

Water Conservation Areas (WCAs): Diked areas of the remnant Everglades that are hydrologically controlled for flood control and water supply purposes. These are one of the primary targets of Everglades restoration and major components of the Everglades Protection Area.

Water quality: Physical, chemical, and biological condition of water as applied to a specific use, typically propagation of fish and wildlife, public water supply, industry, or recreation.

Water Year (WY): Period from May 1 through April 30, during which water quality and other data are collected and reported in SFWMD reports.

Wetland: Area that is inundated or saturated by surface water or groundwater with vegetation adapted for life under those soil conditions (for example, swamps, bogs, and marshes).

Water quality-based effluent limit (WQBEL): Per Chapter 62-650, Florida Administrative Code, the WQBEL is an effluent limitation (discharge limit), which may be more stringent than a technology-based effluent limitation, that has been determined necessary by the FDEP to ensure that water quality standards in a receiving body of water will not be violated. Under the proposed WQBEL for STA discharge into the EPA, TP concentrations in the discharge from each STA may not exceed either 13 micrograms per liter ($\mu g\ L^{-1}$) as an annual flow-weighted mean in more than three out of five years or 19 $\mu g\ L^{-1}$ as an annual flow-weighted mean.

10. LITERATURE CITED

Abtew, W. and J. Obeysekera. 1995. *Lysimeter study of evapotranspiration of cattails and comparison of three estimation methods*. Transactions of the ASAE 38:121-129.

Abtew, W. and A. Melesse. 2013. *Evaporation and Evapotranspiration: Measurements and Estimations.* Springer, New York.

Abtew, W., L. Cadavid, and V. Ciuca. 2013. Chapter 2: South Florida Hydrology and Water Management. In: *2013 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Abtew W., T. Piccone, K. Pietro, and S.K. Xue. 2016. Hydrologic and Treatment Performance of Constructed Wetlands: The Everglades Stormwater Treatment Areas. In: C.M. Finlayson, M. Everard, K. Irvine, R.J. McInnes, B.A. Middleton, A.A. van Dam, and N.C. Davidson (eds.), *The Wetland Book: I: Structure and Function, Management and Methods*. Springer Netherlands, Dordrecht.

Aldous, A., P. McCormick, C. Ferguson, C. Graham, and C. Craft. 2005. Hydrologic regime controls soil phosphorus fluxes in restoration and undisturbed wetlands. *Restoration Ecology* 13:341-347.

Ali, A. 2009. Nonlinear multivariate rainfall-stage model for large wetland systems. *J. Hydrol*. 374:338-350.

Ali, A. 2015. Multi-Objective Operations of Multi-Wetland Ecosystem: iModel Applied to the Everglades Restoration. *Journal of Water Resources Planning and Management* 141:04015008.

Ali, A. 2018. Appendix 5C-1: iModel for Restoration Strategies Operational Protocol Development. In: *2018 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Barko, J.W. and R.M. Smart. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. *Ecology* 67:1,328-1,340.

Brix, H. 1997. Do macrophytes play a role in constructed treatment wetlands? *Water Sci and Tech.* 35:11-17.

Brix, H., B. Lorenzen, I.A. Mendelssohn, K.L. McKee, and S.L. Miao. 2010. Can differences in phosphorus uptake kinetics explain the distribution of cattail and sawgrass in the Florida Everglades? *BMC Plant Biol.* 10:23-37.

Brown & Caldwell. 2002. Basin Specific Feasibility Studies for the Everglades Stormwater Program Basins. Report submitted to the South Florida Water Management District, West Palm Beach, FL. October 2002.

Burns & McDonnell. 2002. Evaluation of Alternatives for the ECP Basins. Report submitted the South Florida Water Management District, West Palm Beach, FL. October 2002.

Burns & McDonnell. 2003. Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area. Report submitted to the South Florida Water Management District, West Palm Beach, FL.

CH2MHill. 2003. PSTA Research and Demonstration Project: Field-scale Soil Amendment Study Report. CH2MHill, Inc., Deerfield Beach, FL.

Chen, H., M.F. Zamorano, and D. Ivanoff. 2010. Effect of flooding depth on growth, biomass, photosynthesis and chlorophyll fluorescence of *Typha domingensis*. *Wetl.* 30:957-965.

Chen, H., M.F. Zamorano, and D. Ivanoff. 2013. Effect of deep flooding on nutrients and non-structural carbohydrates of mature *Typha domingensis* and its post-flooding recovery. *Ecol. Eng.* 53:267-274.

Chimney, M.J. 2015. Phase I Summary Report for the Use of Soil Amendments/Management to Control P Flux Study. Restoration Strategies Regional Water Quality Plan – Science Plan for the Everglades Stormwater Treatment Areas: Soil Amendments/Management to Control P Flux. Technical Publication WR-2015-006. South Florida Water Management District, West Palm Beach, FL.

Chimney, M.J. and K.C. Pietro. 2006. Decomposition of macrophyte litter in a subtropical constructed wetland in south Florida (USA). *Ecol. Eng.* 27:301-321.

Chimney, M.J. and D.E. Gawlik. 2007. The avifauna of constructed treatment wetlands in south Florida used for Everglades restoration. *Fl. Field. Nat.* 35:9-21.

Chimney, M.J., M. Nungesser, J. Newman, K.C. Pietro, G. Germain, T. Lynch, G. Goforth, and M.Z. Moustafa. 1999. Chapter 6: Stormwater Treatment Areas – Status of Research and Monitoring to Optimize Effectiveness of Nutrient Removal and Annual Report on Operational Compliance. In: *1999 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Chimney, M.J., M. Nungesser, J. Newman, K.C. Pietro, G. Germain, T. Lynch, G. Goforth, and M.Z. Moustafa. 2000. Chapter 6: Stormwater Treatment Areas – Status of Research and Monitoring to Optimize Effectiveness of Nutrient Removal and Annual Report on Operational Compliance. In: *2000 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Chimney, M.J., M.K. Nungesser, C. Combs, B. Gu, E. Fogarty-Kellis, J.M. Newman, W. Wagner, and L. Wenkert. 2004. Chapter 4B: STA Optimization and Advanced Treatment Technologies. In: *2004 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Chimney, M.J., Y. Wan, V.V. Matichenkov, and D.C. Calvert. 2007. Minimizing phosphorus release from newly flooded organic soils amended with calcium silicate slag: a pilot study. *Wetl. Ecol. Mgmt.* 15:385-390.

Davis, S.M. 1991. Growth, decomposition, and nutrient retention of *Cladium jamaicense* Crantz and *Typha domingensis* Pers. in the Florida Everglades. *Aquat. Bot.* 40:203-224.

Davis, S.M. 1994. Phosphorus inputs and vegetation sensitivity in the Everglades, pp. 357-378. In: S. Davis and J. Ogden (eds.), *Everglades: The Ecosystem and its Restoration*. St. Lucie Press, Delray Beach, FL.

DB Environmental, Inc. 2017. Investigation of Rooted Floating Aquatic Vegetation in Stormwater Treatment Areas: Update on Progress and Key Findings. Submitted to the South Florida Water Management District in partial fulfillment of Contract 4600003475 on Inter-Agency Agreement to Conduct Scientific Studies Relevant to the Stormwater Treatment Areas. West Palm Beach, FL.

DB Environmental, Inc. 2018. Investigations of STA-3/4 PSTA Performance, Design, and Operational Factors. Submitted to the South Florida Water Management District in partial fulfillment of Contract 4600003695 on Inter-Agency Agreement to Conduct Scientific Studies Relevant to the Stormwater Treatment Areas. West Palm Beach, FL.

DeBusk, T.A. 2011. Presentation of 2011 unpublished data. Everglades Agricultural Area Environmental Protection District reporting to the South Florida Water Management District, West Palm Beach, FL.

DeBusk, T.A., K.A. Grace, F.E. Dierberg, S.D. Jackson, M.J. Chimney, and B. Gu. 2004. An investigation of the lower limits of phosphorus removal in treatment wetlands: mesocosm testing of a shallow limerock-substrate wetland. *Ecol. Eng.* 23:1-14.

Dodds, W.K. 2003. The misuse of soluble reactive phosphorus and inorganic nitrogen to indicate nutrient status of surface waters. *J. North Amer. Benth. Soc.* 22:171-181.

Dunn, E.J. and K.R. Reddy. 2005. Phosphorus Biogeochemistry of Wetlands in Agricultural Watersheds, pp. 105-119. In: E.J. Dunne, R. Reddy, and O.T. Carton (eds.), *Nutrient Management in Agricultural Watersheds: A Wetland Solution*. Wageningen Academic Publishers, Wageningen, The Netherlands.

eBird. 2012. Online database of bird distribution and abundance (web application). eBird, Ithaca, NY. Available at http://www.ebird.org; accessed on February 26, 2013.

Evans, N., J. Trexler, and M. Cook. 2018. Effects of Faunal Communities in the water quality in the Everglades STA. In: O. Villapando and J. King (eds.), 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.

FDEP. 2012a. 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.

FDEP. 2012b. 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. 2014. Record Keeping and Reporting Requirements for Field Procedures, Chapter 62-160.240, Florida Administrative Code. Effective July 2014.

FDEP. 2017. Everglades Forever Act Permit, Everglades Construction Project: Stormwater Treatment Area (STA) 1 East, 1 West, 2, 3/4, 5 and 6 (No 0311207). Florida Department of Environmental Protection, Tallahassee, FL. August 18, 2017.

FDEP and USEPA. 2012. Everglades Water Quality Restoration Framework Agreement between U.S. Environmental Protection Agency, Region IV, Atlanta, GA, and Florida Department of Environmental Protection, Tallahassee, FL. June 12, 2012.

Frederick, P.C. and G.V.N. Powell. 1994. Chapter 23: Nutrient Transport by Wading Birds in the Everglades, pp. 571-583. In: S.M. Davis and J.C. Ogden (eds.), *Everglades: The Ecosystem and its Restoration*. St. Lucie Press, Delray Beach, FL.

Gawlik, D.E. 2005. The role of wildlife science in wetland ecosystem restoration: Lessons from the Everglades. *Ecol. Eng.* 26:70-83.

Gawlik, D.E. and T. Beck. 2010. Assessment of the Environmental Lift of Stormwater Treatment Areas on South Florida Avifauna: Phase II Long-Term Study. Report to the South Florida Water Management District, West Palm Beach, FL. June 2010.

Germain, G. and K.C. Pietro. 2011. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2011 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Goforth, G., T. Bechtel, G. Germain, N. Iricanin, L. Fink, D. Rumbold, N. Larson, R. Meeker, and R. Bearzotti. 2003. Chapter 4A: STA Performance and Compliance. In: *2003 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Goforth, G., K.C. Pietro, G. Germain, N. Iricanin, L. Fink, D. Rumbold, and R. Bearzotti. 2004. Chapter 4A: STA Performance and Compliance. In: *2004 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Goforth, G., K.C. Pietro, M.J. Chimney, J. Newman, T. Bechtel, G. Germain, and N. Iricanin. 2005. Chapter 4: STA Performance, Compliance, and Optimization. In*: 2005 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Gumbricht, T. 1993. Nutrient removal processes in freshwater submersed macrophyte systems. *Ecol. Eng.* 2:1-30.

Hagerthey, S.E., B.J. Bellinger, K. Wheeler, M. Gantar, and E. Gaiser. 2011. Everglades periphyton: A biogeochemical perspective. *Crit. Rev. Env. Sci. Tech*. 41:309-343.

Hansson, L.A. 1989. The influence of a periphytic biolayer on phosphorus exchange between substrate and water. *Archiv für Hydrobiol*. 115:21-26.

Hoge, V.R., R. Conrow, M. Coveney, and M. Peterson. 2003. The application of alum residual as a phosphorus abatement tool within the Lake Apopka restoration area. Proceedings of the Water Environment Federation, WEF/AWWA, CWEA Joint Residuals and Biosolids Management, 1,500-1,513.

Huebner, R.S., C. Pathak, and W. Abtew. 2007. Impact of Using Radar Rainfall Data in Water Budgets for South Florida Stormwater Treatment Areas. In: K.C. Kabbes (ed.), *Proceedings of the World Water and Environmental Resources Congress 2007*. May 15-19, 2007. ASCE, Tampa, FL.

Ivanoff, D.B., H. Chen, and L. Gerry. 2012. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2012 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Ivanoff, D.B., K.C. Pietro, H. Chen, and L. Gerry. 2013. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2013 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Ivanoff, D.B., 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. South Florida Water Management District, West Palm Beach, FL. 24 pp.

Jorge, J., J.M. Newman, M.J. Chimney, G. Goforth, T. Bechtel, G. Germain, M.K. Nungesser, D. Rumbold, J. Lopez, L. Fink, B. Gu, R. Bearzotti, D. Campbell, C. Combs, K.C. Pietro, N. Iricanin, and R. Meeker. 2002. Chapter 4A: STA Performance and Compliance. In: *2002 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Juston, J.M. 2017. Low-P research on P Flux project: the 1st two-years, summary and synthesis. SFWMD P Flux Workshop. November 2017. South Florida Water Management District, West Palm Beach, FL.

Kadlec, R.H. 2006. Free surface wetlands for phosphorus removal: The position of the Everglades Nutrient Removal Project. *Ecological Engineering* 27(4):361-379.

Kadlec, R.H. and S.D. Wallace. 2009. *Treatment Wetlands*. 2nd Edition. CRC Press, Taylor and Francis Group, Boca Raton, FL. 1,016 pp.

Lal, A.W. 2017. Mapping Vegetation-Resistance Parameters in Wetlands Using Generated Waves. *Journal of Hydraulic Engineering* 143:04017023.

Lal, W.A., M.Z. Moustafa, and W.M. Wilcox. 2015. The use of discharge perturbations to understand in situ vegetation resistance in wetlands. *Water Resources Research* 51:2,477-2,497.

Laham-Pass, M. 2018. Appendix 3-3: Annual Permit Report for the A-1 Flow Equalization Basin. In: *2017 South Florida Environmental Report – Volume III*. South Florida Water Management District, West Palm Beach, FL.

Lindstrom, S.M. and J.R. White. 2011. Reducing phosphorus flux from organic soils in surface flow environment. *Chemosph.* 85(4):625-629.

Lake Okeechobee Technical Advisory Council II. 1988. Interim Report to the Florida Legislature. February 29, 1988.

Lorenzen, B., H. Brix, K.L. McKee, I.A. Mendelssohn, and S.L. Miao. 2001. Biomass allocation and nutrient utilization of Cladium jamaicense and Typha domingensis at different phosphorus availability. Aquat. Bot. 70:117-133.

Malecki-Brown, L.M., J.R. White, and M. Sees. 2009. Alum application to improve water quality in a municipal wastewater treatment wetland. *J. Environ. Qual*. 38:814-821.

McBryan, J. 2018. Chapter 5A: Restoration Strategies – Design and Construction Status of Water Quality Improvement Projects. In: *2018 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

McCormick, P.V., S. Newman, S. Miao, D.E. Gawlik, D. Marley, K.R. Reddy, and T.D. Fontaine. 2002. Effects of anthropogenic phosphorus inputs on the Everglades, pp. 83-126. In: J.W. Porter and K.G.

Porter (eds.), *The Everglades, Florida Bay, and coral reefs of the Florida Keys: An ecosystem source book*. CRC Press, Boca Raton, FL.

Miao, S.L. 2004. Different rhizome growth and nutrient resorption of two wetland species with contrasting life history. *Aquat. Bot*. 78:55-56.

Miao, S.L. and C. Thomas. 2011. Fire Project Final Report: Evaluating Natural Recovery and Fire Effects in Phosphorus-Enriched Water Conservation Areas 2A. Report submitted to the South Florida Water Management District. West Palm Beach, FL. 457 pp.

Miao, S.L. and C.B. Zou. 2012. Effects of inundation on growth and nutrient allocation of six major macrophytes in the Florida Everglades. *Ecol. Eng.* 42:10-18.

Moustafa, M.Z., J.R. White, C.C. Coghlan, and K.R. Reddy. 2011. Influence of hydropattern and vegetation type on phosphorus dynamics in flow-through wetland treatment systems. *Ecol. Eng.* 37:1,369-1,378.

Moustafa, M.Z., J.R. White, C.C. Coghlan, and K.R. Reddy. 2012. Influence of hydropattern and vegetation on phosphorus reduction in a constructed wetland under high and low mass loading rates. *Ecol. Eng.* 42:134-145.

MSA. 2008. Analysis of water quality data collected at 10 monitoring sites adjacent to the Everglades National Park to investigate the influence of flow dynamics and short-term spikes on concentration and load estimates. Report prepared under Work Order ST061294-WO03, Contract # STO61294, for the South Florida Water Management District, West Palm Beach, FL.

National Environmental Laboratory Accreditation Conference Institute. 2016. Laboratory Accreditation Standards. Volume 1: Management and Technical Requirements for Laboratories Performing Environmental Analysis. The NELAC Institute.

National Research Council. 2004. Adaptive Management for Water Resources Project Planning. National Academies Press. Washington, D.C.

Newman, J.M., G. Goforth, M.J. Chimney, J. Jorge, T. Bechtel, G. Germain, M.K. Nungesser, C. Pathak, D. Rumbold, J. Lopez, L. Fink, B. Gu, K. Cayse, R. Bearzotti, D. Campbell, C. Combs, K.C. Pietro, N. Iricanin, R. Meeker, G. West, and N. Larson. 2003. Chapter 4: Stormwater Treatment Technologies. In: *2003 Everglades Consolidated Report*. South Florida Water Management District, West Palm Beach, FL.

Newman, S., P.V. McCormick, S.L. Miao, J.A. Laing, W.C. Kennedy, and M.B. O'Dell. 2004. The effect of phosphorus enrichment on the nutrient status of a northern Everglades slough. *Wetl. Ecol. Mgmt*. 12:63-79.

Noe, G.B. and D.L. Childers. 2007. Phosphorus budgets in the Everglades wetland ecosystems: The effect of hydrology and nutrient enrichment. *Wetl. Ecol. Mgmt*. 15:189-205.

Nungesser, M.K. and M.J. Chimney. 2001. Evaluation of phosphorus retention in a southern Florida treatment wetland. *Water Science & Technology* 44(11/12):109-115.

Pandion Systems, Inc. 2008. Avian Protection Plan for Black-necked Stilts and Burrowing Owls Nesting in the Everglades Agricultural Area Stormwater Treatment Areas. Gainesville, FL. 55 pp.

Phillips, G., N. Wilby, and B. Moss. 2016. Submerged macrophyte decline in shallow lakes: What have we learnt in the last forty years? *Aquatic Botany* 135:37-45.

Pietro, K.C. 2012. Synopsis of the Everglades Stormwater Treatment Areas, Water Year 1996-2012. Technical Publication ASB-WQTT-12-001. South Florida Water Management District, West Palm Beach, FL.

