Chapter 5C: Restoration Strategies Science Plan

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SUMMARY

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

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

The Science Plan includes key questions regarding physical, chemical, and biological processes, as well as optimization of management in the STAs. These questions are used to develop research studies. Nine studies were initiated as part of the 2013 Science Plan. Additional studies have been added over time: 3 in 2018, 2 in 2019, and 2 in 2020 (**Table 5C-1**). Of these 16 studies, 7 are complete and 9 are ongoing.

This chapter provides the status, update of progress, and key findings of ongoing or recently completed studies. Detailed updates of many of the studies have been reported in appendices of previous South Florida Environmental Reports (SFERs) including the Faunal Study (Evans et al. 2019, Barton et al. 2020a; see **Table 5C-1** for full study names), P Flux Study (King and Villapando 2020, Villapando and King 2018, 2019), Cattail Study (Diaz and Vaughan 2019, Diaz 2020), Soil Management Study (Chimney 2017; Josan et al. 2019), and Water and P Budget Study (Zhao and Piccone 2018, 2019). The 2018 Five-year (2018–2023) Work Plan (Appendix A of SFWMD 2018) included a list of 10 potential new studies, of which 6 have been initiated and 4 are in the planning phase (**Table 5C-2**). The PSTA Study was completed in 2018 (Zamorano et al. 2018), although monitoring of the inflow and outflow structures continues so that annual performance of the periphyton-based stormwater treatment area (PSTA) cell can be tracked. The Biomarker Study was added in 2020, as was a study not included in the 2018 Five-year Work Plan, Data Integration and Analysis Study. These latter two studies are still in their inception, and no updates are included in this

report. The status and key findings of the Science Plan's ongoing or recently completed studies are summarized below.

Table 5C-1. List of all studies initiated under the Science Plan (short title in parentheses).

Study Title/Description	Initiation and Status
Investigation of STA-3/4 Periphyton-based Stormwater Treatment Area Technology Performance, Design, and Operational Factors (PSTA Study) – assess the chemical, biological, design, and operational factors of the PSTA Cell that contribute to the superior performance of this technology.	2013 Completed in 2018 (inflow and outflow monitoring continue)
Evaluation of the Role of Rooted Floating Aquatic Vegetation in STAs (rFAV Study) – assess the ability of rooted floating aquatic vegetation (rFAV) to further enhance low-level P reduction performance of submerged aquatic vegetation (SAV) communities.	2016 Completed in 2018
Development of Operational Guidance for Flow Equalization Basin (FEB) and STA Regional Operation (Operation Study) – create tools and methodologies to provide operational guidance for FEBs and STAs.	2013 Completed in 2017
Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow P Concentrations (**Canal Study**) – determine if and how conveyance through STA inflow or outflow canals alters TP concentrations or loads.	2013 Completed in 2017
Evaluation of Sampling Methods for TP (Sampling Study) – identify factors that may bias water quality monitoring results in order to improve sampling procedures for the STAs.	2013 Completed in 2017
Evaluation of P Sources, Forms, Flux and Transformation Processes in the STAs (P Flux Study) – improve understanding of the mechanisms and factors that affect P reduction in the STAs, particularly in the lower reaches of the treatment flow-ways.	2013 Completed in 2019
STA Water and P Budget Improvements (Water and P Budget Study) – improve annual estimations of STA water and P budgets of treatment cells to better understand and assess treatment performance of STAs.	2013 Completed in 2020
Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability (Cattail Study) – assess cattail health under different inundation depths and durations to identify thresholds for cattail sustainability in the Everglades STAs.	2013 Ongoing
Use of Soil Amendments and/or Management to Control P Flux (Soil Management Study) – investigate the benefits of soil amendment applications and/or soil management techniques to reduce internal loading of P in the STAs.	2013 Ongoing
Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs (Tussock Study) – determine key factors that cause floating wetlands and cattail tussocks and the probability of their formation in STAs. Identify floating wetlands with unmanned aircraft systems.	2018 Ongoing
Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs (**Faunal Study**) – evaluate faunal processes and factors that affect the P treatment performance of STAs at low TP concentrations.	2018 Ongoing
Improving Resilience of SAV in the STAs (**SAV Resilience Study**)– investigate the effects of operational and natural environmental conditions on SAV health in the STAs.	2018 Ongoing
Periphyton and Phytoplankton P Uptake and Release (Periphyton Study) – estimate P uptake and release rates from periphyton and phytoplankton in downstream STA treatment FWs to determine their influence on the P cycle and TP discharge from STAs.	2019 Ongoing
L-8 FEB Operational Guidance (L-8 FEBOG Study) – provide guidance for FEB operations to moderate TP in discharge as potentially affected by stage, flow, and groundwater.	2019 Ongoing
Quantifying the Recalcitrance and Lability of P within STAs (Biomarker Study) – evaluate relationships between organic matter and P that capture the sources and potential turnover of P within the STAs.	2020 Ongoing
Data Integration and Analysis (Data Integration Study) – integrate STA and Science Plan data and documents to support management decision making.	2020 Ongoing

PSTA STUDY

This completed study evaluated the chemical and biological factors contributing to consistently superior performance of the PSTA Cell (Zamorano et al. 2018). PSTA Study results are provided in previous years' SFERs with a detailed summary of the study findings presented in Appendix 5C-2 of the 2018 SFER – Volume I (Zamorano et al. 2018). One of the key factors controlling TP removal in the PSTA Cell was lack of organic soil. During construction, the muck was scraped and the subsurface limerock was exposed. Another key factor in the PSTA Cell's ability to produce ultra-low TP concentrations was low inflow TP concentrations and low phosphorus loading rates. Monitoring of the inflow and outflow water quality (TP) and flow of this operational PSTA Cell continues. PSTA Cell performance calculations have been updated for Water Year 2020 (WY2020; May 1, 2019–April 30, 2020) and are included in this chapter. For the 13 years of operation, this PSTA Cell has attained the WQBEL with annual outflow flow-weighted mean concentrations (FWMCs) of TP that are equal to or less than 13 µg/L.

P FLUX STUDY

This completed multi-component study evaluated mechanisms and factors that affect P treatment performance in the STAs. (King and Villapando, 2020; Villapando and King 2018, 2019). Within STA-2 Flow-ways (FWs) 1 and 3 and the STA-3/4 Western FW (WFW: Cells 3A and 3B), a total of 10 controlled flow events were conducted between August 2015 and July 2017. Transects from the inflow to outflow regions of these FWs had consistent high to low trends of TP concentration in the water column, suspended sediments, soils, and vegetation. Internal loading of P declined from inflow to outflow through STA-2 FW1 and FW3. Organic P was greater in emergent aquatic vegetation (EAV) regions while inorganic P was greater in submerged aquatic vegetation (SAV) regions. An additional vegetation sampling event was carried out in October 2019 and is reported in this chapter.

WATER AND P BUDGET STUDY

This effort, completed in 2020, improved annual estimates of STA water and P budgets for STA treatment cells to more accurately assess STA performance (e.g., P retention) and to identify areas of uncertainty in these calculations. Improved structure flow estimates improved the water and P budget for STA-3/4 Cells 3A and 3B (Polatel et al. 2014), STA-2 (Zhao and Piccone 2018, 2020) and STA-3/4 (Zhao and Piccone 2019, 2020). Treatment cells with period of record (POR) average annual water budget residuals above 10% were reduced to 1 to 5%, and two treatment cells with extremely high POR average annual water budget residuals of 60 to 62% were reduced to 1 to 4%.

CATTAIL STUDY

This ongoing study evaluates cattail (*Typha domingensis*) health under different inundation depths and durations to identify thresholds for sustainability in the STAs. Phase I of this study was completed in 2019 and observed stress in cattail regions of two STA cells when water levels were greater than 91 centimeters for over 100 consecutive days (Diaz 2018, Diaz and Vaughan 2019). Phase II of this study evaluates effects of water depths on cattail in the controlled environments of 15 STA 1 West (STA-1W) northern test cells. These 0.2-hectare (ha) test cells were refurbished, and cattail were planted and allowed to mature. Water depths were set between 0.25 and 4 feet in July 2019. Cattail density, photosynthesis, foliage area index (LAI), and leaf elongation were measured at biweekly to monthly time periods to gauge stress. Final data collection and sampling was completed July 2020.

SOIL MANAGEMENT STUDY

This ongoing study investigates methods to reduce internal P loading in the STAs including soil amendments, and P removal or burial. Chemical amendments that readily bond with dissolved P in soils may lower water column P concentration in constructed wetlands (Chimney 2015, 2017). Due to uncertainties in treatment efficacy, high estimated costs and effects on STA operations and downstream marsh, evaluations of soil amendments were postponed. An existing deep tilling project, which buried high copper concentrations found in surface soils of STA-1W Expansion Area #1 was leveraged to evaluate the effects of P burial on STA performance. The soil inversion reduced P in surface soils and the potential P flux to the water column (Josan et al. 2019). Soil sampling and water quality sampling undertaken after the Expansion Area #1 cells were flooded found little difference between the inverted and non-inverted cells (DBE 2019b, 2020c). Weekly monitoring of water quality at the inflow and outflow structures of these cells will commence once normal operations begin.

TUSSOCK STUDY

This ongoing study evaluates factors that may contribute to floating wetland community (tussock) formation in STAs and the effects of floating wetlands on STA treatment performance. A literature review (Clark 2019b) led to the development of a nomenclature scheme to describe these communities that vary based on species, size, and floating matter (Clark 2019c). Multispectral imaging sensors carried on unmanned aircraft systems (UAS) were effective in finding tussocks (Clark and Glodzik 2019). Thermographic sensors were less successful (Clark 2019a). Past agriculture uses, maximum annual water depths, and soil P are good indicators of potential tussock formation (Clark and Glodzik 2020). A buoyancy model to provide management recommendations to reduce the formation of tussocks in the STAs is being developed. Improvements in deployment of UAS and post processing of multispectral data should enhance detection of tussocks in the STAs.

FAUNAL STUDY

This ongoing study examines the role of fauna (specifically fish) on P cycling and STA P budgets through measurements of storage, excretion, and bioturbation. It began as a substudy of the P Flux Study (Evans et al. 2018) and continues as a separate study to evaluate the effect of fauna on STA TP cycling primarily through fish abundance surveys, bioturbation experiments, and excretion rate studies (Barton et al. 2020a). Small-bodied fish species recycled substantial amounts of P into the water through excretion, with most of this excretion in less bioavailable particulate forms (Barton et al. 2020c). Large-bodied fish contributed more P to the water column from bioturbation of floc and underlying sediments than from excretion (Barton et al. 2020b). The effect of large-bodied fish is dependent on biomass estimates from electrofishing surveys, which are underestimates (Barton and Trexler 2020b). Electrofishing will be calibrated against known fish densities using the test cells of STA-1W to improve the estimates of faunal contribution to P budgets.

SAV RESILIENCE STUDY

This ongoing study investigates the effects of operational and environmental conditions on the health of SAV in the STAs. A literature review and analysis of 18 years of semi-quantitative SAV surveys in the STAs indicate that water column and soil nutrients, chemical, physical, and biological conditions can affect SAV resilience (DBE 2018). Soil type, P loading, water depth and herbivory are being evaluated in field and mesocosm experiments (DBE 2019a, 2020a). Soil type did not affect biomass of SAV in mesocosm experiments, but plants grown in marl soils had lower concentrations of P and ions in their plant tissue. *Chara* spp. density increased with increased P loads in mesocosm experiments, resulting in decreased dissolved oxygen and light at the soil surface. To determine if these oxygen and light conditions result in a collapse of the *Chara* spp. density, this experiment continues. Preliminary results from soil drying studies suggest that dry conditions may support faster germination and growth of SAV seeds. An in-situ herbivory experiment in STA-2 FW 3 began in mid-2020 and is ongoing.

PERIPHYTON STUDY

This ongoing study evaluates nutrient dynamics of periphyton and phytoplankton in downstream STA treatment FWs where TP concentrations are very low (≤ 20 µg/L). Phase I was a literature review of methods to measure nutrient uptake and release, growth, respiration, senescence, and death (Laughinghouse et al. 2019). Phase II will be a bench top and field study to measure bioavailability of dissolved organic phosphorus (DOP) and nitrogen (N) in STA surface water inoculated with EAV or SAV community periphyton. Phase III will measure nutrient dynamics using additional methods for field and laboratory studies.