Pietro, K.C., R. Bearzotti, M. Chimney, G. Germain, N. Iricanin, T. Piccone, and K. Samfilippo. 2006. Chapter 4: STA Performance, Compliance and Optimization. In: *2006 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Pietro, K.C., R. Bearzotti, M. Chimney, G. Germain, N. Iricanin, and T. Piccone. 2007. Chapter 5: STA Performance, Compliance and Optimization. In: *2007 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Pietro, K.C., G. Germain, R. Bearzotti, and N. Iricanin. 2008. Chapter 5: STA Performance, Compliance and Optimization. In: *2008 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Pietro, K.C., G. Germain, R. Bearzotti, and N. Iricanin. 2009. Chapter 5: STA Performance, Compliance and Optimization. In: *2009 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Pietro, K.C., G. Germain, R. Bearzotti, and N. Iricanin. 2010. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2010 South Florida Environmental Report – Volume I*. 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.

Post, D.M., J.P. Taylor, J.F. Kitchell, M.H. Olson, D.E. Schlinder, and B.R. Herwig. 1998. The role of migratory waterfowl as nutrient vectors in a management wetland. *Conserv. Biol.* 12:910-920.

Rawlik, P. 2017. Appendix 5C-4: Evaluation of Sampling Methods for Total Phosphorus. In: *2017 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

Reddy, K.R. and R.D. DeLaune. 2008. *Biogeochemistry of Wetlands: Science and Applications*. CRC Press, Boca Raton, FL.

Reddy, K.R., R.H. Kadlec, E. Flaig, and P.M. Gale. 1999. Phosphorus retention in streams and wetlands: a review. *Crit. Rev. Env. Sci. Tech*. 29:1-64.

Reddy, K.R., J.R. White, Y. Wang, and J. Newman. 2002a. Stability and Bioavailability of Recently Accreted Phosphorus in Stormwater Treatment Areas. Final report submitted to the South Florida Water Management District. December 2002.

Reddy, K.R., R.G. Wetzel, and R. Kadlec. 2005. Biogeochemistry of phosphorus in wetlands, pp. 263-316. In: J.T. Sims and A.N. Sharpley (ed.), *Phosphorus: Agriculture and the environment*.

Reddy, K.R., M.M. Fisher, J.R. White, Y. Wang, and R.T. James. 2006. Potential effects of simulated sediment dredging on internal phosphorus loading in a shallow, subtropical lake. *Lake Reserv. Manag.* 23(1):27-38.

Richardson, C.J. 1985. Mechanisms controlling phosphorus retention capacity in freshwater wetlands. *Science* 228:1424-1427.

Sekercioglu, C.H. 2006. Increasing awareness of avian ecological function. *Trends Ecol. Evol*. 21:464-471.

SFWMD. 2005a. Regional Simulation Model – Theory Manual. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2005b. Regional Simulation Model – Hydrologic Simulation Engine (HSE) User Manual. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2007a. Rehabilitation/Conversion in Stormwater Treatment Area 1 West. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2007b. Administrative Policies: Part I–District Policies, Chapter 163, Scientific Data Management. South Florida Water Management District, West Palm Beach, FL. October 11, 2007.

SFWMD. 2010. Methodology for Model Implementation and Application. Hydrologic and Environmental Systems Modeling Department, South Florida Water Management District, West Palm Beach, FL. August 2010.

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. 2012c. Standard Operating Procedure for Data Transfer Prior to Departure. SFWMD-QS-SOP-010-01. Effective November 16, 2012. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2012d. Applied Sciences Bureau Standard Operating Procedure for Scientific Data Management. SFWMD-SDM-SOP-001-02. Effective September 20, 2012. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2014a. Standard Operating Procedure for Establishing Authorship and Review of Technical Documents and Presentations. SFWMD-QS-SOP-006-04. Version 4.0. Effective March 10, 2014. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2014b. Quality Management Plan. SFWMD-QS-QM-001-05. Version 5.0. Effective July 11, 2014. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2015. Standard Operating Procedure for Validating of Internal Laboratory Data, Revision 7.0. SFWMD-DVS-SOP-002-7.0. October 2015. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2016a. Operational Project Monitoring Plan for Central Flow-way Stormwater Treatment Area 2 (STA2). SFWMD-FIELD-MP-073-06. Effective April 8, 2016. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2016b. Operational Project Monitoring Plan for L8 Flow Equalization Basin (L8FEB). Effective February 2, 2016. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017a. Monitoring Plan for EAA A-1 Flow Equalization Basin A1FEB. SFWMD-FIELD-MP-095-01. Effective April 25, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017b. Monitoring Plan for Eastern Flow-Way Stormwater Treatment Area One East, ST1E. SFWMD-FIELD-MP-046-06. Effective May 03, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017c. Monitoring Plan for Eastern Flow-Way Stormwater Treatment Area One West, ST1W. SFWMD-FIELD-MP-047-07. Effective April 26, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017d. Monitoring Plan for Western Flow-Way Stormwater Treatment Area 5/6 and Rotenberger (STA5, STA6, RTBG). SFWMD-FIELD-MP-074-05. Effective May 22, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017e. Operational Project Monitoring Plan for Central Flow-way Stormwater Treatment Area 3/4 (STA3/4). SFWMD-FIELD-MP-045-09. Effective October 12, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017f. Field Sampling Quality Manual. SFWMD-FIELD-QM-001-09. Effective June 29, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017g. Standard Operating Procedure for Validating of Contract Laboratory Data. SFWMD-DVS-SOP-001-07, Revision 7.0. SFWMD-DVS-SOP-002-7.0. Effective March 14, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2017h. Standard Operating Procedure for Validating of Processing, Quality Assessment, and Validation of Automated and Field Collected Water Quality Data Using DAS and GVA Applications. SFWMD-DVS-SOP-003-08, Revision 8.0. SFWMD-DVS-SOP-002-7.0. Effective February 1, 2017. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2018a. STA-3/4 Cell 3B Submerged Aquatic Vegetation Survey. Water Quality Treatment Technologies Section. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2018b. Chemistry Laboratory Quality Manual, 2018. FDOH Certification: E46077. SFWMD-LAB-QM-2018-001. Effective January 8, 2018. South Florida Water Management District, West Palm Beach, FL.

SFWMD, University of Florida, and DB Environmental, Inc. 2018. Data Analysis, Integration, and Synthesis Plan: Evaluate Phosphorus Forms, Sources, Flux and Transformation Processes in the Everglades Stormwater Treatment Areas (Restoration Strategies Science Plan Study). DRAFT. South Florida Water Management District, West Palm Beach, FL.

Sharma, K., P. Inglett, K.R. Reddy, A. Ogram, W.T. Cooper III, and R.G. Wetzel. 2004. Biotic hydrolysis of organic phosphorus in effluents of stormwater treatment areas. Report by the University of Florida, Soil and Water Science Department, submitted to the South Florida Water Management District, West Palm Beach, FL.

University of Florida. 2001. Following Thirteen Years of Service, Evaluation of the Existing Capacity of the Orlando Easterly Wetland Treatment System to Remove Phosphorus from Wastewater. Final report submitted to the City of Orlando.

University of Florida. 2018. Evaluation of Soil Biogeochemical Properties Influencing Phosphorus Flux in the Everglades Stormwater Treatment Areas (STAs). Annual Report July 2016-June 2017. Submitted to the South Florida Water Management District in partial fulfillment of Work Order 4600003031-WO01.

U.S. Army Corps of Engineers and SFWMD. 2011. Guidance for Integration of Adaptive Management (AM) into Comprehensive Everglades Restoration Plan (CERP) Program and Project Management. CERP Guidance Memorandum 056.00. Effective February 8, 2011. South Florida Water Management District, West Palm Beach, FL and U.S. Army Corps of Engineers, Jacksonville, FL.

Vanni, M.J. 2002. Nutrient cycling by animals in freshwater ecosystems. *Ann. Rev. Ecol. Syst.* 33:341-370.

Villapando, O. 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.

Walker, W.W. and R.H. Kadlec. 2011. Modeling phosphorus dynamics in Everglades wetlands and stormwater treatment areas. *Critical Reviews in Environmental Science and Technology* 41:430-446.

Walters, C.J. and C.S. Holling. 1990. Large-scale management experiments and learning by doing. *Ecology* 71:2,060-2,068.

Wang, H., J.W. Jawitz, J.R. White, C.J. Martinez, and M.D. Sees. 2006. Rejuvenating the largest municipal treatment wetland in Florida. *Ecol. Eng.* 26:132-146.

Water and Soil Solutions, LLC. 2009. Tilling Practices for Phosphorus, Sediment and Vegetation Management in Lake Okeechobee, Phase I. Final Report. January 2009.

Wetzel, R.G. 2002. Origins, Fates, and Ramifications of Natural Organic Compounds of Wetlands. In: M.M. Holland, M.L. Warren, and J.A. Stanturf (eds.), Proceedings of a conference on sustainability of wetlands and water resources: How well can riverine wetlands continue to support society into the 21st century? Gen. Tech. Rep. SRS-50. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.

Wetzel, P.R., A.G. van der Valk, S. Newman, D.E. Gawlik, T. Troxler Gann, C.A. Coronado-Molina, D.L. Childers, and F.H. Sklar. 2005. Maintaining tree islands in the Florida Everglades: Nutrient redistribution is the key. *Front. Ecol. Environ*. 3(7):370-376.

White, J.R., K.R. Reddy, and M.Z. Moustafa. 2004. Influence of hydrologic regime and vegetation on phosphorus retention in Everglades stormwater treatment area wetlands. Hydrol. Proc. 18:343-355.

White, J.R., K.R. Reddy, and J. Majer-Newman. 2006. Hydrologic and vegetation effects on water column phosphorus in wetland mesocosms. Soil Sci. Soc. Am. J. 70:1,242-1,251.

Wright, A.L. 2009. Stormwater Treatment Areas 2, 5, and 6: Phosphorus sorption and fractionation. Final report submitted to the South Florida Water Management District, West Palm Beach, FL.

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

Zhao, H. and T. Piccone. 2018b. Appendix 5C-4: Evaluation of the Influence of Canal Conveyance Features on Stormwater Treatment Area and Flow Equalization Basin Inflow and Outflow Total Phosphorus Concentrations. In: *2018 South Florida Environmental Report – Volume I*. 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 – Evaluation of the Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow Total Phosphorus Concentrations. Technical Publication WR-2015-003. South Florida Water Management District, West Palm Beach, FL.

Zhao, H., T. Piccone, and S. Hill. 2015b. STA-1 Inflow Basin Canal Investigation Phase I Report – Evaluation of the Influence of Canal Conveyance Features on Stormwater Treatment Area and Flow Equalization Basin Inflow and Outflow Total Phosphorus Concentrations. Technical Publication WR-2015-004. South Florida Water Management District, West Palm Beach, FL.

Zhao, H., T. Piccone, and O. Diaz. 2017. Stormwater Treatment Area 1 West Discharge Canal Evaluation Report. Evaluation of the Influence of Canal Conveyance Features on Stormwater Treatment Area and Flow Equalization Basin Inflow and Outflow Total Phosphorus Concentrations. Technical Publication WR-2017-005. South Florida Water Management District, West Palm Beach, FL.

Zimmer, K.D., M.A. Hanson, and M.G. Bulter. 2001. Effects of fathead minor colonization and removal on a prairie wetland ecosystem. *Ecosystems* 4:346-357.

Zimmer, K.D., B.R. Herwig, and L.M. Laurich. 2006. Nutrient excretion by fish and wetland ecosystems and its potential to support algal production. *Limnol. Oceanogr*. 51:197-207.

APPENDIX A. FIVE-YEAR WORK PLAN

Implementation of the study concepts within the Science Plan is guided by this Five-Year Work Plan, which includes four studies continuing from the previous Five-Year Work Plan, three new studies initiated in Fiscal Year 2018, eight planned studies not yet initiated, and one ongoing study effort that supports the Five-Year Work Plan but does not answer any key questions or sub-questions (water and phosphorus [P] budgets).

The study concepts include background information, study hypotheses and objectives, proposed methodology, and activities and milestones. For the studies continuing from the initial 5 years, the plans were updated to include implementation of remaining tasks.

- **Background**. This section provides information on each key question and sub-question being investigated, including review and analysis of existing literature and data to document what is known/unknown. Additional literature and data review may be conducted to assist hypothesis development for the study plan.

- **Study Hypotheses and Objectives**. Hypothesis development clearly lays out the individual study plan rationale and, more specifically, what will be tested in each plan. A clear hypothesis is critical to guiding the experimental design and statistical analyses. The individual study plan may test several hypotheses. The study plan objectives should link study results to potential management actions and operational activities and, if applicable, to the design of flow equalization basins (FEBs) and stormwater treatment areas (STAs). This section includes the rationale on how the results will be scaled up. Linking the results of the individual study plans to management actions will help hypothesis development.

- **Proposed Methodology**. This section presents a description of location, general scope, and duration of the study and whether the study will be carried out in phases or sub-studies (sequentially or concurrently). Literature review and data analysis are important components of the study plans. Extensive sampling and analyses have been performed over the years in conjunction with STA operations, which could be useful in designing new studies. Field methods and the approach to data collection will be described (e.g., matrix, parameters, frequency, location). Where applicable, a conceptual model and description of management/modeling tools to be developed and used to meet individual study plan objectives is included.

- **Activities and Milestones**. A list of the major activities and milestones with anticipated completion dates for each study plan.

Once approved by the SFWMD, the study concepts will be expanded into more detailed study plans with literature review and technical designs. The study concepts and designs are developed through collaboration among South Florida Water Management District staff and other technical experts in consultation with the Restoration Strategies Technical Representatives. Further details on the specific resource and budget needs will be based on the final study plans.

The studies, with the corresponding key questions and sub-questions, represent the focus of this Five-Year Work Plan (**Table A-1**). The schedule of implementation for the studies planned for the next 5 years is provided in **Table A-2**. To date, eight studies have been approved and funded for Fiscal Year 2018 through Fiscal Year 2019; the remaining six studies are awaiting review and authorization (as highlighted in **Tables A-1** and **A-2**). This document will be updated as needed and at a minimum of every 5 years.

Table A-1. Studies for the second Five-Year Work Plan and the corresponding Science Plan questions addressed by each study.

Study Name	Sub-Question(s) Addressed	Associated Key Questions	Status[1]
1. Use of Soil Inversion to Control P Flux[2]	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?	Continuing
2. Evaluate P Sources, Forms, Flux, and Transformation Processes in the 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 different STAs, and how do they compare to the natural system? What is the role of vegetation in modifying P availability to 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 SRP, PP, and DOP concentrations at the outflow of the STAs?	Continuing
3. Investigation of STA-3/4 PSTA Technology Performance, Design, and Operational Factors	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?	Continuing
4. Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability	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?	Continuing
5. Improving Resilience of Submerged Aquatic Vegetation (SAV) in the STAs	What key factors affect and what management strategies could improve system resilience of SAV communities?	What measures can be taken to enhance vegetation-based treatment in the STAs?	New 2018
6. Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs	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? What are direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (i.e., are they net sinks or sources)?	How can internal loading of P to the water column be reduced or controlled, especially in the lower reaches of the STAs? What is the influence of wildlife and fisheries on the reduction of P in the STAs?	New 2018
7. Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs	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?	New 2018

Study Name	Sub-Question(s) Addressed	Associated Key Questions	Status[1]
8. Sustainable Landscape and Treatment in a Stormwater Treatment Area	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?	Planned
9. Quantifying the Recalcitrance and Lability of Phosphorus (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 SRP, PP, and DOP concentrations at the outflow of the STAs?	Planned
10. 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?	Planned
11. Phosphorus Reduction Dynamics in STA-1E, STA-1W, STA-2, & 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?	Planned
12. 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?	Planned

Study Name	Sub-Question(s) Addressed	Associated Key Questions	Status[1]
13. Assess Benefits and Feasibility of Consolidating Accrued Marl in the Stormwater Treatment Areas' Submerged Aquatic Vegetation 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?	Planned
14. Quantifying phosphorus 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?	Planned
15. 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 PLR and HLR in the STAs, possibly in combination with water treatment technologies or inflow canal management?	Planned

DOP = dissolved organic phosphorus; EAV = emergent aquatic vegetation; FEB = flow equalization basin; P = phosphorus; PP = particulate phosphorus; PSTA = periphyton-based stormwater treatment area; SAV = submerged aquatic vegetation; SRP = soluble reactive phosphorus; STA = stormwater treatment area; TP = total phosphorus.
[1] Continuing studies were initiated under the 2013 Science Plan; New 2018 studies were initiated in Fiscal Year 2018 while the 2018 Science Plan was being developed; Planned studies will be initiated in 2019 or later, under the 2018 Science Plan.
[2] Previous title: Use of Soil Amendments/Management to Control P Flux.

Other Study Efforts:

STA Water and Phosphorus Budget Improvements

The ongoing water and P budget effort supports the Five-Year Work Plan but does not answer any key questions or sub-questions. The goal of the study is to improve the accuracy of STA water flow and P load estimates into and out of the STAs as more accurate data become available. The study concept plan is provided at the end of this appendix and discussed in Section 3.4.1 of the main report.

Table A-2. Estimated schedule for implementation of studies over the next 5 years (2018-2023).

Study	Fiscal Year 2018	2019	2020	2021	2022	2023
1. Use of Soil Inversion to Control P Flux		■	■	■	■	
2. Evaluate P Sources, Forms, Flux, and Transformation Processes in the STAs	■	■				
3. Investigation of STA-3/4 PSTA Technology Performance, Design, and Operational Factors	■					
4. Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability	■	■	■			
5. Improving Resilience of Submerged Aquatic Vegetation (SAV) in the STAs	■	■				
6. Investigation of the Effects of Abundant Faunal Species on P Cycling in the STA	■	■				
7. Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs	■	■				
8. Sustainable Landscape and Treatment in a Stormwater Treatment Area		■	■	■	■	
9. Quantifying the Recalcitrance and Lability of Phosphorus (P) to Optimize P Retention within STAs		■	■	■	■	■
10. The effect of Vertical Advective Transport on TP Concentrations in the STAs			■	■	■	■
11. Phosphorus Reduction Dynamics in STA-1E, STA-1W, STA-2, & STA-5/6		■	■	■	■	
12. Prescribed Burn Effects on Cattail Communities		■	■	■	■	
13. Assess Benefits and Feasibility of Consolidating Accrued Marl in the Stormwater Treatment Areas' Submerged Aquatic Vegetation Cells			■	■	■	■
14. Quantifying phosphorus uptake and release of periphyton and phytoplankton		■	■	■	■	
15. L-8 FEB and STA Operation Guidance	■	■	■	■		
Other Study Efforts: STA Water and Phosphorus Budget Improvements	■	■	■	■	■	■

FEB = flow equalization basin; P = phosphorus; PSTA = periphyton-based stormwater treatment area; STA = stormwater treatment area.