L-8 FEBOG STUDY

This ongoing study evaluates the relationships of L-8 Flow Equalization Basin (FEB) water quality to stage, surrounding groundwater, and the inflow and outflow structures of the FEB. This study will provide guidance for FEB operations to support management of STA-1 East (STA-1E) and STA-1W. Phase I of this study measured water quality (nutrients, ions, temperature, dissolved oxygen, and conductivity) monthly from L-8 FEB surface water, and quarterly from groundwater wells in 2019 (DBE 2020d). The groundwater was not a source of TP. The ongoing Phase II evaluates sediment contribution to P export from the FEB resulting from flow induced resuspension.

BIOMARKER STUDY

Initiated in 2020 and ongoing, the study objectives are to evaluate relationships between organic matter and P that capture the sources and potential turnover of P within the STAs. The statement of work is complete for this study.

DATA INTEGRATION STUDY

Initiated in 2020, the study objectives are to collate and synthesize research and data from STA studies related to P removal in the STAs, refine and develop models of P cycling in the STAs, and develop a guidance document to support management of the STAs to reach the WQBEL.

INTRODUCTION

The Everglades STAs are freshwater treatment wetlands constructed to reduce TP concentration in surface water runoff prior to discharge to the EPA (**Figure 5C-1**). The STAs are a major component of SFWMD's *Restoration Strategies Regional Water Quality Plan* (SFWMD 2012a). There are five Everglades STAs: STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6. The total area of the STAs, including infrastructure components, is roughly 73,000 acres (ac), with 61,000 ac (approximately 24,700 ha) of treatment area currently permitted to operate. This includes the expanded treatment areas of STA-1W, STA-2, and STA-5/6. Two FEBs, A-1 FEB and L-8 FEB, have been constructed as components of Restoration Strategies and are operated to attenuate peak stormwater flows and improve inflow delivery rates to downstream STAs.

The STAs, located primarily on former agricultural lands, retain nutrients through plant and microbial uptake, particulate settling, chemical sorption, and ultimately accretion of this material to the soil layer. Over the period of record, which started in 1994, all STAs combined have reduced TP loads by 77% and achieved an average outflow TP concentration of 31 µg/L (see Chapter 5B, Table 5B-1 of this volume). Treatment performance was affected in WY2018 by two major storms, and the system is recovering with TP discharge concentrations approaching pre-WY2018 levels (Chimney 2020). Work initiated through the Science Plan, and reported in this SFER chapter, supports the development of strategies to attain the WQBEL at the STA outflows.

Two permits established the WQBEL for these STAs, a stringent limit of TP concentration in discharge waters: (1) a National Pollution Discharge Elimination System (NPDES) watershed permit, and (2) an Everglades Forever Act (EFA) watershed permit. Meeting the WQBEL assures that TP discharges from the STAs do not cause or contribute to exceedances of the 10 μg/L TP criterion (long-term geometric mean) within the EPA. The WQBEL includes two parts: (1) TP as an annual FWMC discharged from each STA shall not exceed 13 μg/L in more than 3 out of 5 water years on a rolling basis; and (2) the annual FWMC from each STA shall not exceed 19 μg/L in any water year. The WQBEL is separate from the 4-part test for the Everglades TP criterion (62-302.540(4)(d)1, Florida Administrative Code), which is discussed in Appendix 3A-6 of this volume.

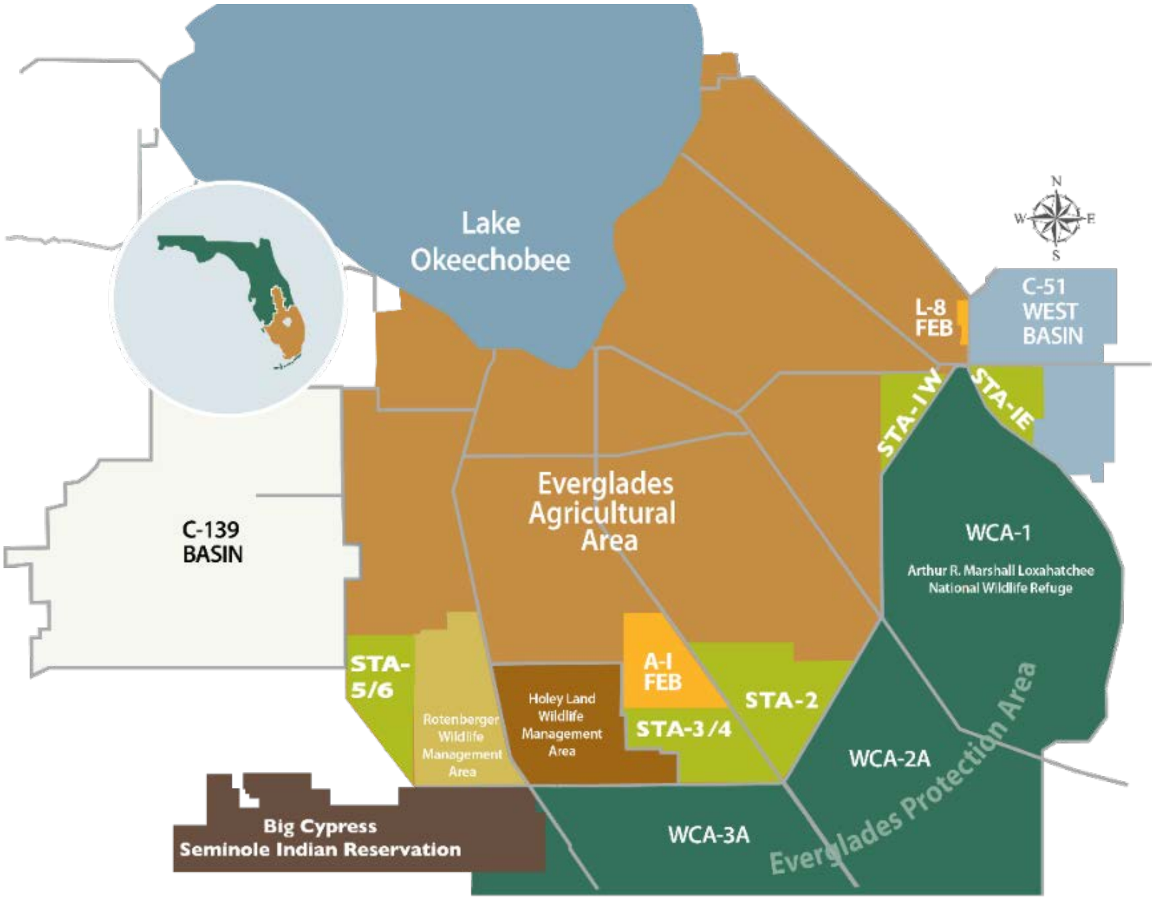

Figure 5C-1. Location of STAs (STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6) and FEBs (A-1 and L-8) in relation to the Everglades Agricultural Area, C-139 Basin, EPA, and other landscape features of South Florida. Maps of individual cells and FWs for all STAs can be found in Appendix 5B-1 of this volume.

Consent orders associated with the two permits for STA operation required SFWMD, in consultation with Restoration Strategies Technical Representatives from the United States Environmental Protection Agency, FDEP, United States Army Corps of Engineers, and United States Department of the Interior (Everglades National Park and United States Fish and Wildlife Service), to develop and implement the Science Plan. The consent orders require the Science Plan to evaluate mechanisms and factors that affect P reduction and treatment performance, particularly those that are key drivers to performance in low TP environments (i.e., < 20 μg/L), with the goal of attaining the WQBEL.

The Science Plan was written in 2013 and defined nine studies that were initiated between 2013 and 2016 (SFWMD 2013). The Science Plan was updated in 2018, and this update included a work plan that added 10 potential new studies (Appendix A of SFWMD 2018). Three of these new studies began in 2018, and two in 2019 (**Table 5C-1**). In 2020, the Biomarker study was started, and another study not included in the 2018 workplan also was added, the Data Integration and Analysis Study. Of the 10 new studies proposed in the 2018 workplan, four are in the planning phase (**Table 5C-2**). Results from all studies will inform the design and management of the STAs to further improve STA performance.

In this SFER Chapter 5C update, the status of all current and recently completed studies are included with a few exceptions. The 2020 studies are still in their inception, and no updates are included in this report. The PSTA study was completed in 2018 (Zamorano et al. 2018), however, monitoring of the inflow and outflow structures continues. The annual performance criteria of the PSTA cell is updated in this report.

RESEARCH QUESTIONS

The original Science Plan included six key questions and 39 sub-questions formulated to improve understanding of factors that affect P treatment performance in the STAs. These questions were developed in workshops and meetings that reviewed existing knowledge and information gaps (SFWMD 2013). After five years, and nine studies that were in various stages of completion, the Science Plan was updated (SFWMD 2018). The key questions and sub-questions were reviewed in numerous workshops and meetings to assess their continued relevance to support the development of strategies to meet the WQBEL, to determine if they had been fully addressed, and to consider if they could be answered through meaningful and cost-effective studies. Several of the original questions were revised for clarity and generalized to encompass multiple variables. Ongoing studies (**Tables 5C-1**) currently address nine research sub-questions:

1. What key factors affect and what management strategies could improve system resilience of SAV communities?
2. What key factors affect and what management strategies could improve system resilience of EAV communities?
3. What is the role of vegetation in modifying P availability to low-P environments, including the transformation of refractory forms of P?
4. What are the key physicochemical factors influencing P cycling in very low P environments?
5. Are there design or operational changes that can be implemented in the STAs to reduce particulate phosphorus (PP) and DOP in the water column?
6. What is the treatment efficacy, long-term stability, and potential impacts of soil amendment management?
7. What are the sources, forms, and transformation mechanisms controlling the residual P pools within the different STAs, and how do they compare to the natural system?
8. What are direct and indirect effects of wildlife communities at temporal and spatial scales on P cycling (e.g., are they net sinks or sources)?
9. How should storage in the FEBs be managed throughout the year so water can be delivered to the STAs in a manner that allows them to achieve desired low outflow TP concentrations?

RESEARCH STUDIES

Since the Restoration Strategies Science Plan was authorized, 16 studies have been carried out. Of these studies, 7 were completed by the end of WY2020. Four additional studies, proposed in the updated Science Plan (SFWMD 2018), are in the planning phase (**Table 5C-2**). The Data Integration Study (**Table 5C-1**) builds upon the Data Integration and Analysis Plan from the P Flux Study and was added to synthesize information gathered from STA studies to combine, condense, and provide an overarching understanding of STA performance; identify uncertainties and information gaps that could direct future studies; and provide guidance for STA management.

Table 5C-2. Studies proposed in the 2018 five-year work plan that are in the planning phase.

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

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

Tracey Piccone and Jacob Dombrowski

The purpose of the PSTA Study, completed two years ago (Zamorano et al. 2018), was to assess the chemistry, biology, design, and operations of the PSTA Cell in STA-3/4 that contribute to superior treatment performance of this technology. One of the key factors controlling TP removal in the PSTA Cell was lack of organic soil. During construction, the muck was scraped and the sub-surface limerock was exposed. Another key factor in the PSTA Cell's ability to produce ultra-low TP concentrations was low inflow TP concentrations and low phosphorus loading rates. Monitoring of the PSTA Cell inflows and outflows and the associated TP concentrations have continued and the annual PSTA Cell performance calculations have been updated through WY2020. For the thirteen years of operation, outflow TP FWMCs ranged from 8 to 13 µg/L compared to inflow TP FWMCs that ranged from 10 to 27 µg/L.

ANNUAL PERFORMANCE

Annual treatment performance of the PSTA Cell was evaluated from measured and calculated values for the WY2008–WY2020 period (**Table 5C-3**). Using measured water inflows and outflows and inflow and outflow TP concentrations obtained from surface water samples, TP loads were calculated and summed by water year. Annual inflow and outflow FWMCs were calculated from TP inflow and outflow loads divided by annual water inflow and outflow, respectively. Annual hydraulic loading rate (HLR), P loading rate (PLR), hydraulic residence time (HRT), and TP settling rate (k) were then calculated (see Piccone and Dombrowski 2020 for calculations). These annual values included the PSTA Cell's operational period for each water year. The operational period was defined as the span of time over which one or both PSTA Cell's inflow structures (G-390A and G-390B) were open. Days when both gates were closed due to protective measures for nesting birds, structure maintenance, or to preserve water during droughts were excluded.

For WY2020, the PSTA Cell produced an annual outflow TP FWMC of 9 µg/L with an inflow TP FWMC of 11 µg/L. HLR, PLR, and k were 6.0 centimeters per day (cm/d), 0.20 grams per square meter per year ($g/m^2/yr$), and 4.4 meters per year (m/yr), respectively. These WY2020 values were within the same range as previous water years. The PSTA inflow gates were closed in early WY2020 to maintain minimum water depths in the upstream SAV cell for the Faunal Study. Over the period of record, inflow FWMC was 15 µg/L and outflow FWMC was 10 µg/L, a reduction in concentration of 33%. Based on superior performance, the PSTA technology is included in our adaptive management strategies toolbox.

Table 5C-3. Summary of annual hydraulic and treatment performance parameters in the STA-3/4 PSTA Cell during each operational period from WY2008 to WY2020. [a]

Water Year	HLR (cm/d)	HRT (d)	Water In (ha-m)	Water Out (ha-m)	FWMC TP in (µg/L)	FWMC TP out (µg/L)	PLR (g/m^2/yr)	k (m/yr)	Operational Period	Operational Period (day) [b]
WY2008	5.5	5.8	360	641	27	12	0.24	14.2	06/05/2007–12/12/2017	161
WY2009	6.0	5.9	408	753	14	8	0.14	13.8	07/09/2008–12/23/2008	168
WY2010	6.2	6.2	866	1,243	20	10	0.42	27.4	05/26/2009–04/30/2010	340
WY2011	6.1	6.7	394	485	18	11	0.17	7.3	05/01/2010–12/072010	159
WY2012	8.6	4.4	919	1,185	17	12	0.39	12.5	07/19/2011–04/05/2012	262
WY2013	7.7	5.1	1,150	1,377	16	11	0.45	17.8	05/01/2012–04/30/2013	365
WY2014	3.3	16.7	497	468	24	13	0.29	10.0	05/01/2013–04/30/2014	365
WY2015	5.8	9.4	862	911	15	11	0.33	11.9	05/01//2014–04/30/2015	365
WY2016	6.9	7.3	1,023	1,285	11	9	0.27	11.6	05/01/2015–04/30/2016	366
WY2017	5.6	12.9	827	659	10	8	0.20	6.7	05/01/2016–04/30/2017	365
WY2018	5.0	10.5	748	1,102	10	9	0.19	3.7	05/01/2017–04/30/2018	365
WY2019	4.7	19.2	693	325	12	9	0.20	4.2	05/01/2018–04/30/2019	365
WY2020	6.0	11.3	754	778	11	9	0.20	4.4	05/01/2019–04/30/2020	310
Mean	**6.0**	**9.6**	**762**	**881**	**15**	**10**	**0.27**	**10.9**		

a. Key to Units: µg/L – microgram(s) per liter; cm/d – centimeter(s) per day; d – days; g/m^2/yr – gram(s) per square meter(s) per year; ha-m – hectare-meter(s); and m/y -meter(s) per year.

b. Both gates may be closed for a few days during the operational period. These days are excluded from the calculations.

EVALUATION OF PHOSPHORUS SOURCES, FORMS, FLUX, AND TRANSFORMATION PROCESSES IN THE STORMWATER TREATMENT AREAS (P FLUX STUDY)

Jill King and Odi Villapando

The goal of the P Flux Study, completed in 2019, was to improve understanding of mechanisms and factors that affect P treatment performance of STAs, especially key performance drivers at lower reaches of STA FWs. To achieve this goal, evaluation of P sources, forms, flux, and transformation processes in the different regions of STA FWs were critical. Study results are expected to support the development or enhancement of STA management strategies to meet the WQBEL.

There are numerous components and sub-studies of the P Flux Study. Components include FW water quality assessments, internal P load measurements, soil P forms, microbial enzymatic patterns, vegetation assessments, and settling and entrainment of STA particulates (**Table 5C-4**). All laboratory and field work associated with the study components have been completed (King and Villapando 2020, Villapando and King 2018, 2019, University of Florida 2019). Further data evaluation and report writing continues through 2020.

A final vegetation sampling event occurred in October 2019 completing the vegetation nutrient study for STA-2 FW 1 and FW 3 and the STA 3/4 WFW. Overall, nutrient—P, N, and carbon (C)—storage was generally similar between respective EAV and SAV cells of STA-2 and STA-3/4 WFW. EAV biomass was typically an order of magnitude higher than SAV biomass, thus nutrient storage was always higher for EAV than SAV. P storage in EAV of STA-2 FW1 was 4.94 ± 1.42 grams P per square meter (g P/m^2) in the inflow region and 2.01 ± 1.00 g P/m^2 in the outflow region. In STA-3/4 WFW, inflow EAV storage was 4.00 ± 1.48 g P/m^2 and outflow EAV storage was 2.43 ± 1.13 g P/m^2.

Table 5C-4. Tasks of the P Flux Study.

Substudy	Process Evaluated	Publications and Reports
Soil Factors and Processes	Recently accreted soils and floc were sampled a different spatial scale-- grids, transects and benchmark locations--within STA-2 FW 1 (EAV) and FW 3 (SAV) and STA-3/4 Cells 3A and 3B. Soils were evaluated for numerous chemical and physical parameters including P extractions, C, N, ions, and organic material. P sorption and release were measured from benchmark locations for Floc, recently accreted soil, and pre-STA soils. Litter decomposition of SAV and EAV material was measured in STA-3/4 Cells 3B and 3A. Nutrient content, and extracellular N- and P-acquiring enzyme activity were measured. The effect of ultraviolet light, sunlight, and hydrogen peroxide on degradable organic matter was measured in the waters of STA-3/4 and STA-2.	University of Florida 2019 Reddy et al. 2020
Biomarkers as Tracers of OM Sources	Biomarkers (lignin phenols, amino acids, and pigments) were measured in samples from STA-3/4 particulate material to evaluate the relative "freshness" of organic matter pools, identify sources of organic matter, and indicate P cycling pathways within the STA water column, floc, sedimented material, and soils.	University of Florida 2019 Morrison et al. 2019
FW Water Quality Assessment	Water quality (TP, DOP, PP, and soluble reactive P (SRP) of STA-2 FW1, FW3 and STA-3/4 Cells 3A and 3B was measured along inflow to outflow transects under different flow conditions: high, moderate, low, and no flow. A total of ten controlled flow events were conducted between August 2015 and July 2017. The trend of water column concentrations along the transect was used to evaluate P removal from the water column over the length of the transect	University of Florida 2019
Internal P Load Measurement	Internal P loading rates in STA-2 FW1, FW3, and STA-3/4 Cells 3A and 3B were estimated from time series water column P concentrations measured from in-situ mesocosm samples collected over a two-week period under no flow condition. Internal P loading rates and equilibrium P concentration at each study site were estimated from these time series with a simple modeling approach. Soil diffusive flux rates also were estimated from measured vertical porewater P concentration profiles.	Jerauld et al. 2019
Particle Dynamics	Velocity was measured at transects within the STAs using an acoustic Doppler profiler. Sediment settling was measured with sediment traps. Critical sheer stress of the soils was determined with a Gust chamber.	Florida International University 2019
Microbial Enzyme Activity	Enzyme assays for N-, P-, and C-acquiring enzymes were measured for all 10 flow events in STA-2 and STA-3/4 to examine trends and patterns of activities along nutrient gradients and within the dominant vegetation communities (EAV and SAV) of each FW. Activities were measured in surface water, periphyton, floc, and litter.	University of Florida 2019
Vegetation Assessment	Satellite data acquired from Worldwide satellite imagery during wet and dry seasons were evaluated to determine if differences in SAV and EAV spectral signatures could be detected for SAV either for a singles species (*Chara*) or mixed species. These images were cross-validated with ground surveys. Vegetation was sampled in STA-2 FW 1 and FW 3 and the western STA-3/4 WFW and analyzed for nutrients to estimate, nutrient (P, N, and C) storage.	Gann et al. 2019
Data Integration and Synthesis	Models using top-down and bottom-up approaches supported analysis, synthesis, and integration of STA data. The top-down approach considered two major controlling variables, internal load and flow. The bottom-up approach developed a mechanistic model of P transformations among the major components within the STA. When integrated with measured data, key processes that affect P concentration along the flow path and at the outflow were identified.	University of Florida 2019 Jerauld et al. 2019

STORMWATER TREATMENT AREA WATER AND PHOSPHORUS BUDGET IMPROVEMENTS (WATER AND P BUDGET STUDY)

Tracey Piccone and Hongying Zhao

The purpose of the Water and P Budget Study, completed in 2020, was to improve annual STA water and P budgets for STA treatment cells. This improved information provided more accurate estimates of STA cell performance and identified areas of uncertainty. Accurate water and P budgets for EAV-dominant and SAV-dominant cells were important to assess STA performance and to predict future long-term STA treatment performance. The water budgets included structure flows (inflows and outflows), rainfall, evapotranspiration (ET), seepage, and change in storage (**Figure 5C-2**). Structure flows were calculated with hydraulic equations developed separately for each water control structure. Rainfall was estimated from rain gauge measurements located within or near each STA. ET was estimated from a model of lysimeter measurements of wetland ET at the Everglades Nutrient Removal Project (Abtew 1996). Seepage through perimeter levees was based on head differences between the treatment cell and outside area water levels, levee length, and a first order seepage coefficient. The SFWMD's Water Budget Application Tool (BPC Group Inc. 2008) was used to develop estimated volumes of seepage, rainfall, ET, and change in storage. The water budget residual—a mathematical difference between all outflow and inflow sources—was a measure of overall accuracy. Developing a closed water budget for the STAs was complicated by the physical characteristics of wetland systems and errors associated with the measurement and estimation of each of the components.

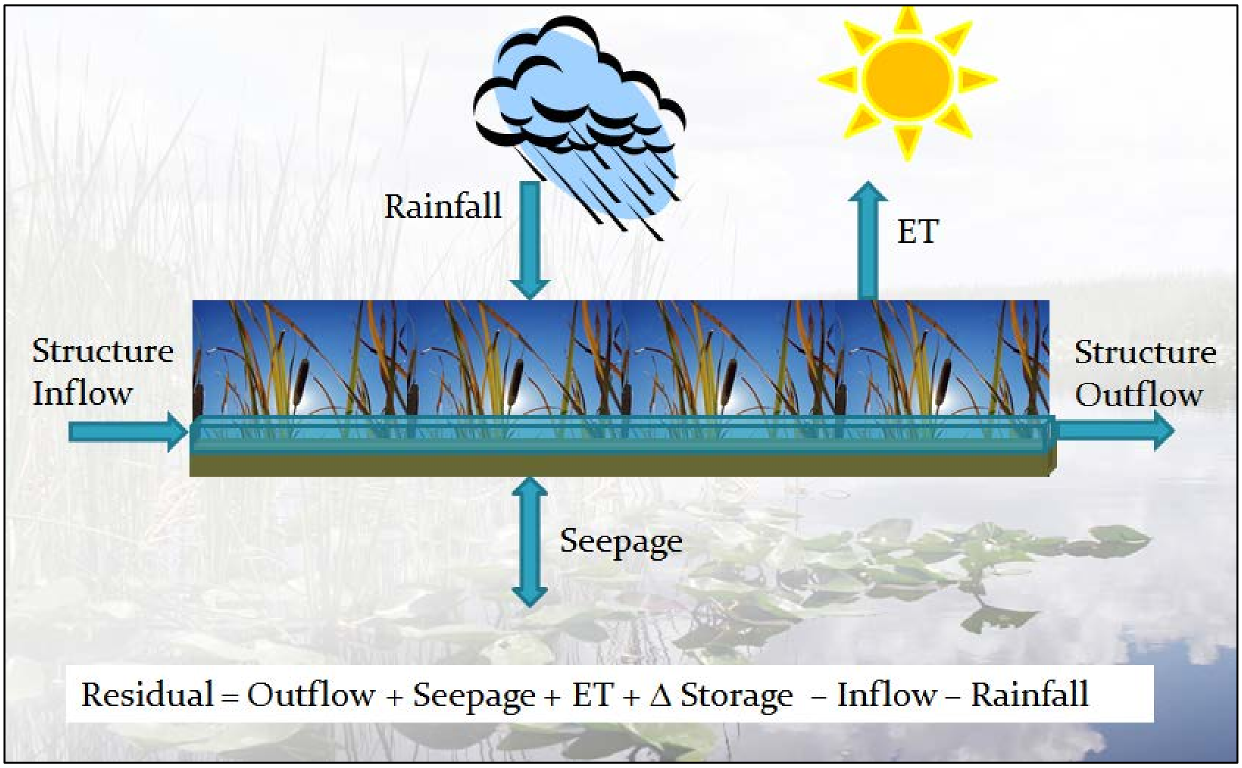

Figure 5C-2. Conceptual model for a water budget in the STAs.