Description of Study Concepts

Use of Soil Inversion to Control P Flux
Key Question Addressed
How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)?
Sub-Question Addressed
What is the treatment efficacy, long-term stability, and potential impact of soil amendment management?
Background and Rationale
This is a continuation (Phase III) of a Science Plan study initiated in 2013: *Use of Soil Amendments/Management to Control P Flux*. Several approaches to reduce wetland soil-P flux and its effect on treatment performance have been investigated at various scales: removing all soil down to the caprock layer, covering the soil with a layer of low-P material (e.g., limerock), deep tilling the soil surface horizon down into the underlying soil layers (i.e., soil inversion) and adding amendments, by broadcasting on top of or incorporation into the soil. This study was scheduled to proceed in three phases with a STOP/GO decision at the end of Phases I and II. Phase I included: 1) a literature review of soil amendments and management techniques applicable to wetlands; 2) a review of relevant South Florida Water Management District-supported research projects; and 3) a feasibility assessment of the constructability, treatment efficacy, operations and regulatory issues, and economics of implementing these technologies in the STA. Completed in 2015, a summary report of Phase I was submitted to District management (Chimney, 2015). Based on Phase I findings, a recommendation was made to modify the scope of Phase II to test a few select soil amendments and concurrently begin the design and construction of the Phase III test facilities; conceptual designs for these facilities were provided in the Phase I report. However, considering the uncertainties in treatment efficacy, potential impacts to STA operations, and the economics associated with conducting field-scale trials and implementing any of these technologies in the STAs, Phase III was modified to only investigate soil inversion in the STA-1W Expansion Area (EA) as proposed in the Phase I report. Work on all other components of this study have been postponed indefinitely. Laboratory soil-core incubations found that inverted marl and peat collected from EA Cell 7 released substantially less soluble reactive P when flooded than did untilled soil from EA Cell 6 (Josan et al., 2018).
References
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. Josan, M., R. Taylor, and K. Grace. 2018. Evaluation of the Benefits of Soil Inversion in Minimizing Release of Phosphorus from Soil in STA-1 West Expansion Area 1. Prepared by the South Florida Water Management District and DB Environmental, Inc.
Hypotheses
Reducing the flux of dissolved P from the soil in an operating STA will lead to a reduction of total phosphorus (TP) concentration in surface water at the outflow. Reducing the flux of dissolved P from the soil during start-up of a new STA will shorten the time required for the wetland to achieve its start-up criterion.
Objectives
1. Invert soil in a 1,323-acre STA cell (Cell 7) to a depth of 2 feet. 2. Compare outflow TP concentrations from the treated cell and an untreated cell. 3. Assess whether soil inversion is a viable management technique to reduce TP concentrations in discharge from the STAs.
Proposed Methodology (Location, Scope, and Duration)
The STA-1W EA will consist of three new cells (Cells 6, 7 and 8) immediately west of the existing STA-1W facility. All soil in Cell 7 (1,323 acres, the experimental unit) will be inverted to a depth of 2 feet, while the soil in Cell 8 (1,231 ac, the control) will be left undisturbed. The treatment performance of Cell 7 will be compared to that of Cell 8 to evaluate the efficacy of soil inversion to reduce outflow TP concentrations. Grab samples will be collected weekly from all sites and analyzed for TP and other constituents such as other P species, nitrogen species, and calcium. The current construction schedule calls for all STA-1W EA cells to be flow-capable by December 31, 2018. An estimated 12 months will be needed for the aquatic vegetation community to become fully established after the

facility is flooded and the cells meet their P start-up criterion. Data collection will begin approximately in June 2019 and will last 4 years. This provisional schedule is subject to revision if the completion of STA-1W EA construction or the start of flow-through operations changes.
Activities and Milestones STA-1W EA cells become flow capable – December 31, 2018 Initiate water quality sampling at inflows and outflows of Cells 7 and 8 – June 2019 End of water quality sampling in Cells 7 and 8 – December 2023 Final project report – May 2024

Evaluate P Sources, Forms, Flux, and Transformation Processes in the STAs
Key Questions Addressed How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)? How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce soluble reactive P (SRP), particulate P (PP), and dissolved organic P (DOP) concentrations at the outflow of the STAs?
Sub-Questions Addressed 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 different STAs, and how do they compare to the natural system? What is the role of vegetation in modifying P availability to low-P environments, including the transformation of refractory forms of P?
Background and Rationale Many years of STA performance data suggest internal processes play a critical role in influencing outflow total P (TP) concentrations. Previous analyses show that at the lower end of the treatment flow-way, where TP concentration and load have been reduced significantly, inflow P concentration and loading are not significantly correlated with outflow P concentration ($p > 0.05$; Juston and DeBusk, 2006). This suggests other variables (e.g., internal flux) may be key influencing factors. Biogeochemical cycling of P within the STAs is controlled by various mechanisms and influenced by several physical, chemical, and biological factors. While numerous publications address these mechanisms and factors in natural and constructed wetlands, there is limited information identifying the key drivers and the magnitude of their influence in low-P wetland environments. TP in the STAs is composed of SRP (also referred to as dissolved inorganic P), PP, and DOP. Water column SRP, the form readily available for plant and microbial uptake, generally is reduced to minimum detection levels near outflow locations. In a well-performing STA, the residual P is composed of PP and DOP. PP generally is composed of living organisms (e.g., bacteria, phytoplankton), detritus, and non-living particulates (Noe et al., 2007). DOP is a soluble form of P associated with organic molecules and can be labile (e.g., simple P monoesters) or stable (e.g., complex organic compounds, P diesters). There are several sources of P in STA outflows (Kadlec and Wallace, 2009): 1. Residual P from inflow that has not settled (PP) or been converted via biogeochemical transformations (PP and DOP), and excess SRP that has not been consumed by microorganisms, periphyton, or plants or has not reacted with cations such as calcium (Ca); 2. P from organic matter decomposition and upward flux from soils within the STA; and 3. P associated with suspended particulates, including suspended solids, plankton, and detritus. This study began in 2014, with a review of available information and literature, and a comprehensive study plan was developed (South Florida Water Management District [SFWMD], 2014). Updates and findings have been reported in the South Florida Environmental Report (Villapando and King, 2018). Key findings include the following: 1. Zonal patterns in processes and factors that control P were observed based on historical data, indicating spatial zones of transformation or transport pathways. 2. Coupled movement and transformation of P and nitrogen. Soil total nitrogen becomes an important factor in TP reduction near the end of the flow-way. 3. Vegetation density is influenced by soil physical properties and nutrients. 4. TP in the water column, soil (concentration and storage), and vegetation tissues follow an inflow to outflow gradient. Soil enrichment is highest at the inflow region. 5. There is no measurable diffusive flux in the outflow regions of STA-2 Flow-ways 1 and 3. However, an increase in water column TP has been observed during no-flow conditions, primarily in the form of PP. 6. For flow-ways where the outflow TP concentration is less than 20 micrograms per liter ($\mu g\ L^{-1}$), higher flows generally resulted in lower outflow TP concentrations.

Data collection and measurements are continuing through 2019 for the following components (sub-studies):

1. P speciation – Identify and quantify the different forms of P that make up the organic P pool in water, floc, and soils using direct and detailed analytical methods. Develop an improved sampling approach for organic P in surface water samples that increases sensitivity and accuracy of evaluations for all P forms. This will allow a more accurate assessment regarding which forms of organic P may be limiting the ability of the low-performing STAs to reduce TP concentrations to those observed in high-performing STAs and in the natural system.
2. Flow-way assessments at different flow condition (transect study) – Evaluate the biogeochemical responses of the different regions along selected STA flow-ways to three different flow scenarios: stagnant, low flow, and high flow, to determine the relative magnitude of influence of those factors, particularly those related to P sources, flux, and transformations.
3. Comparison between STA flow-ways and Water Conservation Area 2A (WCA-2A) – Examine existing sites in WCA-2A with known variation in P enrichment to evaluate which forms of P and what internal processes may be limiting the ability of the low-performing STAs to reduce TP concentrations. This analysis will provide important comparisons on the transformability, or potential recalcitrance of P, in these systems that may help improve STA performance.
4. *In situ* sediment dynamics – Evaluate the effects of specific operational or environmental conditions (e.g., change in flow operation, vegetation community structure, presence of vegetation strips, presence of deep areas) in altering particulate processes. PP burial, reductions in PP resuspension, or decreases in water PP and TP will be considered benefits. The study will identify conditions in which PP resuspension is high but potentially unmanageable (e.g., wind events) and cost-prohibitive or logistically impractical to fix (e.g., preferential flowpaths caused by large remnant canals).
5. Hydrologic and hydraulic measurements – Collect hydrologic (stage, water depth) and hydraulic (flow) measurements to support investigations related to P speciation and transformations, particulate dynamics, vegetation pathways, and fauna pathways. Hydrologic and hydraulic measurements will be taken in conjunction with the other field tests, at flow-way and study site scales.
6. Soil characterization – Collect and analyze soil samples to document baseline soil conditions in the STAs and provide process-level information on P uptake and release, transport of dissolved P across the soil-water interface, and movement of P within the soil profile. Results will be used to evaluate the influence of soil characteristics in flux rates and water column P chemistry.
7. P sorption and desorption characteristics – Compare the P sorption and release properties of floc and soil layers from STA-2 Flow-ways 1 and 3, STA-3/4 Cells 3A and 3B, and WCA-2A, and evaluate the relationships among P sorption parameters and selected soil properties. The study will identify soil variables that best predict P sorption/desorption.
8. P flux – Measure P flux rates from enriched and unenriched areas of the STA, with and without vegetation, under stagnant water conditions using *in situ* mesocosm-scale chambers and porewater equilibrators to identify soil variables that exert influence on P flux.
9. Microbial activity – Evaluate the patterns and trends in microbial activity along a P gradient within STA flow-ways subjected to a range of hydraulic conditions.
10. Vegetation assessments – Survey and sample plant communities and relate those to water column P concentrations, floc and soil P storage and stability, soil characteristics, soil accretion, and ultraviolet radiation/light penetration.
11. Fauna – Quantify animal communities and their effects on water quality and vegetation by surveying the density, biomass, and composition of aquatic fauna (e.g., fishes, large macroinvertebrates) and birds in the outflow cells, and determine the mass-specific P excretion rates of common aquatic fauna.
12. Controlled studies – More detailed scopes, including design and methodologies for the controlled studies, will be developed after initial studies have been completed. A subset of factors and mechanisms is anticipated to emerge as potential key influencers to P reduction processes, information gaps, and uncertainties related to these factors and mechanisms are identified. Isolating certain variables and studying these in a more controlled environment may establish cause and effect relationships between key variables and water column P.

References

Juston, J.M. and T.A. DeBusk. 2006. Phosphorus mass load and outflow concentration relationships in stormwater treatment areas for Everglades restoration. Ecological Engineering 26:206-223.

Kadlec, R.H. and S.D. Wallace. 2009. Treatment Wetlands, Second Edition. Taylor and Francis Group, Boca Raton, FL.

Noe, G.B., J.W. Harvey, and J.E. Saiers. 2007. Characterization of suspended particles in Everglades wetlands. Limnology and Oceanography 52:1,166-1,178.

SFWMD. 2014. Restoration Strategies Science Plan Detailed Study Plan: Evaluate P Sources, Forms, Flux, and Transformation Processes in the STAs. Water Quality Treatment Technologies Section. South Florida Water Management District, West Palm Beach, FL.

SFWMD, University of Florida, and DB Environmental, Inc. 2018. Data Analysis, Integration, and Synthesis Plan: Evaluate Phosphorus Forms, Sources, Flux and Transformation Processes in the Everglades Stormwater Treatment Areas (Restoration Strategies Science Plan Study). DRAFT. South Florida Water Management District, West Palm Beach, FL.

Villapando, O. and J. King. 2018. Appendix 5C-3: Evaluation of Phosphorus Sources, Forms, Flux, and Transformation Processes in the Stormwater Treatment Areas. Volume I: South Florida Environmental Report. South Florida Water Management District, West Palm Beach, FL.

Objectives

This study has multiple objectives:

1. Characterize the different P forms and cycling along the STA inflow to outflow gradient;
2. Understand the composition of the residual P at the outflow;
3. Determine the factors affecting P cycling along the gradient;
4. Understand the differences in P forms, factors, and processes among different flow-ways (best-performing versus poor-performing); and
5. Compare the findings with natural areas (WCAs).

Hypotheses

Due to the complexity of this study, with multiple components, there are many hypotheses. Some of the more general hypotheses developed during the project planning phase are as follows:

1. The ability of an STA flow-way to remove SRP, convert DOP to SRP, and retain PP early in the flow-way affects TP concentrations in the lower reaches of the flow-way and at the outflow.
2. Long-term retention of P in the STAs is a function of the distribution and concentration of labile versus recalcitrant forms of P that accumulate in the soil.
3. Microbially mediated P transformations are essential to achieve low TP concentrations in the lower reaches of the flow-way.
4. Internal P fluxes in lower reaches of an STA flow-way significantly increase water column P and have significant impacts on the flow-way outflow P concentrations.
5. Outflow TP in STAs can be reduced by increasing the settling and burial of PP.
6. Outflow TP in STAs can be reduced by preventing or decreasing resuspension of PP into the water column.
7. There is an optimal spatial vegetation pattern of EAV and SAV for P retention in terms of facilitating particulate settling and Ca-P co-precipitation, controlling internal flux, generation of stability of stored P in soils, and microbial activities.
8. Fauna impact P concentrations in the water column of the outflow cells via consumption and excretion, bioturbation, translocation, and herbivory.

More specific study questions are included in the Detailed Study Plan (SFWMD, 2014) and in the Data Synthesis and Integration Plan (SFWMD et al., 2018).

Proposed Methodology

A comprehensive description of the methodology, including location, scope, and duration, for the different components of this study is included in the Detailed Study Plan (SFWMD, 2014). Additional details are included in individual sub-study work plans and contract statements of work.

Activities and Milestones
1. Develop a study plan/design - March 2013 (Completed)
2. Procurement (contractual consultants, equipment, supplies) – April to June 2013 (Completed)
3. Set up equipment and transect locations – June to July 2013 (Completed)
4. Data collection/sampling – July 2013 to June 2015 (Extended through December 2018)
5. Data analysis and reporting – June to December 2015 (Extended through June 2019)

Investigation of STA-3/4 PSTA Technology Performance, Design, and Operational Factors

Key Questions Addressed

How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)?

How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce soluble reactive P (SRP), particulate P (PP), and dissolved organic P (DOP) concentrations at the outflow of the STAs?

Sub-Questions Addressed

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?

Background and Rationale

Constructed in 2005, the STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Project consists of an upstream 200-acre cell (upper submerged aquatic vegetation [SAV] cell) and two adjacent downstream 100-acre cells (lower SAV and PSTA cells) in the western portion of Cell 2B (**Figure A-1**). Peat was scraped to the caprock in the PSTA cell, removing a potential source of upward P flux. Emergent aquatic vegetation (EAV) strips were planted perpendicular to flow with the goal of improving the PSTA cell's hydraulic efficiency.

Objectives

The STA-3/4 PSTA Project's primary objectives were to conduct a detailed assessment of PSTA technology performance, determine design and operational factors that contribute to performance, and identify opportunities for full-scale replication. The PSTA Project is intended to achieve the following objectives:

1. Determine the important design elements and biogeochemical characteristics that enable the PSTA cell to achieve ultra-low outflow TP levels.
2. Identify the key operational ranges that enable the PSTA cell to achieve ultra-low outflow TP levels.
3. Identify management practices required to sustain the PSTA cell's performance.
4. Consider the feasibility of larger-scale implementation upon completion of this study. Objective 4 most likely will be initiated as a separate study.

Hypotheses

1. Total P (TP) concentrations in outflow water from the PSTA will consistently meet the water quality-based effluent limit (WQBEL).
2. TP concentrations in outflow water from the PSTA will be consistently lower than TP concentrations in the inflow water.

Proposed Methodology

The PSTA Project as originally planned (South Florida Water Management District [SFWMD], 2014) is mostly complete, and results have been presented in many technical and peer-reviewed publications.

The following are descriptions of the remaining sub-studies to be completed in Fiscal Year 2018:

Mesocosm Study to Quantify Operational Boundaries of PSTA: P Loadings and Water Depth

This study is being conducted to understand the effect of maximum P loading ranges and operational depths under which key PSTA biota can be maintained and harnessed for low-level TP reduction. Mesocosms have been operational at the STA-1W research facility since 2011 and sampling was completed in June 2018. This mesocosm facility is being used to explore effects of a range of P loading (0.37 to 1.25 g P m^{-2} $year^{-1}$) and depth (23 to 91 centimeters) regimes on periphyton and macrophyte communities as well as on treatment performance. This facility is being used to document the process basis (e.g., effects of load and depth on biota and enzyme activity) for potential variations in treatment with increasing water depths and P loads. To date, operations within these mesocosms have been successful, with all depth treatments consistently providing outflow TP levels below 13 µg L^{-11}, so they are an ideal platform for establishing operational boundaries on PSTA biota and ultra-low P reduction performance.

Mesocosm Study to Evaluate Alternatives to Muck Removal (PSTA)

In Fiscal Year 2015, the study team completed operations of a mesocosm study to explore the effectiveness of a limerock cap as an alternative to muck removal. The muck soils used for this study, however, were quite stable with respect to P release, so questions related to limerock effectiveness as a cap over more P-enriched muck soils remain. In 2016, a new mesocosm study was established, in which limerock caps of two thicknesses (5 and 15 centimeters) were placed over P-enriched muck soils, obtained from a farm field adjacent to STA-1W. To date, the limerock caps have proven effective at minimizing P release from the enriched soils, although the long-term effectiveness of the limerock caps as well as the interactions between the caps and rooted SAV are not yet well defined. An assessment of the effectiveness of the limerock in reducing P flux as well as curtailing soil P mining by SAV was continued through January 2018. At that time, water quality monitoring was terminated and close-out measurements (e.g., soil, vegetation) were performed.

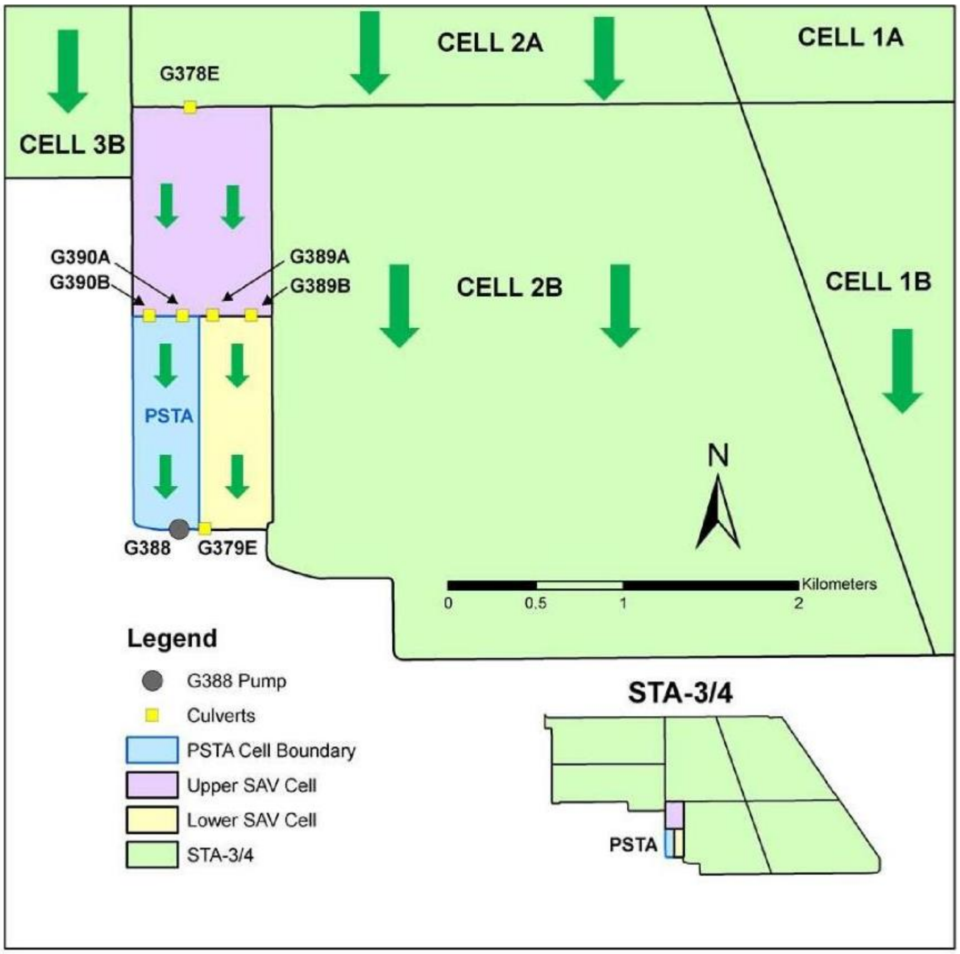


Figure A-1. Schematic of the PSTA project in the western portion of Cell 2B of STA-3/4.