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

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

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

Task	Status and Comments	Publications
	Phase I	
STA-3/4 Cells 3A and 3B water budget improvement test case	Completed in 2014. Improved flow measurements in STA-3/4 through review and correction of flow data, improved flow rating equations and statistical methods to reduce residuals. Seepage. rainfall, ET, and change in water volumes were determined.	Polatel et al. 2014
	Phase II	
STA-2 and STA-3/4 period of record flow data and flow rating improvements	Completed in 2015. Improved period of record flow data for STA-2 FWs 1, 2, and 3, and STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B.	
STA-1E flow data and flow rating improvements	Completed in 2020. Flow data for all STA-1E structures were improved.	
Water Budget Application Tool improvements	Completed in 2018. The Water Budget Application Tool was updated with improved seepage estimates for STA-2 FWs 1, 2, and 3. Water budget estimates for STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B were updated.	
STA-2 and STA-3/4 water and TP budgets and performance evaluation	Completed in 2019. Water and TP budgets for the period of record in STA--2 FWs 1, 2, and 3 and STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B were updated and refined. Treatment cells with POR average annual water budget residuals above 10% were reduced to 1 to 5%, and two treatment cells with extremely high POR average annual water budget residuals of 60 to 62% were reduced to 1 to 4%. Annual and long-term average annual FW and treatment cell TP FWMC in outflows, TP load retention percentage, and TP FWMC reduction percentage were calculated. The effect of annual HLR, annual PLR, annual average HRT, inflow TP FWMC, and annual average water depth on annual outflow TP FWMC were evaluated.	Zhao and Piccone 2018 Zhao and Piccone 2019 Zhao and Piccone 2020
STA-5 flow data and flow rating improvements	Completed in 2017. Flow data for select STA-5 structures were improved.	

EVALUATION OF INUNDATION DEPTH AND DURATION THRESHOLD FOR CATTAIL SUSTAINABILITY (CATTAIL STUDY)

Orlando Diaz

The purpose of the Cattail Study is to identify the inundation depth and duration threshold to sustain cattail (*Typha domingensis*) communities in the STAs. Dense cattail communities in the upper region of a treatment FW reduce PP in the water column and facilitate microbial P cycling through production of litter. Cattail planted in rows within a number of STA cells provide support to SAV communities, reducing turbulence and flow under severe wind events that could negatively affect SAV. Previous field observations and studies indicated that water depths exceeding certain criteria and maintained over long periods resulted in physiological stress, reducing growth, biomass, density, and anchorage capacity of cattail plants in STA treatment cells.

Phase I of this study surveyed many sites in STA-1W Cell 2A in 2015 and STA-3/4 Cell 2A from 2015 to 2018. (Diaz 2018, Diaz and Vaughan 2019). Prolonged water depths above 91 centimeters (cm) for over 100 consecutive days resulted in a decline of both cattail density and total belowground biomass, as well as increased leaf elongation in response to the high water.

Phase II of this study evaluates the effects of various water depth and duration periods under more controlled conditions in fifteen test cells constructed in the early 1990s within STA -1W (**Figure 5C-3**). In the later 1990s, full liners were installed in each test cell to under a few feet of soil to hydrologically isolate them from each other. The test cells were refurbished in 2016 for this study. Cattail seeds (*Typha domingensis*), collected from STA-3/4, were distributed into these cells during the first week of May 2018 (Diaz 2020). Young cattail seedlings 12 to 15 cm in height (50 to 55 days old) were planted at a density of approximately 140 cattail plants per cell from mid-May 2018 through mid-June 2018 to improve uniformity of cattail community in the cells. Water levels were maintained between 10 to 15 cm above the soil surface for 2 to 3 months to encourage seedling growth. Water levels were maintained at about 40 cm from January to June of 2019 to encourage growth and maintain the establishment of the young cattails while minimizing terrestrial weed growth. Cattail plants were mature prior to the initiation of the inundation depth treatments.

Five inundation depths treatments: 40, 61, 84, 104, and 124 cm above soil surface, were established on July 1, 2019, in these cells. Inundation depths were replicated at random in sets of three treatment cells. Duration of inundation was continuous for 10 months. For the first three months, cattail vegetation was surveyed bi-weekly to document responses due to the inundation treatments. These initial observations indicated that monthly field surveys were sufficient to capture the major phenological events due to treatments. Cattail density, photosynthesis, foliage area index (LAI), and leaf elongation were measured.

Water quality samples were collected bi-weekly for the first three months of the study and monthly for the remainder of the study. These water quality samples were collected from the storage cell outlet (representing inflow water) and at the outflow from each test cells. Baseline sediment samples were collected in January 2019 and a final set will be collected in early July 2020. Baseline biomass samples also were collected in May–June 2019. A final biomass sampling was collected at the end of the study in May–June 2020.

Analysis of this cattail monitoring data is in its early stages. Initial results indicate that deep (104 cm) and extremely deep inundation treatments (124 cm) stressed cattail plants—observed from differences in density, photosynthesis, LAI, and leaf elongation—more than those from the moderate (84 cm) and shallow (61 cm) depth treatments. These preliminary results are consistent with the Phase I in-situ study.

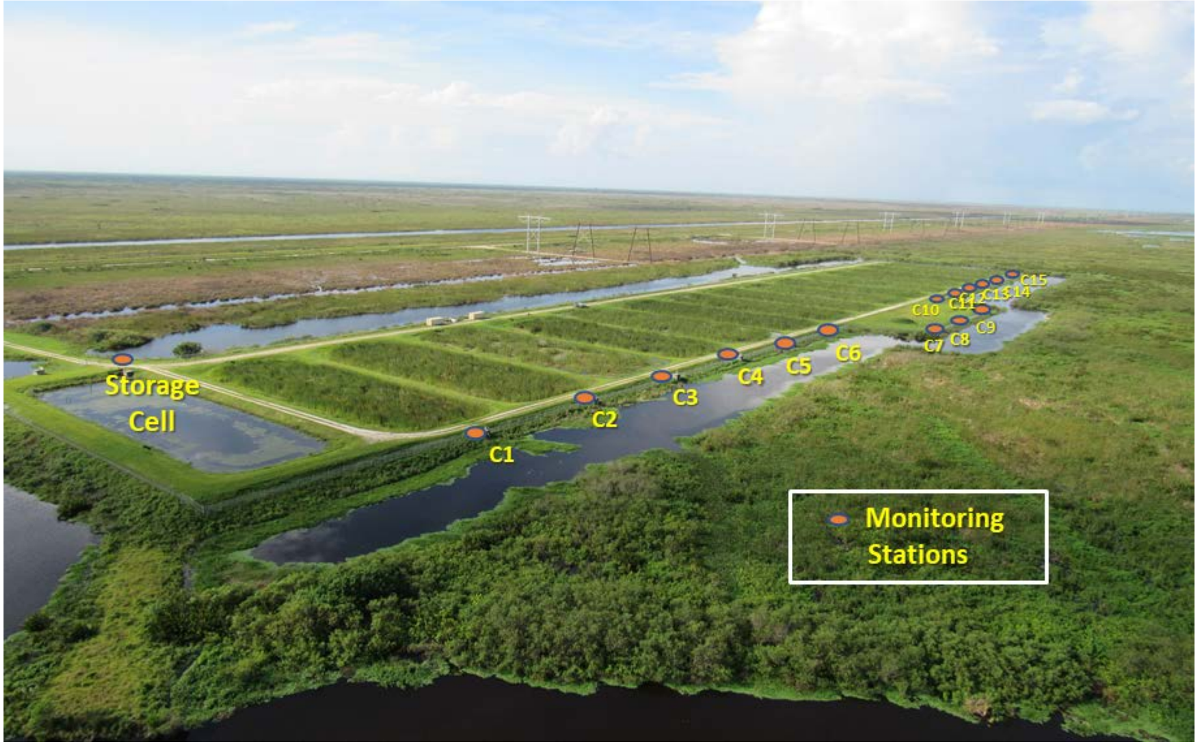

Figure 5C-3 Aerial view of STA-1W Northern Test Cells showing cattail communities and water quality monitoring stations during the study.

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

Michael Chimney

The purpose of the Soil Management Study is to investigate methods that may reduce flux of soluble reactive phosphorus (SRP) from the soil to the water column in the STAs. Reduction of internal P flux may result in lower TP concentrations at STA outflows. These methods include soil amendments (e.g., chemical materials typically rich in metal cations, i.e., aluminum, calcium, iron or magnesium, that readily bond with SRP) and soil management (i.e., soil inversion to bury surface soils that have a high P content). Phase I of the study proposed two options for conducting large-scale field trials within the STAs: (1) leverage a remediation project that used soil inversion (deep tilling) to bury copper-enriched agricultural soils in the STA-1W Expansion Area #1 and (2) build sub-cells in four STAs to test various technologies (Chimney 2015, **Table 5C-6**). Considering the uncertainties in treatment efficacy, potential adverse effects on STA operations, the estimated cost of large-scale field trials, and the practicality of implementing these technologies at full-scale in the STAs, option one was chosen to determine the effect of inverting soils on P flux after flooding (Chimney 2015, 2017). The inversion of the soil column through deep tilling buried the oxidized, P-rich higher copper content soils bringing lower-P subsoil to the surface. Additional studies on a variety of soil amendments and management techniques outlined in Chimney (2015) have been postponed indefinitely due to the uncertainties described above.

Construction of the STA-1W Expansion Area #1 added three new treatment cells to STA-1W: Cells 6, 7, and 8. Soils were tilled to a depth of at least 60 cm in all of Cell 7 and a portion of Cell 6 to remediate for high copper levels in the surface soils (AECOM Technical Services, Inc. 2016). Cell 8 surface soil does not have high copper levels and was not tilled. A preliminary study was conducted to characterize these tilled and untilled soils (Josan et al. 2019). The soil brought to the surface through tilling included peat (inverted-peat) and marl (inverted-marl). The median TP content of the inverted-peat and inverted-marl soils (527 and 160 milligrams per kilogram [mg/kg], respectively) was significantly lower than the median TP content of the untilled soils (830 mg/kg).

P flux was measured from these inverted and untilled soil cores in the laboratory (Josan et al. 2019); these cores were flooded with low-P STA-1W outflow water and incubated under dark, aerobic conditions. After 42 days of incubation, the average water column TP concentration for untilled, inverted-peat and inverted-marl soils was 156, 68, and 13 µg/L, respectively. The corresponding mean SRP flux rate in these cores was 3.3, 1.6, and 0.1 milligrams P per square meter per day (mg P/m^2/d), respectively. The soil core incubations suggested that deep tilling may be beneficial in reducing the flux of P from flooded soil to the overlying water column.