References

SFWMD. 2014. Restoration Strategies Science Plan. Draft Detailed Study Plan. Investigation of STA-3/4 PSTA Performance, Design, and Operational Factors. Water Quality Treatment Technologies Section, South Florida Water Management District, West Palm Beach, FL.

Activities and Milestones

1. Complete remaining PSTA mesocosm sub-studies and related reports by September 2018.

Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability

Key Question Addressed

What measures can be taken to enhance vegetation-based treatment in the stormwater treatment areas (STAs)?

Sub-Question Addressed

What key factors affect and what management strategies could improve system resilience of emergent aquatic vegetation (EAV) communities?

Background and Rationale

Water stages for different STA cells are managed based on a target depth of 1.25 feet. However, peak flows in the wet season, particularly during and/or following storm events, often occur and cause water level pulsing of >3.0 feet, with a frequency of up to 5 times in treatment cells. Small changes in water level (±1.0 feet from the target depth) may not greatly affect cattail growth (Miao and Zou, 2012; Sorrell et al., 2012), but water level fluctuations greater than ±1.5 feet adversely reduce cattail biomass by >50% (Deegan et al., 2007). Where water level pulsing occurs quickly, cattail (*Typha domingensis*) may not have an opportunity to morphologically adjust to rising water levels before water levels change again, requiring a different set of responses to optimize resource capture. Knowledge of how cattail growth relates to water level pulsing is vital to understanding and predicting the responses of cattail communities to hydrologic regimes for STA management practices. Mesocosm studies indicate that 6-week inundations at >3.0-foot water depths negatively impacted cattail health (Chen et al., 2010, 2013), but little research on the impact of water level pulsing on cattail community sustainability is available for the STAs, although water level pulsing often occurs.

In situ field observations and parameter measurements in STA-1W Cell 2A and STA-3/4 Cell 2A were completed in January 2018. The second part of this study will be conducted in the STA-1W North Test Cells.

Preliminary Results

During the first wet season monitoring of events in STA-1W Cell 2A, no significant differences were observed in cattail shoots, including plant density, photosynthesis, foliage area index, and leaf elongation, between the inflow and outflow regions of the cell. Total cattail biomass from initial and final samples from the first wet season of plots in the inflow and outflow regions of this cell were not significantly different from each other ($p > 0.05$). However, there was a significant decline in total biomass in the final sampling collected at the end of the first wet season. Because water depth was assumed to be uniform across STA-1W Cell 2A, continuous inundation of the cell above the target depth without rest periods may be responsible for the decline in biomass. Field observations included cattail damage, presence of floating cattail mats, and presence of other emergent or floating tussocks that may have contributed to the overall decline in cattail population of this cell.

Cattail shoot density from plots in the inflow and outflow regions of STA-3/4 Cell 2A were not significantly different ($p > 0.05$) from each other despite deeper daily average water depths in the inflow region of this cell. Total plant biomass from initial and final samples collected during the first wet monitoring season of inflow and outflow plots were not significantly different from each other. However, the belowground biomass to leaf ratio in both sampling events was higher in the outflow plots compared to the inflow plots of the cell, which suggests the roots and rhizomes were stressed more than the shoots in the cell's inflow region. Daily water depths in STA-3/4 Cell 2A were consistently higher in the inflow region, with depths decreasing toward the outflow region of the cell. A third biomass sampling was completed at the end of the 2017 wet season, which will help corroborate the initial results. Plant biomass was measured at the beginning, after the first year, and at the end of the *in situ* study.

References

Chen, H., M.F. Zamorano, and D. Ivanoff. 2010. Effect of flooding depth on growth, biomass, photosynthesis, and chlorophyll fluorescence of *Typha domingensis*. Wetlands 30:957-965.

Chen, H., M.F. Zamorano, and D. Ivanoff. 2013. Effect of deep flooding on nutrients and non-structural carbohydrates of mature *Typha domingensis* and its post-flooding recovery. Ecological Engineering 53:267-274.

Deegan, B.M., S.D. White, and G.G. Ganf. 2007. The influence of water level fluctuation on the growth of four emergent macrophyte species. Aquatic Botany 86:309-315.

Miao, S.L. and C.B. Zou. 2012. Effects of inundation on growth and nutrient allocation of six major macrophytes in the Florida Everglades. Ecological Engineering 42:10-18.

Sorrell, B.K., C.C. Tanner, and H. Brix. 2012. Regression analysis of growth responses to water depth in three wetland plant species. AoB PLANTS 2012:pls043.

Objectives

1. Evaluate how the survival, growth, and propagation of cattail communities are influenced by field conditions such as water depth and duration and frequency of inundation. Results from the *in situ* study will serve as a basis in the experimental design of the next phase of this study (starting in June 2019).
2. Establish an inundation depth and duration threshold. The results of these studies will help identify the depth and duration threshold for cattail sustainability, which will assist in developing water level management strategies in the STAs.

Hypotheses

1. There is an inundation duration threshold for cattail sustainability at a specific inundation depth, in terms of survival, growth, and propagation.
2. The inundation duration depth threshold is longer at relatively shallow inundation depths than at deep inundation conditions.
3. Longer inundation durations than the threshold result in a decline in cattail growth, in terms of plant density, the ability to propagate, and biomass.

Proposed Methodology

Location

The Test Cell Study will be conducted in the STA-1W North Test Cells.

Scope

1. *In Situ* Study – Completed
2. Test Cell Study:

Before the Test Cell Study could begin, the 15 test cells had to be refurbished to improve soil and drainage conditions, overhaul inflow pumps, and control unwanted vegetation.

Phase 1: Establishment of a Cattail Community and Sampling Plots

Cattail seeding began in March 2018. Water levels in the test cells will be maintained from soil saturation to approximately 1 inch above soil surface to encourage cattail seed germination. In addition, cattail seedlings will be grown in pots and transplanted later to achieve a more uniform cattail population in all cells. Establishing a uniform cattail community is estimated to take 1 year or longer. Cattail will be allowed to grow and fully mature prior to initiation of experimental testing. During the period of cattail establishment, inundation at the test cells will be maintained at a depth of 1.25 feet or lower to encourage cattail seedling growth. Soil samples will be collected at a depth of 0 to 6 inches and analyzed to determine baseline conditions after a uniform healthy cattail stand is established but prior to experimental testing. A second set of soil samples will be collected at the end of the study. The experimental design, including size, location, and number of plots in each cell, is in the planning phase.

Phase II: Implementation of the Experimental Plan

The experiment will have two factors: inundation depth and duration. Due to limitations in the depth of the test cells, inundation depth will range from 1.25 (target depth in EAV cells) to 4 feet. The final combinations of inundation depth and duration are in the design phase, and data collected during the *in situ* study will help refine the treatment levels.

Parameters to be Tested

Soil:

Soil samples will be analyzed for moisture content, bulk density, ash content (ash-free dry weight, calculated), pH, total phosphorus, total carbon, total nitrogen, ammonia (NH_4-N), and ortho-phosphate. Soil redox conditions will be measured in the field. Soil redox data from permanent sampling stations will be downloaded on a bi-monthly basis, or as needed.

Vegetation Survey and Measurement:

Study parameters and field observations during each monitoring event will include plant density (adult and juvenile), photosynthesis, foliage area index, leaf elongation, and water depth using a graduated polyvinyl chloride (PVC) pole. Field observations will include cattail damage and presence of floating mats, presence of other EAV or floating aquatic vegetation within the plots, and photo documentation of each plot. Frequency of monitoring events is under development. Samples for plant biomass measurements, including aboveground and belowground, and live and dead material will be collected at random using a 0.25-m^2 quadrat, prior to initiation of experimental testing and at the

end of the inundation duration treatments in each cell. Biomass samples will be separated into live leaf, rhizome, shoot base, root, and dead plant material.
Activities and Milestones 1. Cattail grow-in – March 2018 to March 2019 (ongoing) 2. Initial soil sampling in test cells – July to August 2018 (ongoing) 3. Plot set-up in the test cells – January to March 2019 4. Beginning of test cell monitoring – June 2019

Improving Resilience of Submerged Aquatic Vegetation (SAV) in the STAs

Key Question Addressed

What measures can be taken to enhance vegetation-based treatment in the stormwater treatment areas (STAs)?

Sub-Question Addressed

What key factors affect and what management strategies could improve system resilience of submerged aquatic vegetation (SAV) communities?

Background and Rationale

SAV plays an important role in removing nutrients, especially phosphorus (P), from the water column in downstream treatment cells of the Everglades STAs. SAV species, especially muskgrass (*Chara* sp.), can grow rapidly if the right water chemistry (e.g., inorganic carbon, low P) and adequate water levels are maintained. Sudden declines of SAV (e.g., *Chara* sp.) have been observed in different parts of the STAs, resulting in a shift from clear to turbid water and a decline in P reduction.

The causes of such die-offs have not been examined, and no data analyses have been conducted to explain the sudden loss of SAV or the gradual transition to different vegetation species in the STAs. Understanding these sudden shifts in vegetation could improve management of the STAs, leading to increased resilience of the target SAV species.

Objectives

The overall objective of the study is to investigate the effects of operational (e.g., water depth, flow velocity, nutrient concentration, mineral concentration) and natural environmental conditions (e.g., seasonality, light penetration, disease, clonal stresses, competition with epiphytic periphyton) on SAV health in the STAs. The study will investigate allelopathic effects of *Chara* sp. that may inhibit growth of other species. SAV loss due to herbivory or extreme weather events is being addressed in another study.

For Phase I implementation, the primary objectives are as follows:

1. Research available literature relevant to SAV biology, growth factors, and stressors;
2. Analyze available information and examine trends in SAV growth and species distribution; and
3. Develop experimental methods and further examine selected factors and/or management strategies.

Hypotheses

Hypotheses will be developed for Phase II implementation, based on knowledge gained from Phase I (literature review and analysis of historical information).

Proposed Methodology

The study will be conducted in two phases, with a STOP/GO decision at the end of Phase I. Knowledge and data gaps will be addressed in Phase I through a literature review and an analysis of STA research. This information should result in a set of factors to investigate in Phase II.

Phase I consists of four tasks:

1. Review literature – Expand on and finalize existing literature review of SAV biology and factors that influence SAV growth. Gather information on SAV community management.
2. Analyze historical SAV data – Analyze existing information from SAV surveys and water quality data in selected STA cells.
3. Develop methods – Propose experimental and analytical techniques to answer study questions.
4. Study plan development – If Phase II is warranted based on Phase I findings, develop a study plan for Phase II implementation.

Activities and Milestones

1. Literature review – March 2018 (Completed)
2. Data analysis and report – June 2018 (Completed)
3. Method development – July 2018 (Ongoing)
4. Phase II study plan development – December 2018

Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs

Key Questions Addressed

How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)?

What is the influence of wildlife and fish on the reduction of P in the STAs?

Sub-Questions Addressed

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?

What are the direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (i.e., are they net sinks or sources)?

Background and Rationale

To understand the mechanisms and factors that affect P treatment performance of STAs at low total P (TP) concentrations, it is important to evaluate P sources, forms, flux/movement, and transformation processes along the STA flow-ways. Fauna can play pivotal roles in these P processes, either directly via consumption and excretion (including transportation and storage of P in body tissues) or indirectly through modifications of the environment such as bioturbation, top-down effects (e.g., consumption of submerged aquatic vegetation [SAV]), and trophic cascades. Preliminary studies have shown that some faunal populations are extremely abundant in the STAs and could have significant effects on water column TP. Abundances are much more temporally and spatially variable compared to natural systems. This inherent patchiness makes it difficult to estimate populations with the precision needed to scale up data for development of nutrient budgets. Robust and scalable budgets will require a better understanding of the abundance, distributions, and size structure of species.

Objectives

The overall study objective is to continue and expand on faunal research conducted as part of the study: Evaluate P Sources, Forms, Flux, and Transformation Processes in the STAs. This will include the following actions:

1. Quantify and record biomass of large-bodied fishes (by electrofishing) and small-bodied fishes/macroinvertebrates (by throw-trapping) in STA outflow cells.
2. Determine *in situ* mass-specific P excretion rates of the most abundant fish and macroinvertebrate species.
3. Evaluate the potential for abundant benthic foraging species (e.g., tilapia-*Oreochromis spp*., catfish-*Pterygoplichthys spp*.) to enhance water column TP by resuspension (i.e., bioturbation and translocation) of stored P from floc and soil.
4. Combine faunal biomass data with excretion, bioturbation, and movement results to estimate areal P excretion and resuspension rates at relevant spatial and temporal scales.

Hypothesis

Faunal activities in lower reaches of the flow-way significantly increase STA outflow TP concentrations, negatively impacting the low-discharge requirements.

Proposed Methodology

1. Quantify faunal biomass and community composition in STA outflow cells – The biomass and composition of large-bodied fishes will be sampled by electrofishing, and small-bodied fishes/macroinvertebrates will be sampled by throw-trapping in STA outflow cells. Sampling will be conducted over a 1-year period in the same STAs and outflow (SAV) cells that were sampled during the initial 1-year survey. Analysis of nutrient content in faunal body tissues will be conducted by the South Florida Water Management District (SFWMD) laboratory.
2. Measure animal impacts on P turnover – Excretion rates will be measured in the STAs using short-term incubations methods developed by Trexler (2016). Water samples will be collected from the field, filtered, and used to estimate dissolved P before and after faunal incubations. Controls will contain no animals. Bioturbation of TP will be experimentally measured in field mesocosms stocked with three densities of each target species: 1) no fish, 2) average density for the area, and 3) maximum recorded density for the area. Weekly samples of floc, vascular plants, periphyton, and water will be taken for 4 weeks after the start of the study. Plastic strips acting as periphytometers and P-absorbing substrates will be sampled. Water samples will be analyzed at the SFWMD laboratory for soluble reactive P or total dissolved P. Floc, floral, and faunal body tissue nutrients also will be analyzed by the SFWMD laboratory.

3. Scale up the P budget parameters – Areal biomass data from the faunal surveys will be combined with species- and mass-specific excretion rates and fish movement models to generate total community excretion estimates. Areal estimates of P resuspension based on faunal biomass and mesocosm results will be scaled up to appropriate STA cell areas. These estimates will be compared with concentrations in the surface water as well as changes across the STA cells (input and output values) to consider the magnitude of the source of P internal recycling compared with external sources and change in the P concentration as water moves through the cells. The calculated P excretion rates, resuspension rates, and movements will be used to parameterize P budgets and models for the STAs.

References

Trexler, J. 2016. Task 3 – Report of Final Study Design Quantification of the Aquatic Faunal Community and its Effect on Water Quality in the Everglades Stormwater Treatment Areas (STAs). Report submitted to the South Florida Water Management District in partial fulfillment of WO 460000303.

Activities and Milestones

1. Seasonal sampling – May 2018 to April 2019 (Ongoing)
2. Excretion/bioturbation rates – June to December 2018 (Ongoing)
3. Final report – May 2019

Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs
Key Question Addressed What measures can be taken to enhance vegetation-based treatment in the stormwater treatment areas (STAs)?
Sub-Question Addressed What key factors affect and what management strategies could improve system resilience of emergent aquatic vegetation (EAV) communities?
Background and Rationale The Everglades STAs are highly dynamic, managed systems subject to variations in hydrology, hydraulic loading, and topography. As a result, water levels in the STAs often are outside the optimal depth range for the EAV community. Deepwater conditions in STAs may affect cattail (*Typha domingensis*) health and coverage. Floating cattails and cattail tussocks may be the result of prolonged deepwater conditions. Tussock formation in the STAs could be aggravated by other factors such as vegetation type, soil characteristics, and physical and chemical processes.
Objectives The study's overall objective is to determine the key factors that cause floating of cattail plants and tussocks in the STAs. Specifically, the study would characterize and compare conditions between areas of healthy cattail coverage (without signs of floating cattail plants or floating tussocks) and areas prone to chronic floating tussock formation in the STAs. The study will examine STA operational ranges that promote the formation of floating tussocks. In addition, the study will assess the effects of floating tussocks on STA treatment performance. Finally, results from this study should provide an understanding of the factors that contribute to the formation of floating tussocks in the STAs.
Hypotheses Hypotheses will be developed for Phase II implementation based on knowledge gained from Phase I (literature review and analysis of historical information).
Proposed Methodology The study will be conducted in two phases, with a STOP/GO decision at the end of Phase I. Knowledge and data gaps will be addressed in Phase I through a literature review and an analysis of STA research. This information should result in a set of factors to be investigated in Phase II. Phase I consists of four tasks: 1. Literature search and review – A preliminary review of previous research and existing information on floating tussocks, causal factors, and management strategies will be conducted and summarized. 2. Assessment of floating tussock coverage in STA EAV cells – A comprehensive spatial survey (ground and aerial) of each STA EAV cell will be conducted to determine the current coverage and extent of floating cattails and tussocks. Affected areas will be mapped and the approximate coverage and type of floating mat or tussock (based on vegetative community) will be determined. 3. Data mining – Operational ranges, including hydrologic conditions and patterns in selected affected areas, will be evaluated based on findings from Task 2. Available data (vegetation, soil, water quality, stage, and flow) will be examined to determine patterns or commonalities among affected areas. 4. Evaluation of findings/report – Findings from all previous tasks will be summarized and a comprehensive report will be prepared, indicating recommendations (STOP/GO) for further evaluation and the development of Phase II. Phase II will require development of an in-depth study plan, including experimental design and study methods.
Activities and Milestones 1. Literature search and review – March 2018 (Completed) 2. Assessment of floating tussock coverage in STA EAV cells – November 2018 3. Data mining – January 2019 4. Evaluation of findings/report – March 2019

Sustainable Landscape and Treatment in a Stormwater Treatment Area

Key Questions Addressed

What operational or design refinements could be implemented at existing stormwater treatment areas (STAs) and future features, including the STA expansions and flow equalization basins (FEBs)/reservoirs, to improve and sustain STA treatment performance?

What measures can be taken to enhance vegetation-based treatment in the STAs?

Sub-Questions Addressed

What are the effects of topography on STA performance?

What key factors affect and what management strategies could improve system resilience of emergent aquatic vegetation (EAV) communities?