The STA-1W Expansion Area #1 was flooded in 2019 after all soil tilling was completed. The permit start-up criteria required to initiate flow-through operation were met, however, normal operation of this facility has been delayed due to ongoing construction, which should be completed by late calendar year 2020. In the interim, a grid of geo-referenced sample sites was established in Cells 7 (the study's tilled-soil treatment; 25 sites) and 8 (the study's untilled-soil control; 34 sites). Baseline water and sediments samples were collected in April 2019 from a subset of sites in both cells. Average surface-soil TP content was similar at the tilled and untilled sites: 963 ± 154 mg/kg and 821 ± 31 mg/kg, respectively. Surface water TP concentrations varied considerably within both cells, with TP concentrations ranging between 40 and 636 µg/L in Cell 7 and 43 to 155 µg/L in Cell 8 (DBE 2019b). In addition, an initial SAV survey was conducted at all sites in Cells 7 and 8 during August 2019 (DBE 2020c). No SAV was observed in Cell 7 while coverage was sparse in Cell 8 where SAV occurred at only 16 of the 34 sites. Only four species were encountered in this survey: chara (*Chara* sp.), southern waternymph (*Najas quadalupensis*), spiny waternymph (*Najas marina*), and floating bladderwort (*Utricularia gibba*). *U. gibba* was the most common species. Temporary reverse flow-through began on March 11, 2020. Once normal flow-through operation of the STA-1W Expansion Area #1 begins, the treatment efficacy of Cell 7 (tilled soil) will be compared to Cell 8 (untilled soil) using weekly measurements of inflow and outflow TP concentrations at both cells.

Table 5C-6. Progress to date of the Soil Amendments/Management to Control P Flux Study.

Task	Status and Key Findings	Publications and Reports
Phase I: Literature review	Completed in October 2015. A literature review of technologies, including a synthesis of relevant SFWMD supported projects and an assessment of feasibility of implementing at full-scale in the STAs.	Chimney 2015
Phase II: Small-scale experiments	A decision was made not to proceed with Phase II, which would screen a variety of soil amendments/management techniques identified in Phase I	Chimney 2015 Chimney 2017
Phase III: Large-scale field trials	Ongoing. A field-scale treatment of soil inversion for copper remediation in the STA-1 W Expansion Area #1 was initiated in 2017. Water and soils samples are being analyzed along with SAV growth to determine if soil inversion improves initial and long-term STA performance in reducing P discharge.	Josan et al. 2019 DBE 2019b DBE 2020c

EVALUATION OF FACTORS CONTRIBUTING TO THE FORMATION OF FLOATING TUSSOCKS IN THE STORMWATER TREATMENT AREAS (TUSSOCK STUDY)

Mark Clark[1], Katie Glodzik[1], and Orlando Diaz

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

Phase I included a literature review of floating wetland research, a nomenclature scheme that described various types of floating vegetation and floating mats in the STAs (**Figures 5C-4** and **5C-5**), and an assessment of current areas that contain floating cattail communities/tussocks in STA EAV cells (**Table 5C-7)**.

Global and local terminologies were found in the literature review that described many of the floating wetland communities in the STAs. The review did not find a universal terminology or classification scheme for these floating complexes, despite such floating communities being found often in wetlands around the world from the tropics to the tundra. However, floating substrate (presence/absence), horizontal connectivity, and dominant vegetation were often components of terms used to describe floating wetlands. These descriptive terms were used to develop a floating wetland nomenclature that describes the variety of emergent plant communities in the STAs (**Figure 5C-4**; Clark 2019c).

The floating wetland nomenclature uses a hierarchical terminology. “Tussock” and “floating aquatic vegetation (FAV)” are floating vegetation with no associated organic substrate (**Figure 5C-4**). “Floating island” or “floating mat/complex” describes floating vegetation with associated substrate or unvegetated floating substrate. An “island” is free floating substrate not connected along any side, and a “mat” or “complex” is floating substrate connected along at least one side. The differentiation between “mat” and “complex” is based on size and species richness. For areas less than 10 square meters (m^2) and or composed of a single species the term “mat” is used. For contiguous areas greater than 10 m^2 or composed of multiple species, the area is termed a “complex”.

The nomenclature for these floating wetlands can be defined further based on dominant vegetation type. For example, floating substrate dominated by *Typha* that is attached to any adjacent vegetation and composed of organic matter would be labeled “*Typha* floating island”. If that same *Typha*-dominated floating substrate were attached to other vegetation, and the area was greater than 10 m^2, the area would be labeled “*Typha* floating complex”. A floating substrate area with mixed herbaceous vegetation that is contiguous and attached to non-floating vegetation would be labeled “marsh floating complex”. STA-1W Cell 2A contains a variety of these floating wetlands (**Figure 5C-5**).

Floating wetland communities were identified and measured in two EAV cells of the STAs: STA-1W Cell 2A and STA-2 Cell 7 using an unmanned aircraft system (UAS; Clark and Glodzik 2019). Post-processing and classification schemes were developed to identify floating wetland communities in these EAV cells. Multispectral drone imagery data discovered *Typha* floating complexes that otherwise would not be apparent in satellite imagery.

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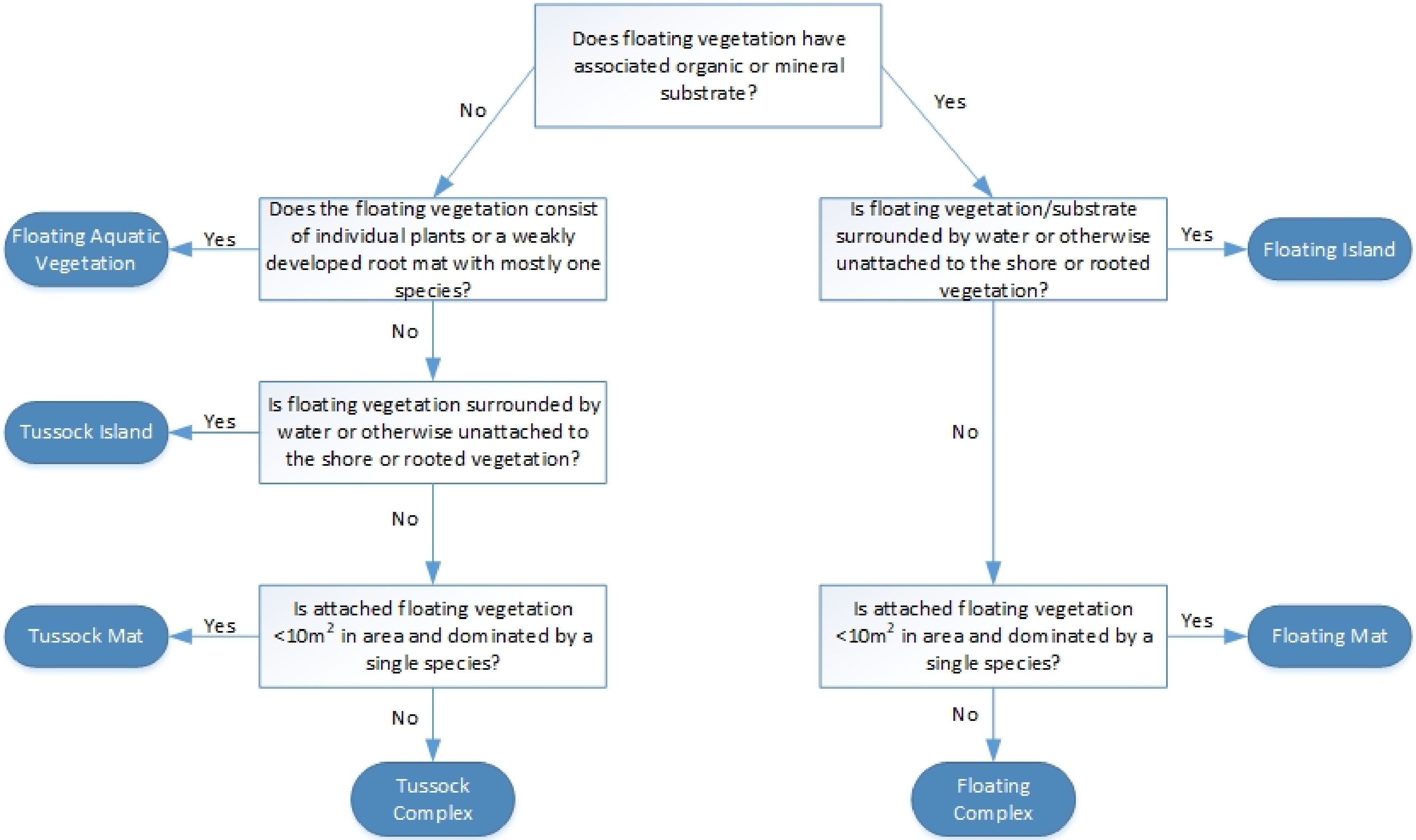

Figure 5C-4. Dichotomous key to the floating wetland nomenclature.

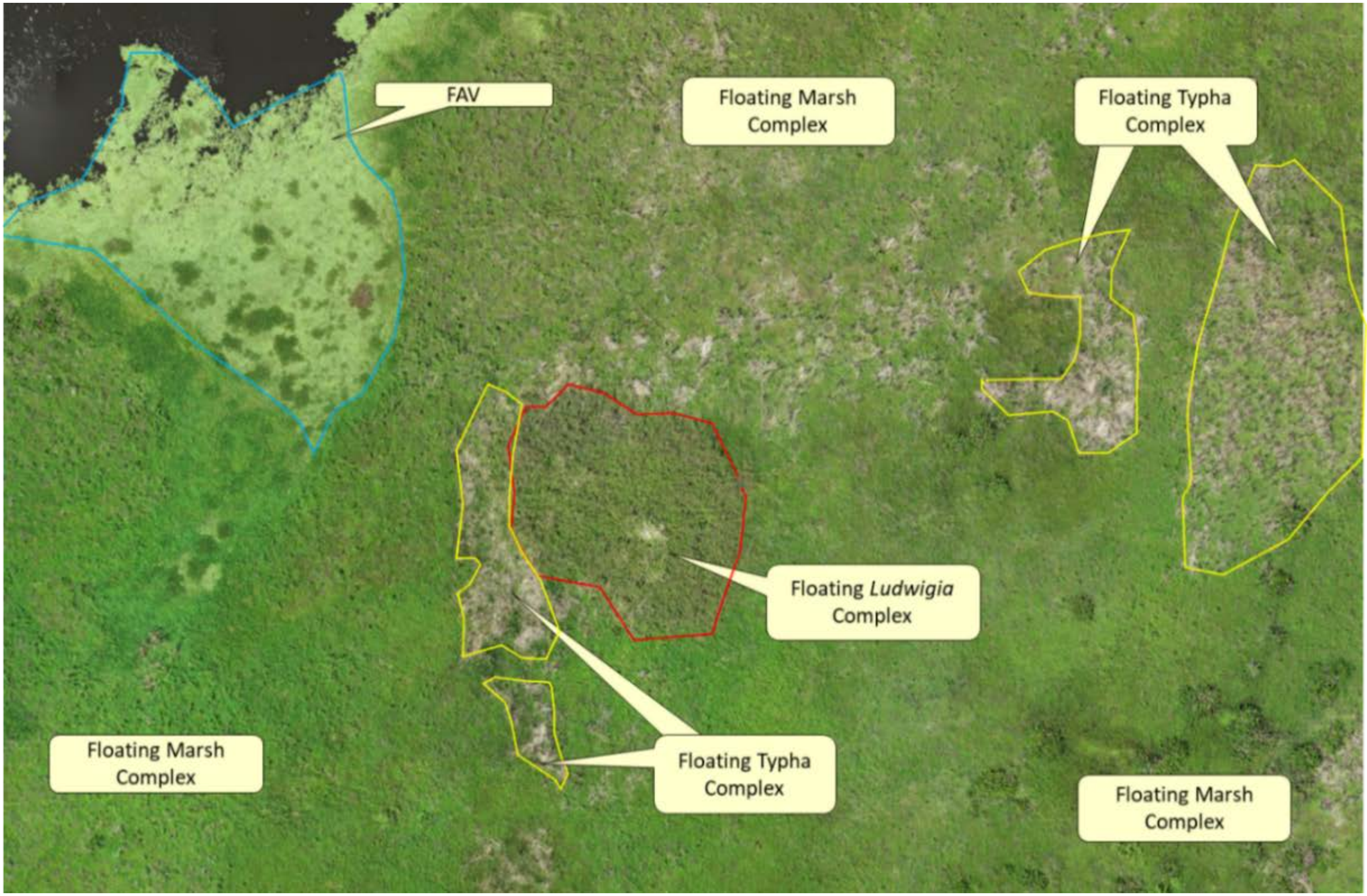

Figure 5C-5. Examples of floating wetland nomenclature applied to an aerial image of STA-1W Cell 2A.

Thermal imagery was evaluated as a method to find floating wetland communities with a thermal-infrared camera attached to the UAS. It was expected that healthy cattail would have distinctly different thermal signatures from floating wetland communities. However, thermal signatures were not unique among the various floating and non-floating wetland communities assessed. Differences detected were strongly influenced by time of day reducing the ability to detect floating wetlands with thermal infrared imagery (Clark 2019a). Under very specific conditions (at solar noon when shadows are minimal) thermal-infrared imagery, when added to red, green, blue, near infrared, and red-edge spectral images, may support the differentiation between emergent and floating *Typha*. The influence of localized hot and cold spots can be reduced by aggregating pixels, which would reduce variability, allowing the underlying integrated energy balance to be expressed.

The processes and procedures using UAS classification to find floating wetlands in the STAs will be optimized and improved in Phase II (**Table 5C-7**). In addition, more direct measures of floating wetlands formation and a model to indicate the potential for tussock formation will be developed. This process model will be used to predict changes in floating wetlands formation potential based on factors such as water level, soil composition, and plant biomass. To support the process model and to determine management options to reduce tussocks formation, environmental factors that could trigger floating wetlands formation have been evaluated through an analysis of SFWMD historical data of the STAs.

Historical data from the SFWMD's STAs were analyzed to identify statistically significant predictors of floating wetland communities across EAV cells (Clark and Glodzik 2020). Ratings of floating wetland community coverage for each treatment cell were obtained by interviewing SFWMD scientists responsible for on-the-ground management of STA vegetation. The results suggested a higher likelihood of floating vegetation occurrence in treatment cells with greater high-water levels (characterized as Q90 or 90th percentile of water level recorded in the cell), cells that had lower TP soil storage at the start of cell operations, and cells built on agricultural land that was farmed in recent years prior to cell construction. These results are considered preliminary until a more quantitative estimate of floating wetland community coverage can be determined using UAS imagery.

Quantification of buoyancy measurements (Hogg and Wein 1988, Clark 2000) will provide insight into mechanisms of buoyancy. The *Typha* community buoyancy model will estimate increased or decreased potential for formation of floating wetland communities based on these buoyancy measurements, environmental parameters, and management conditions. This model should determine the probability that a floating wetland community will occur based on conditions within an STA cell. Input variables to be considered are water level, plant density, temperature, and soil holding capacity.

Due to travel restrictions associated with COVID-19, UAS mapping activities and field assessment of buoyancy budgets have been significantly delayed (**Table 5C-7**). Assessment of these Phase II project components will resume as soon as feasible.

Table 5C-7. Status of tasks for the Tussock Study.

Task	Status and Key Findings	Reports
Phase I		
Literature review	Task is complete.	Clark 2019b
Floating wetlands nomenclature	Task is complete. A hierarchical nomenclature scheme was developed to describe floating wetlands in STAs (**Figures 5C-4** and **5C-5**).	Clark 2019c
Assessment of floating tussocks coverage in STA EAV cells	This task is complete. A multispectral camera on a UAS was used to determine if tussocks could be observed in areas that otherwise would not be apparent in satellite imagery.	Clark and Glodzik 2019
Thermography assessment	This task is complete. A thermal camera on a UAS was used to determine if thermal reflectance of vegetation can differentiate between emergent and floating *Typha.*	Clark 2019a
Phase II		
Data mining	This task is complete. Historical data related to formation of floating wetland communities in STAs was evaluated to determine if significant statistical relationships with water levels, soil P, and past agricultural history could be found.	Clark and Glodzik 2020
Refine UAS methodology and workflow	Delayed due to COVID-19 restrictions. This task will evaluate improvement of UAS methods including use of a real-time kinematic or post-processed kinematic global positioning system (GPS) unit.	
UAS assessment of STA EAV cells	Delayed due to COVID-19 restrictions. This task will map tussocks in 21 STA Cells where EAV is dominant to find floating wetland communities.	
Typha wetland buoyancy model	Delayed due to COVID-19 restrictions. This task will estimate the potential for formation of floating wetland communities based on buoyancy measurements and water conditions.	
Evaluation of findings and final report	Delayed due to COVID-19 restrictions. Final report and recommendations to reduce potential of floating wetland communities.	

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

Mark Barton[2] , Joel Trexler[1], Mark Cook, and Sue Newman

The objective of the Faunal Study is to evaluate the influence of large populations of fish and aquatic invertebrates on P reduction in STAs. Specifically, this study estimates (1) standing stock biomass of small fish (< 8 cm standard length) and aquatic macroinvertebrates in STA-2 and large fish (> 8 cm standard length) in STA-2, STA-1E, STA-1W, and STA-3/4; (2) mass-specific P excretion rates of the most abundant species; and (3) the potential of benthic aquatic species to enhance water column nutrient concentrations through bioturbation (**Table 5C-8**). Biomass and excretion estimates are combined and scaled up to estimate areal (per ha) P excretion by the entire aquatic faunal assemblage in STA-2 (i.e., rates of P released to the water column via excretion, micrograms phosphorus per hectare per hour [µg P/ha/h]). Excreted loads of P are compared to external loads of P and other important nutrient cycling pathways in the STAs. Bioturbation estimates are used to evaluate the potential of fauna to counter the efficiency of P removal by STA soils. These estimates may be included in nutrient budgets and provide guidance for management actions aimed at improving P retention efficiency.

Table 5C-8. Status of tasks for the Faunal Study.

Task	Status and Key Findings	Publications and Reports
Community analysis	Task was completed in 2019. Determined the abundance and distribution of fish and macroinvertebrates in STA communities in relation to the local vegetation habitat through throw trap and electrofishing sampling.	Barton and Trexler 2020a
Winter fish excretion rate estimates	Task was completed in 2019. Estimated nutrient excretion in day and night experiments for large and small fish in winter and summer months.	Barton et al. 2020a Barton et al. 2020c
Winter bioturbation by large fish	Task was completed in 2019. Bioturbation was measured in enclosures over a 14-day period for low and high densities of large fish.	Barton et al. 2020b
Scaling up the P budget	Task was completed in 2019. Total excretion and bioturbation for the STAs were estimated through the excretion estimates multiplied by the fish density and STA area.	Barton and Trexler 2020b

The influence of animals on P forms, fluxes, and transformations in the Everglades STAs is an important uncertainty for their efficient management of P removal. Animals, including water birds, fish, and macroinvertebrates, contribute significantly to nutrient cycling in aquatic ecosystems (Vanni 2002, Doughty et al. 2016; **Figure 5C-6**). The abundance and diversity of aquatic animals can affect water column nutrient concentrations through several pathways. Animals function as a source of internal nutrient loading by directly mobilizing benthic or particulate nutrients through their feeding and excretion (Vanni et al. 2006). They also can indirectly affect nutrient loading through modifications of the environment (e.g., bioturbation; Vanni et al. 2006) and by herbivory or predation, which result in interactive effects felt

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through the food web (Dorn 2013, Kellog and Dorn 2012). Bioturbation, including all animal activities leading to mixing of the substrate, particle ingestion, and defecation, elevates water column nutrients through the resuspension of benthic nutrients and seston. Top-down effects may modify nutrient cycles by altering the abundance of species and affecting the efficiency of animal-mediated nutrient cycles.

Previous results from this work suggested a pivotal role of animals in STA nutrient cycling (Evans et al. 2018, 2019, Barton et al. 2020a). Further work is needed to measure direct and indirect roles of fauna on nutrient cycles and their effect on P transformations in the STAs. Work continued in the past year to estimate aquatic-animal contributions to water-column nutrient concentrations by fish excretion and bioturbation. To scale up rates of P transformation from these processes, biomass of fish, amphibians, and aquatic macroinvertebrates in STA-2, and aquatic-animal community composition in STAs 3/4, 1E, and 1W was continued. The results of experiments carried out over the past year are highlighted here.

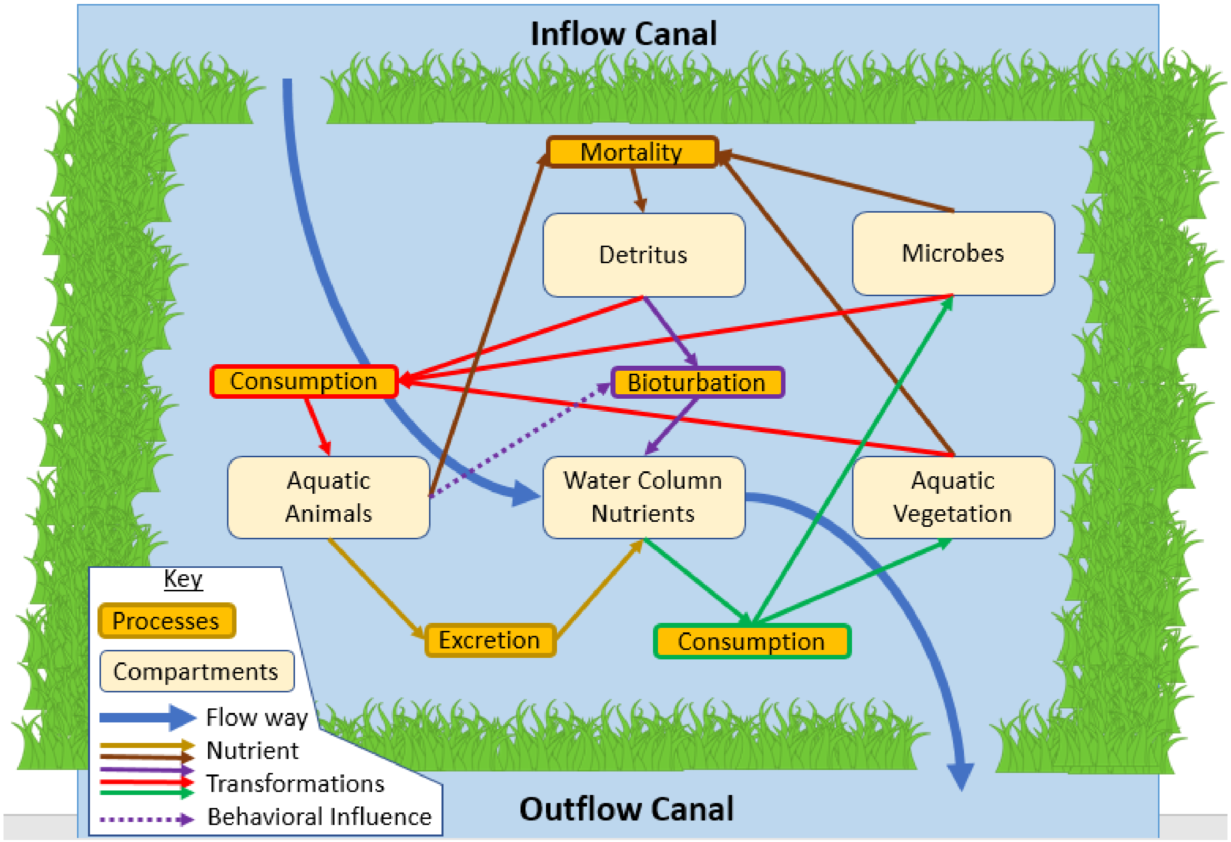

Figure 5C-6 Conceptual model of P transformations by fauna in the STAs.

Fish excretion, measured from incubation experiments in the field, contributes a significant amount of P to the water column in the STAs due to high fish abundance. Fish excretion is not an additional source of P to the STAs but is recycled P from internal storage and external nutrient loads. This means that the P load introduced to the water column from upstream of the STAs is recycled through fish and possibly displaced from sediments and plant biomass through aquatic animal activities. It was estimated that six common fish species excrete 115 kilograms per day (kg/d) of P, resulting in 41,975 kilograms per year (kg/y) in Cells 3, 4, 5, and 6 of STA-2 (combined). This is equivalent to 116% of the average annual P load to STA-2 for years 2011 through 2019 (36,247 kg/y; Zhao and Piccone, 2020). The estimates of excretory contributions to STA-1E, STA-1W, and STA-3/4 are speculative because small fish densities were not measured in these regions. Small fish comprised 99% of excretory contributions of P reported for STA-2. If a similar proportion of small to large fish make up the biomass in other STAs, these six species may excrete an estimated 73 kg/d (26,645 kg/y) of P in STA-1E, 202 kg/d (73,730 kg/y) in STA-1W, and 17 kg/d (6,205 kg/y) in STA-3/4. These are equivalent to 129, 199, and 13% of the average P load from 2008 through 2019 entering all of STA-1E (20,683 kg/y), STA-1W (37,069 kg/y), and STA-3/4 (47,100 kg/y), respectively (Zhao and Piccone, 2020; Chimney et al. 2020).