What are the key physicochemical factors influencing phosphorus (P) cycling in very low-P environments?

Are there design or operational changes that can be implemented in the STAs to reduce particulate P (PP) and dissolved organic P (DOP) in the water column?

Background and Rationale

Wave-based field tests were carried out at STAs to understand the hydraulics and flow resistance. The results were used to produce two-dimensional maps of hydraulic resistance, type of hydraulic behavior ranging from kinematic to diffusive flow, and parameters of power law equations describing resistance at different discharge rates. Improved estimation of water depths and residence times could help real-world application and physically based models for project planning or design. The results of the field tests revealed macroscale anomalies in flow distribution in STAs. Such features include areas where flow is restricted by microtopographic features, dense vegetation, or accumulated plant litter and other deeper or sparsely vegetated areas where flow is accelerated, and treatment processes may be short-circuited. Such conditions greatly reduce overall wetland treatment capacity. Determining the spatial distribution of these features may identify opportunities for altering the structural or vegetation characteristics of a wetland to improve its performance. With the results of previous wave-based field tests and renewed understanding of flow through STAs, a series of controlled field tests are proposed to provide more information on flow through wetlands; its potential effects on soil stability, nutrient transport, mixing, and treatment; and the behavior of vegetation. These experiments will be carried out in test cells instead of in STAs because of the difficulty to control the parameters in STAs and potential interference with STA operations.

Objectives

The overarching objective of this project is to provide guidance on how to build or maintain a sustainable STA that experiences hydraulic regimes consistent with *in situ* landscape vegetation, thereby enhancing P treatment while reducing vegetation loss. Specifically, the study plans to:

1. Develop ranges and relationships of depth, slope, and discharge that lead to sustainable treatment cells.
2. Quantify the effects of different flow and nutrient loading conditions on hydraulic mixing, including solute diffusion and dispersion.
3. Evaluate the effects of hydraulic parameters, vegetation parameters, and landscape modifications on treatment performance.
4. Develop a benchmark test under controlled conditions that can be used to predict future modifications to STAs.

Proposed Methodology

Two 80-m × 30-m test cells close to STA-1W will be used. One tapered V-shaped treatment channel has been built inside each test cell with channel banks tapering towards the downstream, providing 0.2 feet of additional width for each foot of canal length (**Figure A-2**). The unique shape of the tapered channel allows for variable discharge per unit width within the same test cell, which increases experiment efficiency in treatment levels. Treatment will include different levels of flows (constant, pulsing), vegetation (uniform, short-circuit, buffer strip), and conservative and non-conservative solutes (tracer, P, calcium). One test cell (open water cell) will be used as a control; the other (vegetated cell) will be planted with different configurations of EAV. Short-circuits will be created in the vegetated cell. The stability of the short-circuits (stable, unstable, neutral) will be documented by studying erosion and/or deposition of soil during the experiment under various steady-state flow conditions. Tracer, P, and other nutrients (e.g., calcium) will be added to the inflow and measured along the transects downstream. Constant and pulsing flow regimes also will be used to compare their effects on transport and mixing due to diffusion and dispersion within the test cells.

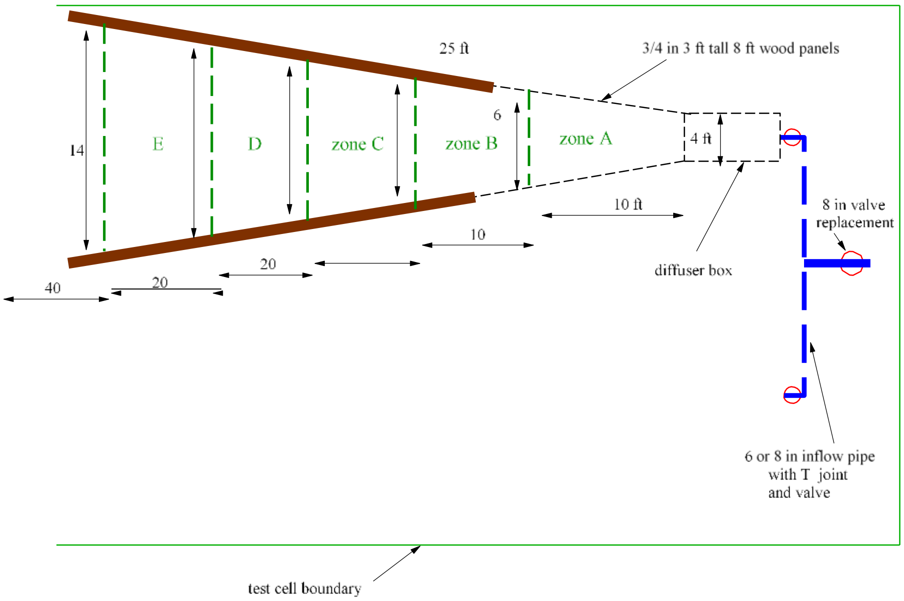


Figure A-2. Schematic of V-shaped treatment channel to be used in the Sustainable Landscape and Treatment in a Stormwater Treatment Area study.

Activities and Milestones

1. Steady-state experiments and creating a steady-state benchmark – December 2020
2. Pulsing experiment and creating a benchmark experiment for transient state – June 2021
3. Landscape modifications and testing various modifications on the benchmarks – June 2022
4. Data analysis and reporting – September 2022

Quantifying the Recalcitrance and Lability of Phosphorus (P) to Optimize P Retention Within STAs
Key Questions Addressed How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)? How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce soluble reactive P (SRP), particulate P (PP), and dissolved organic P (DOP) concentrations at the outflow of the STAs?
Sub-Questions Addressed 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 different STAs, and how do they compare to the natural system? What is the role of vegetation in modifying P availability to low-P environments, including the transformation of refractory forms of P?
Background and Rationale The ability of STAs to achieve low outflow total P (TP) concentrations depends on the system's capacity to reduce P by transforming it from one form to another, with P bioavailability and recalcitrance being important controlling characteristics; a key factor in recalcitrance is the carbon (C) forms associated with organic P. However, the quantification of P species and their lability has been hindered by methodological limitations. Studies conducted during the first 5 years of the 2013 Science Plan have developed more precise measures of P forms, and these approaches can now be implemented, along with C speciation, to assess the P distribution in particulate and dissolved forms, such that how key processes, biota, and transformations can alter the performance of STAs can be clearly demonstrated.
Objectives 1. The overall objective of the study is to use advanced techniques developed as part of the study: Evaluate P Sources, Forms, Flux, and Transformation Processes in the STAs (e.g., mass spectrometry, biomarkers) to link C and P forms and fluxes along the nutrient/flow gradient, within different vegetation communities (submerged/emergent aquatic vegetation) and associated with different faunal communities, to determine their origin and assess whether they were created *in situ* or, less likely, remain unchanged from inflow. 2. A secondary objective is to assess C and P pools at enriched and unenriched sites in Water Conservation Area 2A (WCA-2A) to ascertain whether further transformation of the forms is possible or the most recalcitrant state has been reached.
Hypotheses 1. Outflow TP concentrations in poorly performing STAs can be reduced through increased storage and decreased internal recycling in surface waters along the flow-way. 2. Internal P fluxes in lower reaches of the flow-way significantly increase STA outflow P concentrations, negatively impacting the low discharge requirements. 3. Long-term storage of P in STAs will be a function of the storage of recalcitrant forms in biota or soils.
Proposed Methodology The study will be conducted in two phases, with a STOP/GO decision at the end of Phase I. *Phase I:* 1. Collect water, floc, soil, and faunal excretion samples from one well-performing and one poor-performing STA and analyze for advanced chemical speciation and biomarkers. 2. Collect water, floc, and soil from a moderate/unenriched site in WCA-2A and analyze for advanced chemical speciation and biomarkers. 3. Analyze and report data.

STOP/GO: If no significant compositional differences in P species are observed at oligotrophic or different performing STA sites, detailed P speciation data are assumed to be unnecessary to assess P turnover, and further P speciation assessments of STAs will not occur. *Phase II:* 1. Compare P degradation and turnover under different conditions (e.g., hydraulic loading rate, vegetation, faunal community) in a field/benchtop mesocosm study. 2. Analyze and report data. 3. Recommend approaches (i.e., hydrologic operations and active management of desired vegetation or fauna) to minimize internal cycling (e.g., from biomass, litter, and soil into surface water) and maximize long-term storage in biomass, litter, and soil.
Activities and Milestones 1. Sample collection and processing – October 2019 2. Reporting of P forms and sources – June 2020 3. Mesocosm studies – August 2021 4. Final report – January 2023 5. Recommendations to STA management – March 2023

The Effect of Vertical Advective Transport on TP Concentrations in the STAs

Key Question Addressed

What operational or design refinements could be implemented at existing stormwater treatment areas (STAs) and future features, including the STA expansions and flow equalization basins (FEBs)/reservoirs, to improve and sustain STA treatment performance?

Sub-Question Addressed

Will reduced advective loading from the soil to the water column reduce phosphorus (P) concentrations out of the STAs?

Background

The input terms in a P budget of an STA include loading due to lateral inflows (from pumps and structures), atmospheric deposition, advection or diffusion from the base of the STA, and internal processes that transform P or move it between the water column and soils. Substantial effort has been expended to quantify and understand the role of structure flows and loads on STA performance. While some work has been done on possible loading at the soil-water interface, much of the work has been on diffusion from soil/pore water to the water column due to the high concentration gradient that could occur in an STA, especially one established on previously farmed lands.

Objectives

The objective of this study is to quantify the relative magnitude of advective transport (with upward seepage) of P across the soil-water interface. The study will determine if the P load from upward seepage through P-rich soil significantly contributes to discharge concentrations, especially at low water column P concentrations that characterize the end of the STA treatment train. In addition, the study will quantify the effect of a persistent downward gradient (flow towards the soil from the water column) on advective loads.

Hypothesis

Increased downward advection will reduce the upward contribution of total P (TP) in the water column.

Proposed Methodology

Phase I: Literature review and model simulations

Conduct a literature review on advective loading (e.g., seepage) in wetlands. Develop water and P budgets of lower STA cells to determine the potential of advective seepage into the cell. A simple one-box model will be developed based on these budgets and simulations to quantify contribution of advective loading and determine if downward advection can reduce diffusive loading to the water column, resulting in lower water column TP concentrations. Candidate conditions where persistent downward gradients result in material reduction of TP concentrations will be simulated to determine if downward seepage can reduce TP concentration in the water column.

STOP/GO:
If results from Phase I indicate downward advection will produce lower P concentrations in the water column under specific conditions, continue to Phase II.

Phase II: Data mining

Mine the available data on STA cells near the outflow to determine areas meeting specific conditions and where increased downward advection may reduce TP concentration in the water column.

STOP/GO:
If Phase II determines a potential STA region, continue to Phase III.

Phase III: Field experiments

Develop and test *in situ* experiments to increase downward advection and evaluate if TP concentrations decline as a result.

Activities and Milestones

1. Initiate Phase I – January 2020
2. Complete Phase I, including summary report – November 2020
3. Initiate Phase II – January 2021
4. Complete Phase II – January 2023
5. Initiate Phase III – To be determined, as needed

Phosphorus Reduction Dynamics in STA-1E, STA-1W, STA-2, & STA-5/6

Key Questions Addressed

What operational or design refinements could be implemented at existing stormwater treatment areas (STAs) and future features, including the STA expansions and flow equalization basins (FEBs)/reservoirs, to improve and sustain STA treatment performance?

How can internal loading of phosphorus (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, particulate, and dissolved organic phosphorus concentrations at the outflow of the STAs?

Sub-Question Addressed

What are the key physicochemical factors influencing P cycling in very low-P environments?

Background and Rationale

The ability of an STA to reduce P concentrations in the water column and achieve low concentrations at the outflows is influenced by many factors, including treatment area size, P loading rates, hydraulic loading rates, inflow concentration, internal P flux, soil and water chemistry, and vegetation condition (Reddy et al., 1999; Richardson and Qian, 1999; Kadlec and Wallace, 2009; Ivanoff et al., 2013; Chen and Vaughan, 2014). In addition, other factors such as short-circuits, extreme weather conditions, and bioturbation could affect outflow total P (TP) concentrations. The effects of these factors could be short or long term. While some of the factors are natural occurrences and not controllable, some could be moderated to benefit STA performance.

A separate Science Plan study initiated in 2014 focused on understanding the biogeochemical mechanisms and factors influencing P reduction (P flux study) in well-performing flow-ways (e.g., STA-3/4 Western Flow-way, STA-2 Cells 1 and 3). The current planned study will focus on the STAs that have not reached 13 micrograms per liter ($\mu g\ L^{-1}$), the current long-term water quality-based effluent limit (WQBEL).

References

Chen, H. and K. Vaughan. 2014. Influence of Inundation Depth on *Typha domingensis* and its Implication for Phosphorus Removal in the Everglades Stormwater Treatment Area. Wetlands 34:325-334.

Ivanoff, D., G. Goforth, and K.C. Pietro. 2013. Influence of Calcium and Calcium Carbonate Saturation on the Performance of Stormwater Treatment Area 5. South Florida Water Management District, West Palm Beach, FL.

Kadlec, R.H. and S.D. Wallace. 2009. Treatment Wetlands, Second Edition. CRC Press, Boca Raton, FL. 366 pp.

Reddy, K.R., G.A. O'Connor, and C.L. Schelske. 1999. Phosphorus Biogeochemistry of Sub-Tropical Ecosystems. CRC Press, Boca Raton, FL.

Richardson, C. J. and S.S. Qian. 1999. Long-Term Phosphorus Assimilative Capacity in Freshwater Wetlands: A New Paradigm for Sustaining Ecosystem Structure and Function. Environmental Science & Technology 33(10):1,545-1,551.

Objectives

The overall objective of the study is to analyze the operational and biogeochemical challenges for P reduction performance in STA-1E, STA-1W, STA-2, and STA-5/6. A better understanding of key challenges would help formulate operational and management recommendations for each flow-way or STA.

Hypotheses

To be determined.

Proposed Methodology

The study will be conducted in two phases, with a STOP/GO decision at the end of Phase I.

Phase I:

1. Review of available information for STA-1E, STA-1W, STA-2 (Flow-ways 2, 4, and 5), and STA-5/6, including hydrologic and hydraulic data, P budget, period of record performance at flow-way or cell level, water quality, soil, and vegetation information.
2. Data analysis and modeling – Using modeling and analytical tools developed from the P flux study to identify factors from each STA that may influence TP concentrations at the outflow.

STOP/GO:

If the results of Phase I cannot identify the primary challenges or if the primary challenges cannot be moderated for a specific STA (e.g., through operational or management strategies), that STA or key challenge variable will be excluded from further study (Phase II).

Phase II:

3. Field measurements and sampling – Sampling will be done in selected STA flow-ways to evaluate spatial and temporal trends in P forms and the key factors affecting these trends. At a minimum, water column grab samples will be collected at pre-determined transects; porewater will be collected at pre-determined depth intervals to measure flux rates; and floc and surface soil samples will be collected. Data analysis will be performed using a similar approach as the P flux study.

Activities and Milestones

1. Phase I – June 2019 to September 2020
2. Phase II – October 2020 to September 2022
3. Final report – September 2022

Prescribed Burn Effects on Cattail Communities

Key Question Addressed

What measures can be taken to enhance vegetation-based treatment in the stormwater treatment areas (STAs)?

Sub-Question Addressed

What key factors affect and what management strategies could improve system resilience of emergent aquatic vegetation (EAV) communities?

Background and Rationale

Prescribed burns in constructed wetlands are expected to cause short-term changes in surface water nutrient concentrations (White et al., 2008), canopy cover (Tian et al., 2010), pH (Neary et al., 2005), and aboveground biomass and necromass (Miao and Carstenn, 2006). Long-term effects of prescribed fires in constructed wetlands are less understood, but recurring prescribed fires may reduce aboveground biomass and improve distribution of water flow through the wetland. A prescribed burn experiment conducted in the Orlando Easterly Wetland in 2001 reduced aboveground vegetation biomass by 68.5 percent (White et al., 2008). A similar study in 1994 at the Orlando Easterly Wetland reported an increase in water column nutrient concentrations following the gradual rehydration of the cell, but the water was not discharged until concentrations declined to an acceptable level (University of Florida, 2001).

A prescribed burn experiment was conducted in cattail (*Typha domingensis*) dominated areas of Water Conservation Area 2A (WCA-2A) (Miao and Thomas, 2011). Temporary spikes in water column phosphorus (P) occurred, primarily from ash deposition, along with considerable loss (28 to 62 percent) of aboveground vegetation. Canopy leaf area index decreased between 30 and 70 percent with increased light penetration to the marsh surface. The canopy recovered to pre-burn levels within 1 year of the first fire at the highly enriched plot, with increased leaf elongation after the fire. These results suggest fire can benefit the cattail community.

References

Miao, S.L. and S.M. Carstenn. 2006. Assessing long-term ecological effects of fire and natural recovery in a phosphorus enriched Everglades wetlands: Cattail expansion, phosphorus biogeochemistry, and native vegetation recovery. In: Options for Accelerating Recovery of Phosphorus Impacted Areas of the Florida Everglades Research Plan. Final report to the South Florida Water Management District. West Palm Beach, FL.

Miao, S. and C. Thomas. 2011. Evaluating Natural Recovery and Fire Effects in Phosphorus-Enriched Water Conservation Area 2A (Fire Project). Final report to the South Florida Water Management District. West Palm Beach, FL.

Neary, D.G., J.D. Landsberg, A.R. Tiedemann, and P.F. Folliott. 2005. Chapter 6: Water Quality. In: D.G. Neary, K.C. Ryan, and L.F. DeBano (eds.), Wildland Fire in Ecosystems: Effects of Fire on Soil and Water. Gen. Tech. Rep. RMRS-GTR-42. Vol. 4. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station. Ogden, UT. 250 pp.

Tian, H., X. Xu, S. Miao, E. Sindhoj, B.J. Beltran, and Z. Pan. 2010. Modeling ecosystem responses to prescribed fires in a phosphorus-enriched Everglades wetland: I. Phosphorus dynamics and cattail recovery. Ecol. Model. 221:1,252-1,266.

University of Florida. 2001. Following Thirteen Years of Service, Evaluation of the Existing Capacity of the Orlando Easterly Wetland Treatment System to Remove Phosphorus from Wastewater. Final report submitted to the City of Orlando.

White, J.R., L.M. Gardner, M. Sees, and R. Corstanje. 2008. The short-term effects of prescribed burning on biomass removal and the release of nitrogen and phosphorus in a treatment wetland. J. Environ. Qual. 37:2,386-2,391.

Objectives

The overall objective of the study is to investigate the benefits of controlled burns on sustainability of cattail communities in EAV cells of the STA and the effects of soil and P accretion.

Hypotheses

1. Prescribed burns of cattail in EAV cells of the STA will result in denser cattail communities and improved STA performance.
2. Prescribed burns in cattail-dominated EAV cells of the STA will result in short-term increases in surface water total P (TP) levels, which then will return to pre-burn levels within 1 month of the fire event.