These excretion rate estimates are likely underestimates of fauna contributions to P budgets in the STAs. For example, water temperature directly affects fish metabolism and excretion. Since all excretion experiments to date were completed in winter months, excretion measurements are likely lower than would occur in the summer. Thus, these measurements are being repeated in summer months to obtain a more balanced annual budget. Macroinvertebrates, particularly grass shrimp (*Palaemonetes paludosus*), can be very abundant in the STAs and thus may be significant sources of P through excretion. Additional work to incorporate macroinvertebrate contributions is needed.

Large-bodied fish do not make large contributions to water column TP through excretion, however, their contributions through bioturbation are substantial. P contributed through bioturbation to the water column by largemouth bass (*Micropterus salmoides*), blue tilapia (*Oreochromis aureus*), and sailfin catfish (*Pterygoplichthys* spp.) was estimated as 16,400 kg/y of P in STA-2, 4,057 kg/y in STA-3/4, 14,993 kg/y in STA-1W, and 15,193 kg/y in STA-1E. These values equate to 51%, 9%, 40%, and 73% of the inflow TP loads of STA-2, STA-3/4, STA-1W, and STA-1E, respectively. Unlike excretory processes, which retain P in the water column by cycling it through the food web, bioturbation resuspends P formerly sequestered in soils. Both processes function in opposition to processes targeted to clean water added to the STAs before introducing it to the Everglades.

Estimates of bioturbation rates are also underestimates. There are four assumptions that deserve further scrutiny: (1) the rate of TP released through bioturbation remains constant at densities of fish lower than the low treatment level; (2) the TP content in floc is homogenous across STAs; (3) the rate of bioturbation is constant across the size range of fish collected with electrofishing gear (we only estimated it for relatively large specimens of the species studied), and (4) the areal biomass of fish from electrofishing is a simple correction factor.

Correction factors for abundance and biomass estimates from electrofishing surveys exist for some native species (Chick et al. 2004, Schoenebeck et al. 2015). These correction factors were determined under environmental conditions that were different from those found in the STAs. A recent study used a mark-recapture experiment to assess catchability of abundant South Florida species and found that local conditions (depth, microhabitat, turbidity, and conductivity) can lead to large differences in electrofishing efficiency (Trippel, personal communication). Trippel showed that mean catch efficiency for largemouth bass ranged between 25% and 35%, and that catchability was higher with higher abundance. For tilapia (*Oreochromis* spp.; predominantly blue tilapia), catch efficiency ranged between 1 and 8% and the higher catchability was achieved with lower abundance of tilapia. This result was attributed to the high turbidity and poor visibility in one of the sites. Catch efficiency of sailfin catfish was consistently low across habitats (2 to 3%) while abundance differed by an order of magnitude. Cichlids have long been considered relatively insensitive to electrofishing and under-sampled compared to native centrarchid species.

If estimated region-wide excretion were adjusted for largemouth bass, tilapia, and sailfin catfish using 35, 8, and 3% catch efficiency, respectively (for more conservative estimates) these fish in STA-2 would contribute 7,299 kg/y of P more through excretion, an increase of 10%. Similarly, excretion estimate for large fish in STA-1E, STA-1W, and STA-3/4 would increase by 3,186 kg/y, 4,173 kg/y, and 285 kg/y, respectively. If estimates of region-wide bioturbation were also adjusted using correction factors from Trippel, these fish would release 116,815 kg/y of P more in STA-2, 30,540 kg/y more in STA-3/4, 56,378 kg/y more in STA-1W, and 101,275 kg/y more in STA-1E. Most of these changes in bioturbation rates are attributed to the sailfin catfish correction (834% increase), which released substantially more TP through bioturbation per capita than the other two species (5.4 milligrams per square meter [mg/m^2] versus 1.5 and

0.59 mg/m^2). These electrofishing corrections increase the effect of bioturbation on water column TP beyond that of excretion.

The estimated region-wide contribution of excretion and bioturbation of fish suggest that fish recycle nutrients from the benthos and plant biomass at such a high rate that nutrients are being exported from the STAs faster than they are imported, however this is not the case. TP retention in STAs is on average between 64 and 85% (Chimney et al. 2020) from 2002 through 2017 for STA-2 and from 2006 through 2017 for STA-3/4. This may in part be explained by the large proportions of TP excreted by fish consisting of labile dissolved forms (total dissolved phosphorus [TDP]). Excreta from large-bodied fish consisted of more TDP (76 ± 7%) whereas small-bodied fish excreta consisted of much less TDP (37 ± 20%). This TDP is more easily absorbed and used by heterotrophic and autotrophic bacteria, algae, and vascular plants, and it is likely that these dissolved forms of P are reabsorbed very quickly after release. The particulate form is much less bioavailable and likely settles out to either accumulate in floc or is resuspended through bioturbation.

In conclusion, small-bodied fish species recycle substantial amounts of P into the water through excretion, and most of this excreted mass are less bioavailable particulate forms. Though large-bodied fish also make contributions to water column nutrients through excretion, their greatest effect on water column TP is from suspension of nutrients buried in floc and underlying sediments. Estimates of recycled TP via excretion or bioturbation of large-bodied fish are highly dependent on biomass and population estimates derived from electrofishing surveys; known uncertainties in the electrofishing data require the assumption that the scaled-up numbers are underestimates, perhaps dramatically so. The ongoing work to improve calibration of the electrofishing estimates will provide helpful information for planning of STA management activities to achieve the mandated discharge limits in part through manipulation and control of fish populations.

IMPROVING RESILIENCE OF SUBMERGED AQUATIC VEGETATION IN THE STORMWATER TREATMENT AREAS (SAV RESILIENCE STUDY)

Jacob Dombrowski and Kevin Grace[3]

The purpose of the SAV Resilience Study is to assess physical, chemical, and biological processes that reduce the sustainability of SAV communities. SAV is an important and abundant component of the STAs. Substantial declines in SAV coverage and density have occurred at times in several STA cells, which could impair nutrient removal performance of these systems (Dombrowski et al. 2020). Factors that may contribute to SAV species distribution, persistence, colonization, and recovery in the STAs include SAV biology, water chemistry, nutrient loading, soil/sediment chemistry including deposition of fine marl sediments, physical characteristics, herbivory, and interactions among these factors (DBE 2018). Temporal changes of soil characteristics and extreme weather events (e.g., hurricanes and drought) also have resulted in stress on SAV in the STAs

The SAV Resilience Study is comprised of four sub-studies: (1) effect of marl soil on SAV growth (**complete**), (2) effect of nutrient loading rates on *Chara* sustainability, (3) effect of dry out on SAV growth, and (4) impediments to SAV growth in STA-2 FW3 (**Table 5C-9**). One substudy is complete and three are ongoing.

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

Table 5C-9. Status of the tasks for the SAV Resilience Study.

Task	Status and Key Findings	Reports
SAV growth as affected by accumulation of new marl sediments	Task completed in September 2019. Southern waternymph (*Najas guadalupensis*), shiny pondweed (*Potamogeton illinoensis*), and the non-rooted macroalgae chara (*Chara* spp.) growth and nutrient content were evaluated in mesocosms of marl soil, muck soil, and aged muck soils.	DBE 2020a
Chara sustainability at different nutrient loading regimes	Task is ongoing. This task involves the evaluation of *Chara* spp. in mesocosms of different PLRs, and evaluating density, dissolved oxygen, pH, temperature, and light. The experiment is ongoing with various manipulations to determine the conditions that result in vegetation collapse.	DBE 2020b
STA Dryout	Task is ongoing. Soil collection, drying, and SAV germination phases are complete. An SAV growth phase will be completed following germination in Water Year 2021 (WY2021; May 1, 2020–April 30, 2021.	DBE 2020b
Impediments to SAV growth in STA-2 FW 3	Task is ongoing. The substudy is determining if SAV growth is impeded in current soil conditions in STA-2 FW 3. Corrals in bare soils regions were inoculated with *Chara* spp., spiny waternymph (*Najas marina*) , *Potamogeton illinoensis*, or *Najas guadalupensis*. Biomass will be determined at the end of the experiment to measure growth rate.	DBE 2020b

The first substudy to evaluate marl soil accumulation on SAV growth sought to address the question, Does growth of selected SAV species become impaired by the accumulation of new marl sediments, as compared to growth on the substrate (previously-farmed muck soil) present at the time of STA construction? Leaf tissue nutrient accumulation, biomass growth, root development, and water column P reduction by two common rooted SAV species: *Najas guadalupensis* and *Potamogeton illinoensis* and a non-rooted macroalgae (*Chara* spp.) were monitored. Each SAV species was grown within outdoor mesocosms on three different substrate types: farm muck (recently farmed soil, typical of STA start-up), aged muck (soil from SAV-dominated STAs that has been operational for an extended period), and marl (substrate from within SAV beds that represents the current condition). Following establishment, plant growth continued for 20 weeks while water was exchanged with fresh, low nutrient water every 2 weeks. Plant tissues were harvested at 10 and 20 weeks, and analyzed for total dry weight, ash-free dry weight, macro nutrients (P, N, C, and calcium), and micro nutrients (iron, manganese, copper, boron, zinc, nickel, and molybdenum). Soil samples were taken at the same time steps as plant tissues and analyzed for the same micro and macro nutrients as well as bulk density. Water sampling was conducted inside each replicate during and 14 days following water exchange.

Differences in physical and chemical characteristics were observed between the substrate types suggesting STA substrate changes overtime as marl accumulates. However, substrate type did not influence biomass or root production by any SAV species except *Najas guadalupensis*, which produced shallower rooting in the marl treatments. Bulk density was lower in marl treatments when compared to muck treatments, which could influence the volumetric nutrient availability and stability of rooted SAV. Reduced tissue macro (P) and micro (zinc, copper, iron) nutrients were found in plants grown on marl compared to plants grown on farm muck, suggesting reduced nutrient availability to plants as STAs ‘age’. Further research is necessary to determine how the physical and chemical differences in marl substrates influence SAV growth rates and sustainability.

The second sub-study, the effect of nutrient loading rates on *Chara* sustainability, examines the potential for the common macroalgae *Chara* spp. to suddenly and rapidly decline or collapse. Specifically, the sub-study seeks to answer the following questions: Does *Chara* have an upper limit to its tolerance to nutrient loading? Are there early signs of declining health in STA *Chara* beds? Mesocosms inoculated with

Chara are subjected to either low (~0.3 P g/m^2/yr), moderate (~1 P g/m^2/yr), or high (~2 P g/m^2/yr) P loading rates (PLR). Nutrient loading regimes are intended to mimic the conditions at the inflow, middle, and outflow of an STA FW while HLRs are held constant at 5.4 cm/d. The relative density and nutrient removal performance of *Chara* are assessed as indicators of SAV 'health'. *Chara* growth is monitored over time alongside routine sampling of water column chemistry, while water physical chemistry parameters (dissolved oxygen, temperature, and pH) are recorded at continuous 30-minute intervals. Additional measurements of soil redox potential, photosynthetically active radiation (PAR), and vegetation relative density are also performed monthly.

Initial results show *Chara* density responds to external nutrient loading, with the highest, moderate, and lowest densities in the high, moderate, and low PLR treatments, respectively. P removal efficiency follows the nutrient loading gradient as well; however, the moderate and low loading treatments produce the lowest outflow P concentration (13 µg/L for both treatments). Although P removal efficiency remains highest within the high loading treatment, anoxic conditions have developed near the soil surface in these treatments. There is high light limitation within these treatments with < 5% PAR remaining at the soil surface as compared to 10 to 20% and 40 to 60% PAR remaining in the moderate and low loading treatments, respectively. The low loading treatment may be hindered more by nutrient limitation than light, as elevated outflow DOP levels are observed relative to the high and moderate loading treatments. Despite the development of limiting conditions, a collapse has not occurred in any treatment. This experiment will continue into Water Year 2021 (WY2021; May 1, 2020–April 30, 2021), with additional manipulations (water depth and flow rate) that mimic seasonal changes and may act as catalysts for *Chara* decline.