3. Increased dead biomass concurrent with increased soluble reactive P (SRP) uptake following prescribed burns will result in a higher proportion of dissolved organic P (DOP) and particulate P (PP) relative to SRP. 4. Prescribed burns in cattail-dominated EAV cells of the STA will result in reduced vegetative resistance and improved hydraulic efficiency compared to unburned EAV cells.
Proposed Methodology Candidate areas for prescribed burns will be identified. Several measurements and analyses will be conducted pre-burn. *Soil:* Soil samples will be analyzed for moisture content, bulk density, ash content (ash-free dry weight, calculated), pH, TP, total carbon, total nitrogen, ammonia (NH_4-N), and ortho-phosphate. Soil redox conditions will be measured in the field. *Vegetation Survey and Measurement:* Measurements will be made for plant density (adult and juvenile), photosynthesis, foliage area index, leaf elongation, and water depth using a graduated polyvinyl chloride (PVC) pole. Field observations will include cattail damage and presence of floating mats, presence of other EAV or floating aquatic vegetation within the plots, and photo documentation of each plot. Samples for plant biomass measurements, including aboveground and belowground as well as live and dead material, will be collected at random using a 0.25-m^2 quadrat. Biomass samples will be separated into live leaf, rhizome, shoot base, root, and dead plant material. At a minimum, inflow and outflow TP, SRP, DOP, total nitrogen, nitrogen oxides (NO_x), and ammonia will be measured during flow events. When the conditions are acceptable (e.g., wind, humidity, temperature, fuel moisture), a prescribed burn will be carried out by contractors and South Florida Water Management District staff with assistance from the Florida Forest Service. Post-burn surveys, sampling, and measurements will be conducted for the same parameters measured during pre-burn. Sampling will occur 1, 6, 12, and 24 months post-burn. A final report will be submitted.
Activities and Milestones 1. Site selection and pre-burn sampling – October 2018 to March 2019 2. Prescribed burn – March 2019 to June 2019 3. Post-burn sampling – June 2019 to September 2021 4. Final report – September 2022

Assess Benefits and Feasibility of Consolidating Accrued Marl in the Stormwater Treatment Areas' Submerged Aquatic Vegetation Cells

Key Questions Addressed

How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)?

How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce soluble reactive P (SRP), particulate P (PP), and dissolved organic P (DOP) concentrations at the outflow of the STAs?

Sub-Questions Addressed

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?

Background and Rationale

There are 24 cells (approximately 32,000 acres) within the Everglades STAs designed to be dominated by submerged aquatic vegetation (SAV). SAV, in general, has an important role in reducing P concentrations from the water column in downstream treatment cells of the STAs. As SAV turns over or dies off then decomposes, amorphous marl is produced. Approximately 78 percent of the floc material and 68 percent of the recently accreted soils are inorganic in STA-2 Flow-way 3 (University of Florida, 2018). Calcium, the major component of marl, is mainly in the form of calcite and aragonite, accrued in STA-2 Flow-way 3 at an estimated rate of 452 ± 215 g m^{-2} $year^{-1}$ (40 percent by weight of the macro-elements accreted) and in STA-3/4 Cell 3B SAV region at a rate of 573 ± 199 g m^{-2} $year^{-1}$ (48 percent by weight of the macro-elements accreted; University of Florida, 2018). The rate of accretion can be higher as a result of extreme events (e.g., dryout, storms, herbivory, high nutrient loading). To sustain SAV communities, the cells are maintained at target water depths (38 to 46 centimeters), and at a minimum of 15 centimeters during the dry season.

Previous observations during collection of soil cores indicate the accreted marl does not consolidate or aggregate as effectively as organic soil. As the amount of inorganic floc and amorphous soil accrues, resuspension, bioturbation, and floc movement and their influence on water column P become a concern. In STA-1W Cells 2B and 4, accretion of excessive amounts of inorganic floc resulted in persistent turbidity in the water column, which prevented SAV growth. Calcium carbonate ($CaCO_3$), in the form of limerock and other derivatives, was one of many chemical amendments investigated in a separate Science Plan study and in earlier years of advanced treatment technologies in the STAs that could effectively reduce P concentrations in the water column. Calcium carbonate provides sorption sites for P, thereby helping suppress P flux from the soil, and favors growth of periphyton. One of the drawbacks of adding calcium carbonate to an STA cell is the cost of application and the uncertainty with regard to the duration of benefits and frequency of re-application of the amendment. If the aggregation of amorphous marl could be improved in a cost-feasible way, this may result in a more stable storage of P in SAV cells and better suppression of flux and the negative effects of P mining in the SAV cells.

References

University of Florida. 2018. Evaluation of Soil Biogeochemical Properties Influencing Phosphorus Flux in the Everglades Stormwater Treatment Areas (STAs). Annual Report July 2016-June 2017. Submitted to the South Florida Water Management District in partial fulfillment of Work Order 4600003031-WO01.

Objectives

The overall objective of the study is to determine if consolidation or improved aggregation of marl can further lower water column P concentrations. A secondary objective is to find a cost-feasible way to improve marl aggregation.

Hypotheses

1. Net P reduction is greater in the presence of limerock over muck than in amorphous marl over muck.
2. Water column P is reduced when amorphous marl is consolidated or aggregated.
3. Amorphous marl can be consolidated or aggregated through periodic drawdown.
4. Amorphous marl can be consolidated or aggregated with addition of organic residue (e.g., cattail litter) over time.

Proposed Methodology
The study will be conducted in two phases, with a STOP/GO decision at the end of Phase I. *Phase I:* 1. Review of literature. 2. Benchtop mesocosm experiments/trials on marl aggregation/consolidation. 3. Data analysis and reporting. STOP/GO: If Phase I indicates benefits in consolidating/aggregating marl, proceed with Phase II. *Phase II:* 4. Field mesocosm study to compare P reduction in limerock over muck, amorphous marl over muck, and aggregated marl over muck. 5. Data analysis and reporting. STOP/GO: If results of Phases I and II indicate significant benefits in consolidating/aggregating marl, proceed with Phase III. *Phase III:* 6. Determine cost-feasible methods of improving marl aggregation. 7. Data analysis and reporting.
Activities and Milestones
1. Literature review – October 2020 2. Benchtop experiment – June 2021 3. Field mesocosms – June 2023 4. Final report – September 2023

Quantifying Phosphorus Uptake and Release from Periphyton and Phytoplankton Communities

Key Questions Addressed

How can internal loading of phosphorus (P) to the water column be reduced or controlled, especially in the lower reaches of the stormwater treatment areas (STAs)?

How can the biogeochemical or physical mechanisms, including internal flux of P, be managed to further reduce soluble reactive P (SRP), particulate P (PP), and dissolved organic P (DOP) concentrations at the outflow of the STAs?

Sub-Questions Addressed

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?

Background and Rationale

The ability of STAs to achieve low outflow total P (TP) concentrations depends on the system's capacity to reduce P by transforming it from one form to another. One set of transformations is the P uptake and release by periphyton or phytoplankton. This transformation could be very important, particularly in low-P conditions (i.e., near the STA outflows).

Estimates of P uptake and release in the periphyton/phytoplankton community have not been evaluated. The influence of periphyton/phytoplankton communities on TP concentrations in surface water at mid-flow and outflow regions within the STA flow-ways may differ depending on the dominant vegetation community. For example, TP concentrations in surface water at the mid-flow and outflow regions of submerged aquatic vegetation (SAV) dominated flow-ways in STA-2 are higher under stagnant conditions than flowing conditions. In flow-ways dominated by emergent aquatic vegetation (EAV), this increase was not observed. Differences in the periphyton community may contribute to these different responses.

Objectives

1. Estimate P uptake and release rates from periphyton and phytoplankton in downstream STA treatment flow-ways where TP concentrations are very low (≤20 micrograms per liter [$\mu g\ L^{-1}$]).
2. Estimate periphyton and phytoplankton growth and senescence in STAs where TP concentrations are very low.
3. Evaluate the influence of periphyton and phytoplankton within different dominate vegetation communities (e.g., SAV, EAV) and under various flow conditions.
4. Provide critical rates for the microbial components in the integrative model. This will be achieved by measurements of P uptake, productivity, growth, respiration, and death.

Hypotheses

1. Periphyton and phytoplankton P uptake, productivity, growth, and senescence (e.g., P transformation) is constant throughout the year.
2. The rate of periphyton and phytoplankton P transformation and cycling is the same within the major plant communities (i.e., EAV, SAV) and the influence of this transformation does not affect surface water TP concentrations.
3. The rate of periphyton and phytoplankton P transformation and cycling is the same under flowing or stagnant conditions and the influence of this transformation does not affect surface water TP concentrations.

Proposed Methodology

Phase I

1. Evaluate literature on methods that measure periphyton and phytoplankton growth and death to determine the most appropriate methods. Analyze existing information on periphyton STA research.
2. Develop study plan to evaluate the most promising measurement methods to address the objectives.
3. Select two sites (one SAV and one EAV dominant outflow cell) for pilot studies, and retrieve water column, floc and plant tissue for benchtop experimental trials on periphyton and phytoplankton uptake, productivity, growth, and senescence.

4. Analyze data and prepare a report.

STOP/GO

If benchtop measurements of uptake, productivity, growth, and senescence are quantifiable and repeatable, continue to Phase II.

Phase II

5. Evaluate periphyton and phytoplankton uptake, productivity, and growth for SAV- and EAV-dominant conditions in mesocosm studies. Experiments will include stagnant, low-flow, and high-flow trials.
6. Conduct field studies to augment mesocosm experiments to measure biomass on natural or artificial substrates and water column conditions, including nutrients, light, flow, and dissolved oxygen.
7. Prepare a final report.

Activities and Milestones

1. Literature survey – September 2019
2. Study plan – September 2019
3. Pilot studies – September 2020
4. Data analysis report – December 2020
5. Mesocosm studies – December 2022
6. Field studies – December 2022
7. Final report – June 2023

L-8 FEB and STA Operational Guidance

Key Question Addressed

How can the flow equalization basins (FEBs) be designed and operated to moderate phosphorus (P) concentrations and optimize P loading rates and hydraulic loading rates entering the stormwater treatment areas (STAs), possibly in combination with water treatment technologies or inflow canal management?

Sub-Question Addressed

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?

Background and Rationale

The L-8 FEB, a critical component of the Restoration Strategies Regional Water Quality Plan, is a 950-acre former rock mine capable of storing approximately 45,000 acre-feet (15 billion gallons) of water. It is located approximately 20 miles west of West Palm Beach, immediately west of the L-8 Canal and approximately 1 mile north of Southern Boulevard/State Road 80.

The primary purpose of the L-8 FEB is to attenuate peak stormwater flows and temporarily store stormwater runoff and improve inflow delivery rates to STA-1E and STA-1W, thereby providing enhanced operation and P treatment performance to assist in achieving state water quality standards in the Everglades Protection Area. The L-8 FEB also may be used to maintain minimum water levels and reduce the frequency of dryout conditions within STA-1E and STA-1W, which will sustain P treatment performance. The L-8 FEB began operations in June 2017. Following the Operational Cycle Testing Evaluation phase, the L-8 FEB began routine operations in December 2017.

Objectives

The study's data and analyses will be used to provide insight into the relationship of water quality with stage, flows, and potential groundwater interaction. The study shall include the development of operational guidance for the L-8 FEB in a manner that assists STA-1E and STA-1W in achieving compliance with the effluent limits for total P (TP) in discharges to the Everglades.

Proposed Methodology

In addition to the permit-required routine collection of stage, flow, and water quality data, a detailed study plan will be prepared to guide the development of strategies to analyze existing data and additional parameters within the L-8 FEB to evaluate conditions at various water levels. Potential water quality data to be collected may include TP, soluble reactive P, total suspended solids, specific conductance, pH, temperature, dissolved oxygen, calcium, and chlorophyll *a*. Data also may be collected at various water depths using multiparameter probes for temperature, dissolved oxygen, pH, and specific conductance. Aerial imagery/satellite imagery may be used for the analysis, if appropriate.

Scope

This study plan includes analysis and evaluation of data collected at the L-8 FEB in order to develop operational guidance to optimize P loading rates and hydraulic loading rates entering STA-1E and STA-1W.

Duration

This is anticipated to be a 3-year study, beginning in June 2018 and ending by September 2021.

Activities and Milestones

1. Complete detailed study plan – September 2018
2. Complete first annual study report – September 2019
3. Complete second annual study report – September 2020
4. Complete final annual study report – September 2021

STA Water and Phosphorus Budget Improvements

Question Addressed

Can improvements be made to stormwater treatment area (STA) water and phosphorus (P) budgets published in past South Florida Environmental Report editions?

Other Questions

What are the sources of error(s) in STA water budgets?

How can errors in water budget components be reduced?

Background and Rationale

Water budget analysis is used to understand STA treatment performance and develop accurate P budgets. Previously reported (Ivanoff et al., 2013) STA treatment cell annual water and P budgets contained high residuals, which limited their use to characterize and understand treatment performance. Water budgets are composed of structure inflows and outflows, seepage, rainfall, evapotranspiration, and change in storage. P budgets are composed of structure inflow loads and outflow loads, rainfall load, and seepage load. During Phase I of this study, the sources of error in STA water budgets were evaluated and recommendations were developed to reduce the errors and improve the accuracy of the STA water budgets. Also, during Phase I, a test case water budget improvement was performed for STA-3/4 Cells 3A and 3B, using improved structure flow data (Polatel et al., 2014). 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 percent to less than 8 percent.

References

Ivanoff, D., K. Pietro, H. Chen, and L. Gerry. 2013. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. Volume I. South Florida Environmental Report. South Florida Water Management District, West Palm Beach, FL. 102 pp.

Polatel, C., W. Abtew, S.L. 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.

Objectives

Phase I: Complete – see above.

Phase II: Develop revised P budgets, loading rates, and settling rates for the STA cells using the improved flow estimates and water budgets.

Phase III: If the results of Phase II indicate the need for further improvements to flow estimates or other water budget components, other items such as structural improvements, enhanced monitoring, seepage studies, or operational refinements may be considered.

Hypotheses

N/A

Proposed Methodology

Phase II builds on the efforts of Phase I and includes ongoing improvement of flow data stored in DBKEYS, as well as development of STA water and P budgets for selected treatment cells. Phase III, if approved, could include contract costs (e.g., labor, materials, equipment). For example, further improvements in water budgets may require development and maintenance of additional DBKEYs, field investigation (e.g., surveying, seepage measurements), enhanced monitoring, equipment installation, structural retrofits, and operational changes.

Duration

Phase I began in February 2013 and lasted approximately 1.5 years (Phase I report was finalized in November 2014).
Phase II is estimated to last approximately 7 years (approximate end date September 30, 2020).
Phase III, if needed and approved by the Restoration Strategies Steering Group, could last an additional 2 to 3 years, or more, depending on the scope.

Activities and Milestones

1. Phase I – February 2013 to November 2014 (completed)
2. Phase II – January 2014 to September 2020 (ongoing)
3. Phase III initiation – To be determined, as needed

APPENDIX B. STORMWATER TREATMENT AREA AND FLOW EQUALIZATION BASIN DESCRIPTIONS

B.1 STA-1E

Stormwater Treatment Area 1 East (STA-1E) is approximately 18 miles west of West Palm Beach, just south of State Road 80 and the C-51 West Canal. This STA is adjacent to the northeastern boundary of the Arthur R. Marshall Loxahatchee National Wildlife Refuge, also known as Water Conservation Area 1 (WCA-1), and directly east of the STA-1 Inflow and Distribution Works (referred to as the STA-1 Inflow Basin). STA-1E consists of three parallel treatment paths, or flow-ways, with eight treatment cells flowing from north to south. STA-1E provides an effective treatment area of approximately 5,000 acres (**Figure B-1**). Inflow to STA-1E primarily comes from the C-51 West Basin, S-5A Basin, East Beach Water Control District, L-8 Basin, Rustic Ranches subdivision, and Acme Basin B (Village of Wellington). The L-8 Flow Equalization Basin (FEB) was constructed to attenuate peak stormwater flows and improve STA-1E and STA-1W inflow delivery rates (**Section B.6**).

B.2 STA-1W

STA-1W is immediately west of the Arthur R. Marshall Loxahatchee National Wildlife Refuge, also known as WCA-1, in Palm Beach County. STA-1W is composed of three flow-ways, totaling approximately 6,500 acres of effective treatment area: Eastern Flow-way (Cells 1A, 1B, and 3), Western Flow-way (Cells 2A, 2B, and 4), and Northern Flow-way (Cells 5A and 5B) (**Figure B-2**). STA-1W treats stormwater runoff from the S-5A Basin, East Beach Water Control District, C-51 West Basin, and L-8 Basin.

B.3 STA-2

STA-2 is immediately west of WCA-2A in western Palm Beach County. STA-2 has eight treatment cells and five flow-ways, with a total effective treatment area of approximately 15,500 acres (**Figure B-3**). STA-2 receives agricultural runoff from the S-2/S-6 and S-2/S-7 basins, a portion of the S-5A Basin via the Ocean and Hillsboro canals, and the Chapter 298 drainage districts situated on the eastern shore of Lake Okeechobee. The A-1 FEB (**Section B.7**) was constructed to attenuate peak stormwater flows and improve inflow delivery rates to STA-2 and STA-3/4.

B.4 STA-3/4

STA-3/4 is northeast of the Holey Land Wildlife Management Area and north of WCA-3A. This STA provides a total treatment area of approximately 16,300 acres and is composed of three flow-ways: Eastern Flow-way (Cells 1A and 1B), Central Flow-way (Cells 2A and 2B), and Western Flow-way (Cells 3A and 3B). A 445-acre section of Cell 2B is the site of the STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Project. STA-3/4 receives stormwater runoff from the S-2/S-7, S-3/S-8, S-236, and C-139 basins as well as the South Florida Conservancy District and the South Shore Drainage District (**Figure B-4**).

B.5 STA-5/6

STA-5/6 is in Hendry County and bordered by the L-2/L-3 borrow canal to the west and the Rotenberger Wildlife Management Area to the east. This STA receives inflows primarily from the C-139 Basin. The total effective treatment area of 13,700 acres within STA-5/6 is distributed within eight parallel flow-ways (**Figure B-5**).

B.6 L-8 FEB

The L-8 FEB began operations in 2017. It was constructed in a 950-acre former rock mine in central Palm Beach County, north of STA-1E and STA-1W and adjacent to and west of the L-8 Canal (**Figure B-6**). The L-8 FEB is designed to attenuate peak stormwater flows and improve STA-1E and STA-1W inflow delivery rates, thereby providing enhanced phosphorus treatment performance within the two STAs. The L-8 FEB can help maintain minimum water levels and reduce the frequency of dryout conditions within STA-1E and STA-1W, which also sustains phosphorus treatment performance.

B.7 A-1 FEB

The A-1 FEB began operations in 2015. It is a shallow, aboveground impoundment with a capacity of approximately 60,000 acre-feet at an approximate maximum operating depth of 4 feet (**Figure B-7**). This FEB is adjacent to and directly north of STA-3/4. The A-1 FEB is designed to attenuate peak stormwater flows collected by the North New River and Miami canals, and to improve inflow delivery rates to STA-2 and STA-3/4, thereby providing enhanced phosphorus treatment performance within the two STAs. The A-1 FEB can be used to help maintain minimum water levels and reduce the frequency of dryout conditions within STA-2 and STA-3/4, which also sustains phosphorus treatment performance.

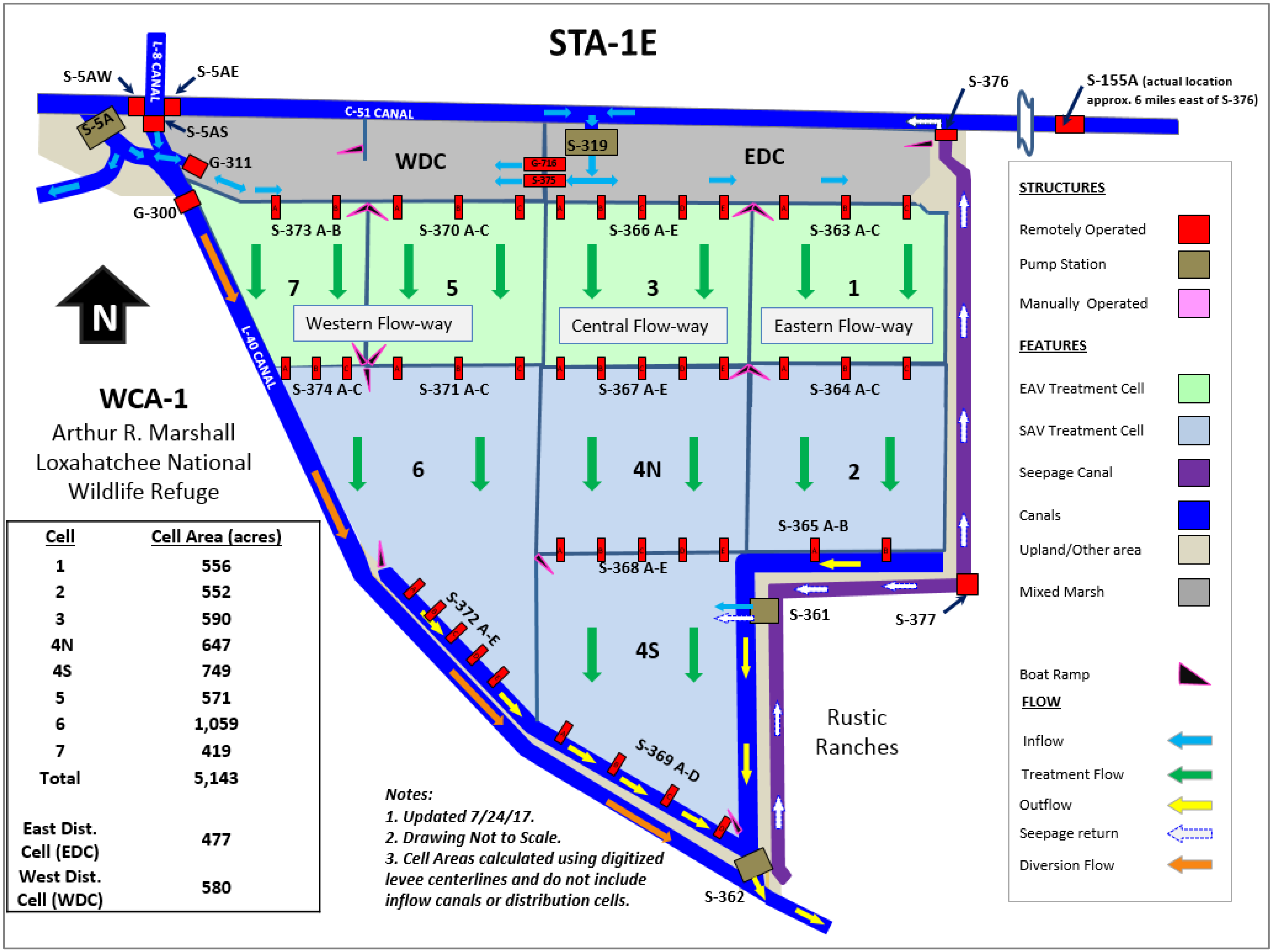
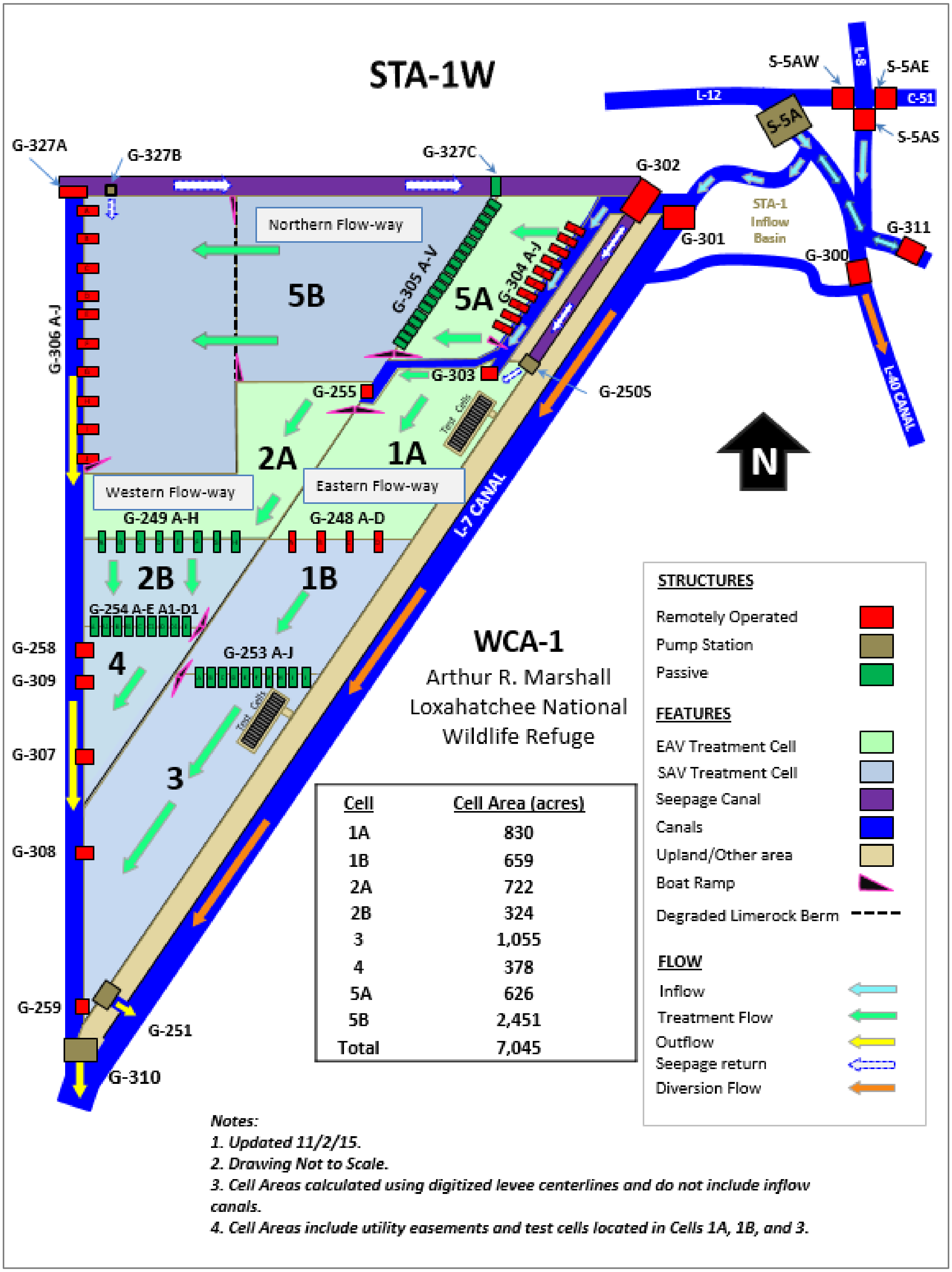


Figure B-1. Stormwater Treatment Area 1 East (STA-1E) schematic showing configurations of the treatment cells, flow direction, dominant vegetation type, and locations of flow structures.



Cell	Cell Area (acres)
1A	830
1B	659
2A	722
2B	324
3	1,055
4	378
5A	626
5B	2,451
Total	7,045

Figure B-2. Stormwater Treatment Area 1 West (STA-1W) schematic showing configurations of the treatment cells, flow direction, dominant vegetation type, and locations of flow structures.

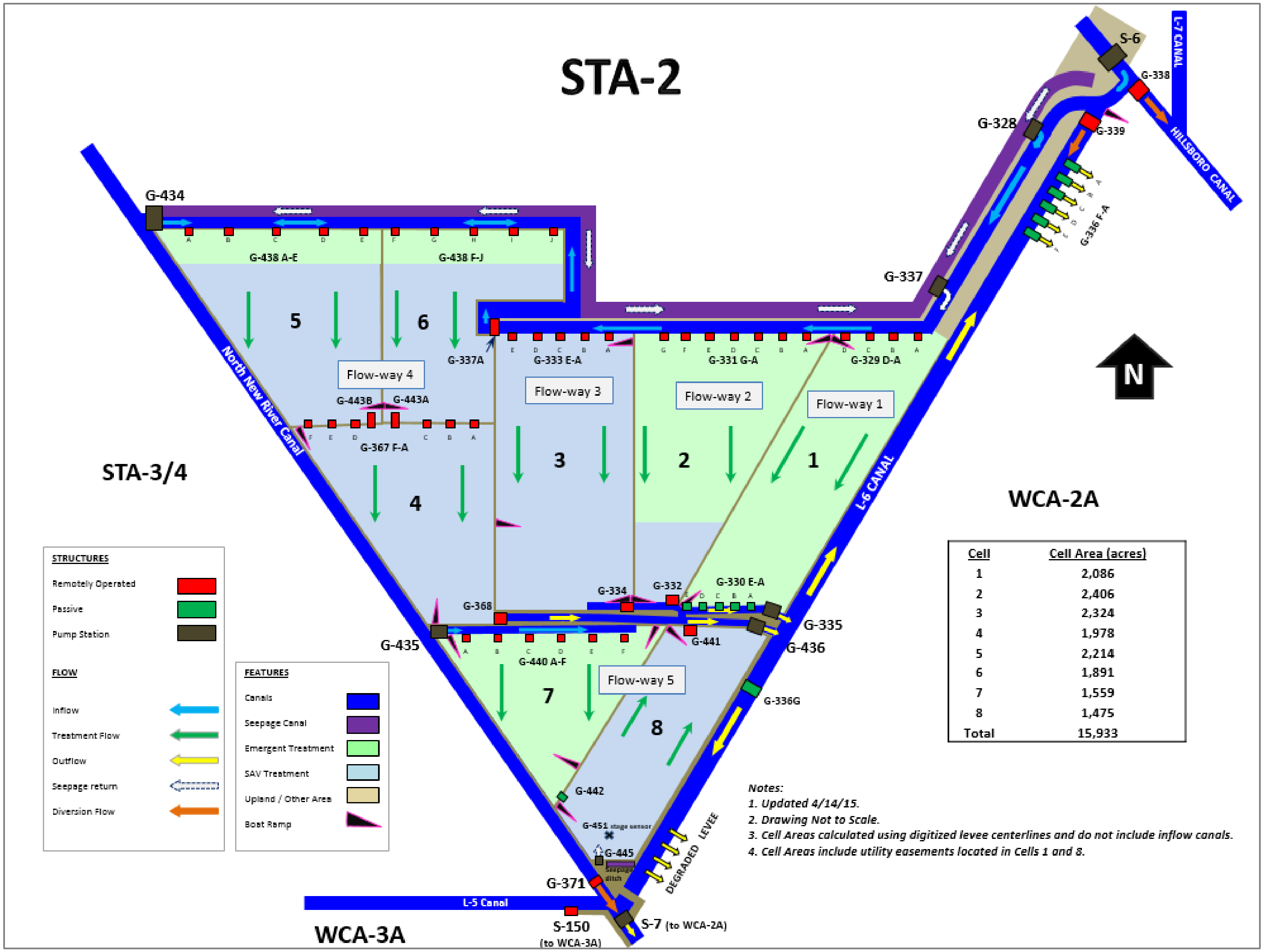


Figure B-3. Stormwater Treatment Area 2 (STA-2) schematic showing configurations of the treatment cells, flow direction, dominant vegetation type, and locations of flow structures.

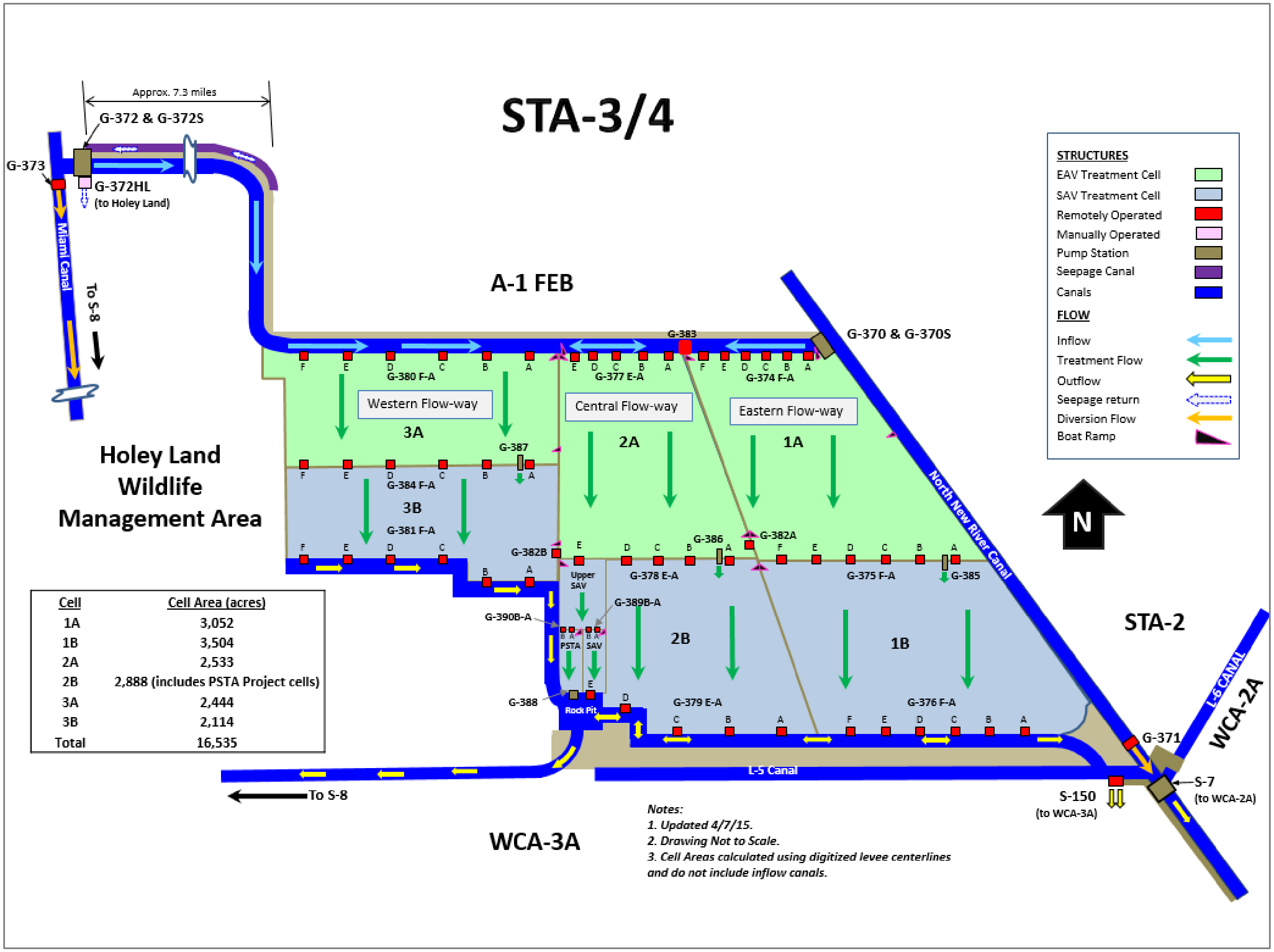
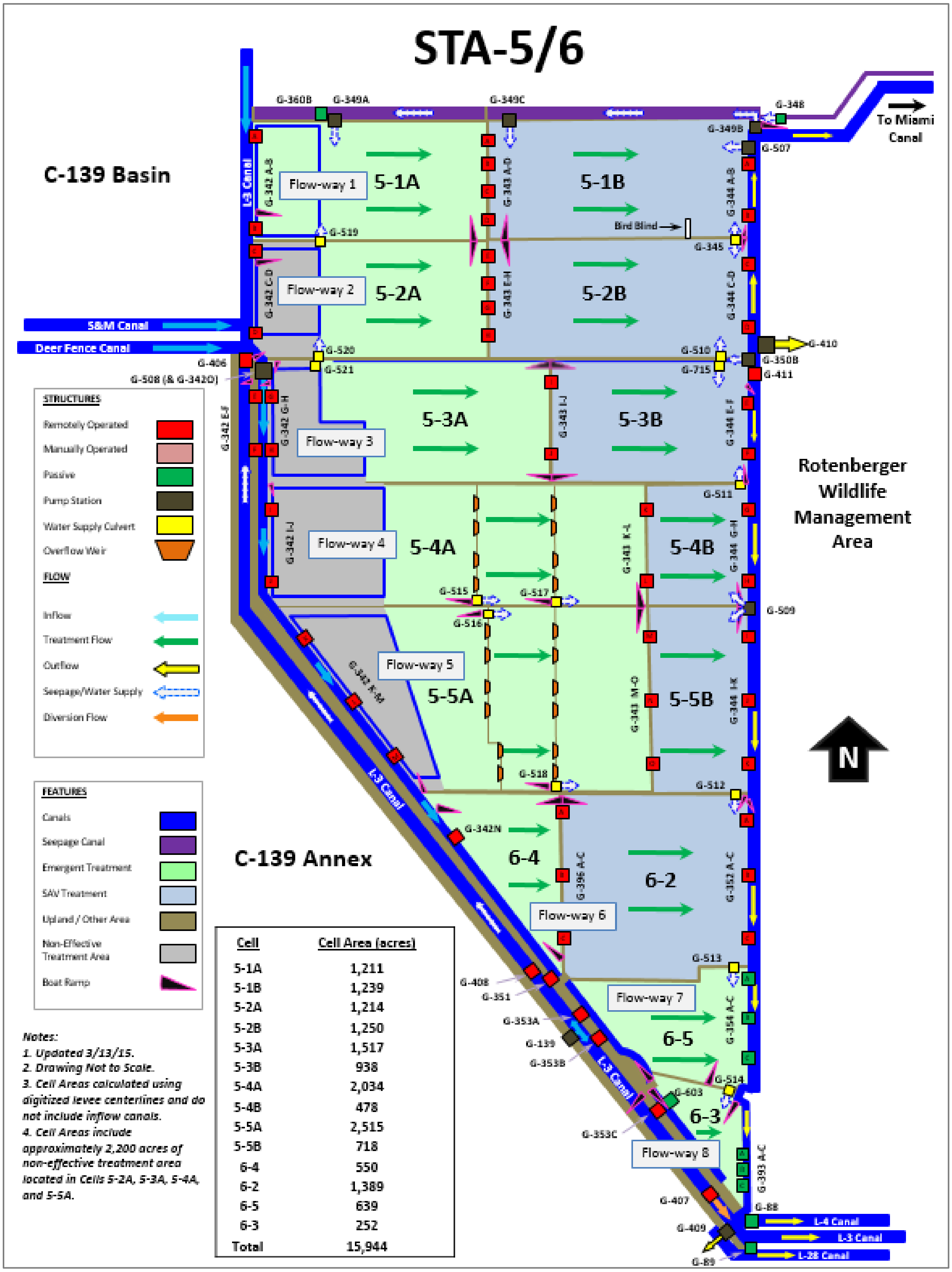


Figure B-4. Stormwater Treatment Area 3/4 (STA-3/4) schematic showing configurations of the treatment cells, flow direction, dominant vegetation type, and locations of flow structures.



Cell	Cell Area (acres)
5-1A	1,211
5-1B	1,239
5-2A	1,214
5-2B	1,250
5-3A	1,517
5-3B	938
5-4A	2,034
5-4B	478
5-5A	2,515
5-5B	718
6-4	550
6-2	1,389
6-5	639
6-3	252
Total	15,944

Figure B-5. Stormwater Treatment Area 5/6 (STA-5/6) schematic showing configurations of the treatment cells, flow direction, dominant vegetation type, and locations of flow structures.

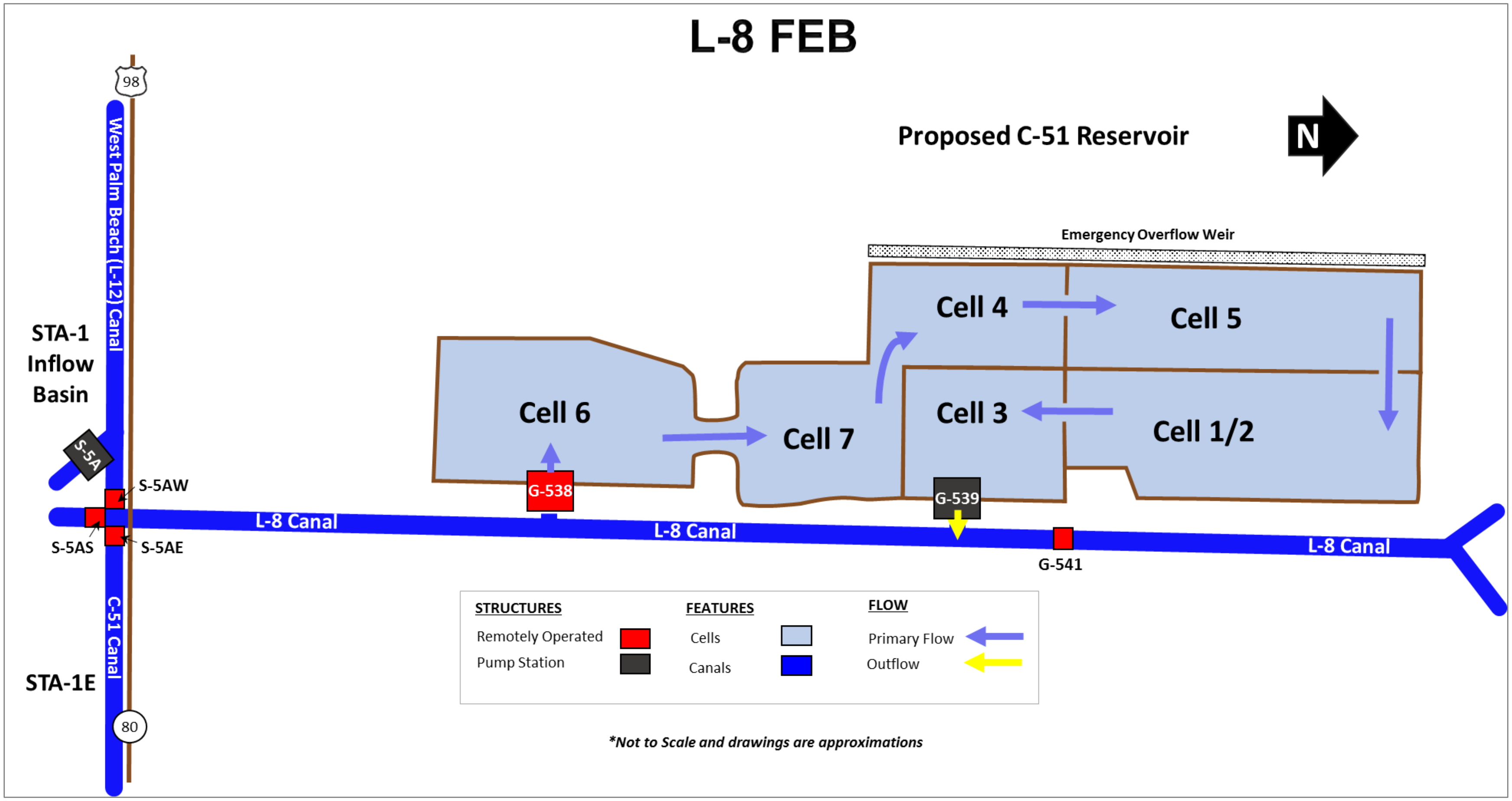


Figure B-6. L-8 Flow Equalization Basin (FEB) schematic showing configurations of cells, flow direction, and locations of flow structures.

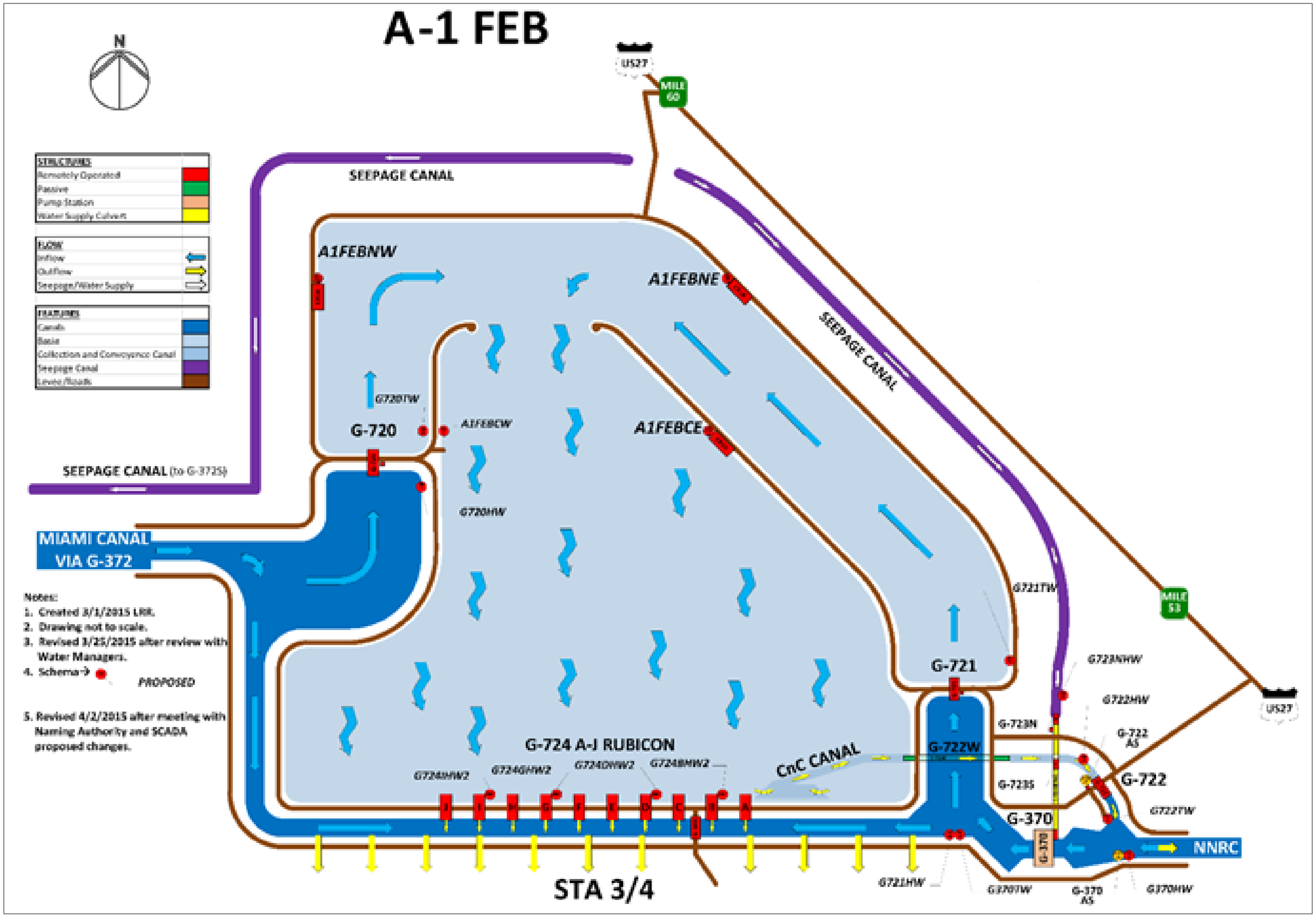


Figure B-7. A-1 Flow Equalization Basin (FEB) schematic showing configurations of basin, canals, flow direction, and locations of flow structures.

APPENDIX C. ARCHIVED SUB-QUESTIONS

For the 2018 update of the Restoration Strategies Science Plan, four teams of scientists and engineers from the South Florida Water Management District were asked to re-evaluate the 2013 Science Plan key questions and sub-questions. Each team evaluated the questions based on testability, feasibility, timeliness, and importance. The teams then ranked each question to determine if a question should be carried forward or archived. Also, new questions could be added. Many of the specific sub-questions were consolidated into broader sub-questions that have been carried forward. This appendix lists original questions that were archived and the rationale for archiving. These questions will be maintained for future use if needed.

Original Question	Rationale for Archiving
Would canal management or design improve STA and FEB performance?	Answered partially by the canal study, which determined soil may be a source of P under high flow conditions, and by the Operation Guidance for STAs and FEBs study, which showed reduction of peak flows and enhancement of overall system performance through implementation of FEBs.
What components and operational activities could potentially be incorporated into the FEB designs that would promote settling of sediment and associated PP to prevent transport into the STAs?	Knowledge gained through operation and management of the FEBs and STAs has been and can continue to be used to address this issue (e.g., maintaining vegetation communities near the discharge structures, optimizing discharge flow).
What water quality treatment technologies should be evaluated along with the FEBs?	Numerous studies completed through the Advanced Treatment Technologies Research Program and additional amendment studies (Chimney, 2015) showed treatment technologies could reduce TP in the water column. However, the District is not considering the potential use of water quality treatment technologies in the FEBs at this time.
Should the establishment of FAV be promoted in the L-8 FEB?	The District has no plans to promote FAV in the L-8 FEB at this time.
If FAV is promoted in the L-8 FEB, is mechanical harvesting beneficial or feasible?	The District has no plans to promote FAV in the L-8 FEB at this time.
As EAV will colonize the shallow FEBs (A-1 and C-139), should SAV establishment and management be promoted in these FEBs?	Upon initial operation, the A-1 FEB was inoculated with a variety of EAV, SAV, and FAV seeds. Most of these did not survive due to high water conditions early on. SAV is establishing in the A-1 FEB through natural recruitment. Current practices in the A-1 FEB are focused on controlling nuisance vegetation and planting desired vegetation.
If SAV is promoted in the shallow FEBs, what is the optimal EAV/SAV design configuration?	SAV is establishing in the A-1 FEB through natural recruitment. Because the A-1 FEB can dry out, a specific SAV/EAV mix will be difficult to manage.
Should littoral zones be established in the shallow FEBs to reduce flow impedance?	The question, as stated in the original plan, was unclear. Vegetation is establishing naturally and planted in strategic areas (e.g., upstream of outflow structures).

Original Question	Rationale for Archiving
How does water depth affect sustainability of dominant vegetation?	Included in new, more general sub-questions: What key factors affect and what management strategies could improve system resilience of SAV communities? What key factors affect and what management strategies could improve system resilience of EAV communities?
How do water depths and soil characteristics affect sustainability of dominant vegetation: is the formation of floating mats and tussocks determined by water depth and duration regimes and soil characteristics?	Included in a new, more general sub-question: What key factors affect and what management strategies could improve system resilience of EAV communities?
Can STA performance and sustainability be improved with increased plant species diversity or relative coverage of vegetation types: can fire flag *(Thalia geniculata),* knotweed *(Ploygonum densiflorum*), and giant bulrush *(Schoenoplectus californicus)* provide similar P uptake and reduction potential as cattail?	Included in new and revised sub-questions: What are the differences in long-term P reduction between pure SAV communities and mixed SAV/EAV communities? Can various vegetation types (subtypes) enhance P uptake and reduction in SAV cells? What are the relative short-term and long-term P reduction capacities of the dominant and alternative vegetation species in the STAs?
What factors determine spatial and temporal variability of SAV community structure (species composition, cover, density): will sediment deposition and nutrient loadings lead to a decline in the sustainability and P uptake performance of SAV cells?	Included in a new, more general sub-question: What are the differences in long-term P reduction between pure SAV communities and mixed SAV/EAV communities?
How do water depths and soil characteristics affect sustainability of dominant vegetation: will lowered stages during the dry season enhance sustainability and associated P uptake performance of hydrilla (and other dominant SAV species)?	Included in new, more general sub-questions: What key factors affect and what management strategies could improve system resilience of SAV communities? What key factors affect and what management strategies could improve system resilience of EAV communities?
Do dryouts result in changes in the relative cover of musk grass (*Chara sp*.) and southern naiad (*Najas guadalupensis*)?	Included in a new, more general sub-question: What key factors affect and what management strategies could improve system resilience of SAV communities?
What are the impacts and potential benefits of dryouts and drawdowns on STA performance and sustainability: are the rates of reestablishment of cover and associated P uptake processes of dominant SAV species (*Chara* sp. and *Najas guadalupensis*) dependent on the duration and intensity (water table depth) of dryout events?	Included in a new, more general sub-question: What key factors affect and what management strategies could improve system resilience of SAV communities?
Can STA performance and sustainability be improved with increased plant species diversity or relative coverage of vegetation types: what is the appropriate relative cover of emergent vegetation in the SAV cells?	Included in new, more general sub-questions: What key factors affect and what management strategies could improve system resilience of SAV communities? What key factors affect and what management strategies could improve system resilience of EAV communities?

Original Question	Rationale for Archiving
Can STA performance and sustainability be improved with increased plant species diversity or relative coverage of vegetation types: will rotation of SAV and emergent vegetation cover enhance sustainability of SAV cells?	Included in new, more general sub-questions: What key factors affect and what management strategies could improve system resilience of SAV communities? What key factors affect and what management strategies could improve system resilience of EAV communities? What are the differences in long-term P reduction between pure SAV communities and mixed SAV/EAV communities?
Can STA performance and sustainability be improved with increased plant species diversity or relative coverage of vegetation types: can *Potamogeton illinoensis, Vallisneria americana*, and floating leaved species, such as *Nelumbo lutea* and *Nuphar lutea,* survive in deeper portions of SAV cells and complement P uptake by dominant SAV species?	Included in new and revised sub-questions: What key factors affect and what management strategies could improve system resilience of SAV communities? Can various vegetation types (subtypes) enhance P uptake and reduction in SAV cells? What are the relative short-term and long-term P reduction capacities of the dominant and alternative vegetation species in the STAs?
Can STA performance and sustainability be improved with increased plant species diversity or relative coverage of vegetation types: what is the effect of the size and distribution of emergent vegetation strips on SAV sustainability?	Studying the effects of size and distribution of vegetation strips will be difficult to study. Included in new, more general sub-questions: What are the differences in long-term P reduction between pure SAV communities and mixed SAV/EAV communities? What are the relative short-term and long-term P reduction capacities of the dominant and alternative vegetation species in the STAs? Can various vegetation types (subtypes) enhance P uptake and reduction in SAV cells?
What are the impacts and potential benefits of dryouts and drawdowns on STA performance and sustainability: will P uptake processes in EAV cells be reestablished within one month of reflooding after a controlled drawdown?	Second part of the question regarding re-establishment is already known through years of STA observation. Included in new, more general sub-questions: What key factors affect and what management strategies could improve system resilience of SAV communities? What key factors affect and what management strategies could improve system resilience of EAV communities?
What design or operational changes can be implemented to reduce PP and DOP at the outfall of the STA?	Two similar sub-questions were combined into one revised sub-question: Are there design or operational changes that can be implemented in the STAs to reduce PP and DOP in the water column?
Does pumping at lower STA inflow and outflow rates over 16 or 24 hours in a day, versus 8-hour day shifts, improve STA performance?	While this question has not been directly studied, the implementation of FEBs upstream of STAs is intended to address the issue of peak flow impacts on STA performance.

Original Question	Rationale for Archiving
What is the best period within a 24-hour day to discharge water from an STA in order to achieve the lowest phosphorus concentrations?	The Sampling Methodologies Study indicated the time of discharge (e.g., sampling) likely would not change treatment performance (e.g., average annual P concentration at the STA outflows).
What are the best structural design features for delivering water to and from the STAs and FEBs?	A modeling approach or field studies could be used to evaluate this question. However, due to resource priorities, a study to address this issue is not being considered at this time.
What is the cost-benefit of adding more operational flexibility to transfer water between cells and flow-ways or to deliver supplemental water during droughts?	While an analysis of this question is not currently being considered, the results from the planned study, Phosphorus Reduction Dynamics in STA-1E, STA-1W, STA-2, & STA-5/6, could provide input to a cost/benefit analysis where dryout is shown to contribute to poor performance.
What factors determine spatial and temporal variability of SAV community structure (species, composition, cover and density): what are the short and long-term impacts of herbivory by wintering waterfowl on SAV cover, community structure, and sustainability or P uptake of SAV cells?	Included in new, more general sub-questions: What are the direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (e.g., are they net sinks or sources)? What key factors affect and what management strategies could improve system resilience of SAV communities?
What options are there for mitigating or reducing the impacts of fish and wildlife on STA performance through wildlife management or change in operations?	Included in a new, more general sub-question: What are the direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (e.g., are they net sinks or sources)?
What are the direct and indirect effects on alligators on water column P concentrations in the downstream cells of the STAs?	Included in a different sub-question: What are the direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (e.g., are they net sinks or sources)?
Can the outfall areas of the STAs be designed or operated in a manner to discourage congregations of birds, alligators, or other fauna?	A study is not proposed at this time to answer this question. The results of the study, Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs, should determine if this issue is a concern and may provide information that could be used to address this question or to design a future study.

District = South Florida Water Management District; DOP = dissolved organic phosphorus; EAV = emergent aquatic vegetation; FAV = floating aquatic vegetation; FEB = flow equalization basin; P = phosphorus; PP = particulate phosphorus; SAV = submerged aquatic vegetation; STA = stormwater treatment area; TP = total phosphorus.

Chimney, M.J. 2015. Phase I Summary Report for the Use of Soil Amendments/Management to Control P Flux Study. Restoration Strategies Regional Water Quality Plan – Science Plan for the Everglades Stormwater Treatment Areas: Soil Amendments/Management to Control P Flux. Technical Publication WR-2015-006. South Florida Water Management District, West Palm Beach, FL.