The third substudy, STA dryout, has examined temporary drawdowns as a potential management tool to consolidate and compact soil, which could improve the germination and growth of SAV communities. Drawdowns could potentially expedite SAV recovery in FWs following large-scale losses of SAV, such as occurred in STA-2 FW 3 in 2017. This FW previously contained dense beds of *Chara*, *Najas guadalupensis*, and *Potamogeton illinoensis*, thus a viable seedbank may exist within the soil. To examine the effects of drawdown on soil consolidation and SAV germination, soil cores were taken from STA-2 FW 3 and STA-1E Cell 6. The latter cell currently supports species similar to those previously found in STA-2 FW 3. Cores were subject to controlled drying, including thorough dryout (dry) or partial dryout, or left in a field-moist (wet) condition. Subsamples of each treatment core were taken to assess bulk density and soil P after a drying period (analytical results pending). Each treatment was then monitored for SAV germination over a 6-week period. Germination was observed in all treatments over the observation period, with *Chara* spp. as the dominant taxa represented in each FW. Initial results suggest germination was quicker and more biomass developed from dry treatments compared to wet treatments. Following the germination phase, a growth phase is planned where *Najas guadalupensis* is inoculated into each treatment and monitored for 12 weeks, culminating in biomass harvest and determination of growth rates.

The fourth substudy, impediments to SAV growth in STA-2 FW 3, examines if growth of SAV taxa is impeded by current soil conditions in STA-2 FW 3. A complete SAV collapse occurred in 2017 in STA-2 FW 3 following a gradual decline in SAV coverage. To date, recolonization by common SAV taxa has been limited. In combination with the dryout/germination study, this experiment will assess what characteristics of STA-2 FW 3 are hindering SAV recolonization. Reconnaissance surveys for appropriate site conditions (deep marl sediment and a persistent lack of vegetation) have been conducted during the December–February periods, and the replicated field trials of this SAV growth study were initiated in May 2020. Net corrals (sample size [n] =20) were established within the FW where SAV has not yet reestablished. Two corrals will serve as unplanted controls, while the remainder will be inoculated with *Chara* spp., *Najas marina*, *Potamogeton illinoensis*, or *Najas guadalupensis*. Plant biomass will be measured at the end of the experiment, which will be used to calculate SAV growth rates under current sediment conditions in this FW.

QUANTIFYING LIFE CYCLE AND PHOSPHORUS UPTAKE AND RELEASE FROM PERIPHYTON AND PHYTOPLANKTON COMMUNITIES (PERIPHYTON STUDY)

Kathleen Pietro

The purpose of the Periphyton Study is to evaluate nutrient dynamics of periphyton and phytoplankton in downstream areas of STA treatment FWs where TP concentrations are very low (≤ 20 µg/L). Periphyton is defined in this study as the biological matrix of algae, fungi, bacteria, and detritus attached to submerged surfaces in the water column of STAs. This study focuses on measurements of nutrient uptake and release, growth, respiration, senescence, and death. These processes may be significant factors for P removal in outflow region of the STAs.

Phase I of this study reviewed periphyton literature regarding nutrient uptake, growth, respiration, and death in tropical and subtropical oligotrophic (low nutrient) or mesotrophic (moderate nutrient) freshwater wetlands subjected to relatively low P conditions (≤ 20 µg/L; Laughinghouse et al. 2019; **Table 5C-10**). A list of methods to measure biomass, metabolism, rates, pigments (chlorophylls and phycocyanin), taxonomic composition, cell biovolume, amplicon sequencing, metagenomics, metatranscriptomics, stable isotopes (^{31}P, ^{32}P, ^{15}N, ^{14}C), and enzyme activity was compiled. Phase II will begin in September 2020 with a study designed to measure the bioavailability of dissolved organic nitrogen (DON) and DOP material by periphyton in laboratory incubations. The study will compare periphyton communities found in EAV and SAV communities and their effect on water quality within the outflow region of STA-2 FW 3. The first incubation study is expected to be conducted in September or October 2020. Additional periphyton studies from Everglades STAs, Everglades Water Conservation Areas (WCAs), and the Everglades will be compiled and evaluated in a component of the Data Integration and Analysis Study (see **Table 5C-**1 at the beginning of the chapter). Phase III is being planned.

Table 5C-10. Status of tasks for the Periphyton Study.

Task	Status and Key Findings	Publication or Report
Phase I: Literature review of periphyton nutrient cycling in tropical and subtropical oligotrophic systems	Task Completed in 2019.	Laughinghouse et al. 2019
Phase II: Laboratory incubations	These tasks are in the planning stage. The tasks include measuring bioavailability of DOP and DON by periphyton collected from EAV and SAV dominated areas located in the outflow region of STA-2 FW 3.	
Compilation of microbial-related research from STAs, WCAs, and Lake Okeechobee	This task is included as a part of the Data Integration and Analysis Study.	
Phase III: Design mesocosm and field-scale study to measure periphyton life cycle and nutrient uptake rates within EAV and SAV communities.	This task is in the planning stages. Specifics of are to be determined.	

L-8 FLOW EQUALIZATION BASIN AND STORMWATER TREATMENT AREA OPERATIONAL GUIDANCE (L-8 FEBOG STUDY)

Matt Powers

The purpose of the L-8 FEBOG study is to collect water quality, stage, flow, and groundwater data from within the L-8 FEB to support operational guidance. The primary objective of this FEB is to improve the operations of STA-1E and STA-1W by attenuating peak flows and temporarily storing stormwater runoff (SFWMD 2015), which will support these STAs to achieve compliance with the WQBEL.

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

This study is separated into phases with stop and go points between each phase. Phase I focused on the influence of groundwater on L-8 FEB P concentrations (**Table 5C-11**). This was accomplished through monthly water quality sampling in the interior compartments of the FEB and quarterly water quality sampling in the surrounding groundwater wells from January to August 2019 (**Figure 5C-7**). Phase II began in September 2019 and is ongoing focusing on the possible resuspension of sediments into the water contributing to elevated TP in the FEB.

Table 5C-11. Status of tasks of the L-8 FEBOG study.

Task	Status	Reports
Phase I		
Detailed study plan	Task is complete. The plan describes Phase I water sampling and potential phases to evaluate sediments, runoff, and biota as sources of P.	SFWMD 2019
Phase I: Water quality sampling and summary final report	Task is complete. Characterization of surface water and groundwater from January to August 2019.	DBE 2020d
Phase II		
Surface water monitoring	Task is complete. Completed one year of monthly sampling (through December 2019).	DBE 2020e
Sediment characterization	Ongoing. Sediment samples from the interior of the FEB and canals to and from the FEB are to be collected. Samples will be measured for nutrients and physical characteristics.	
Event based surface water quality sampling	Ongoing. Autosamplers are deployed to collect water during large flow events.	

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5C-7. Sampling sites of the L-8 FEBOG study.

Phase I surface water samples show stratification of P by depth with the highest P concentrations, primarily in particulate form, at the bottom of the FEB. Groundwater is not a source of PP or TP as samples from groundwater wells surrounding the FEB had lower PP and TP concentrations than FEB surface water (**Table 5C-12**). P loading from groundwater seepage was relatively small compared to surficial inflow and contributed an estimated 6 to 14% of the total P load to the FEB (DBE 2020d). Evidence to date excludes groundwater as the major contributor of P in discharges from the FEB.

Collection and analysis of Phase II data are ongoing. Preliminary analysis of sediments collected from inside the FEB indicate these sediments contain P-enriched organic matter that can be resuspended and remain in suspension for over a week (**Table 5C-11**). These resuspended sediments result in elevated turbidity and elevated PP and TP concentrations in the water column. The effect of inflow and outflow structure operations on TP concentrations is ongoing.

Table 5C-12. Groundwater and surface water quality values from the L-8 FEGOG Study.

Parameter (Units [a])	Groundwater		Surface Water	
	Mean	Range	Mean	Range
Dissolved Oxygen (mg/L)	0.57	0.0–2.70	6.14	0.01–12.80
pH	7.21	6.90–7.60	8.26	7.30–10.00
Conductivity (µS/cm)	1,739	516–9,229	1,623	1,226–2,624
Temperature (°C)	25.6	24.3–27.9	23.2	16.9–29.0
Total Phosphorus (mg/L)	0.028	0.008–0.075	0.112	0.025–0.675
Particulate Phosphorus (mg/L)	0.013	0.002–0.042	0.095	0.021 -0.511
Total Dissolved Phosphorus (mg/L)	0.015	0.006–0.033	0.017	0.004–0.164
Soluble Reactive Phosphorus (mg/L)	0.012	0.004–0.028	0.012	0.001–0.153
Dissolved Organic Carbon (mg/L)	14.23	6.50–18.80	18.77	16.80–21.20
Total Nitrogen (mg/L)	1.859	0.429–5.970	2.223	1.170–4.330
Ammonia (mg/L)	1.122	0.148–4.950	0.193	0.005–2.502
Nitrate + Nitrite (mg/L)	0.006	0.005–0.015	0.475	0.005–2.330
Hardness	470.0	163.3–1,029.2	352.0	308.4–487.3
Alkalinity (mg/L)	277	148–610	221	186–284
Chloride (mg/L)	265.0	22.1–2,320.0	268.0	192.0–670.0
Sulfates (mg/L)	184	18–712	156	116–266
Dissolved Calcium (mg/L)	132.4	48.8–353.1	99.4	88.1–121.1
Dissolved Potassium (mg/L)	7.1	3.7–18.3	8.9	8.4–13.1
Dissolved Magnesium (mg/L)	23.9	6.2–102.0	24.1	21.5–43.0
Dissolved Sodium (mg/L)	189.9	23.8–1,588.0	184.2	128.4–461.3

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

LITERATURE CITED

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

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

Barton, M., J. Trexler, M. Cook, and S. Newman. 2020a. Appendix 5C-1: Estimating Phosphorus and Nitrogen Excretion in Fishes in the Everglades Stormwater Treatment Areas. In: *2020 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL

Barton, M., J. Trexler, M. Cook, and S. Newman. 2020b. *Estimating Phosphorus and Nitrogen Excretion in Fishes in the Everglades Storm Water Treatment Areas (STAs) Task 4b: Bioturbation under Agreement 4600003032-WO03*. Submitted by Florida International University, Miami, FL, to South Florida Water Management District, West Palm Beach, FL.

Barton, M., J. Trexler, M. Cook, and S. Newman. 2020c. *Estimating Phosphorus and Nitrogen Excretion in Fishes in the Everglades Storm Water Treatment Areas (STAs) Task 4.1: Excretion under Agreement 4600003032-WO03*. Submitted by Florida International University, Miami, FL to South Florida Water Management District, West Palm Beach, FL.

Barton, M., and J. Trexler. 2020a. *Estimating Phosphorus and Nitrogen Excretion in Fishes in the Everglades Storm Water Treatment Areas (STAs) Task 3: Community Analysis under Agreement 4600003032-WO03*. Submitted by Florida International University, Miami, FL to South Florida Water Management District, West Palm Beach, FL.

Barton, M., J. Trexler. 2020b. *Estimating Phosphorus and Nitrogen Excretion in Fishes in the Everglades Storm Water Treatment Areas (STAs) Task 5: Scaling Up the P* Budget under Agreement 4600003032-WO03. Submitted by Florida International University, Miami, FL to South Florida Water Management District, West Palm Beach, FL.

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

Chick, J.H., S. Coyne, and J.C. Trexler. 2004. Effectiveness of airboat electrofishing for sampling fishes in shallow, vegetated habitats. *North American Journal of Fisheries Management* 19:957–967.

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

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

Chimney, M.J. (ed.). 2020. Chapter 5B: Performance and Operation of the Everglades Stormwater Treatment Areas. In: *2020 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

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

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

Department, University of Florida, Gainesville, FL, to South Florida Water Management District, West Palm Beach, FL.

Clark M. 2019b. *Literature Review of Formation Factors and Management of Floating Wetlands. 4600003031-W004, Task 2a*. Submitted by Soil and Water Science Department, University of Florida, Gainesville, FL, to South Florida Water Management District, West Palm Beach, FL.

Clark M. 2019c. *Proposed Floating Wetlands Nomenclature under Agreement No. 4600003031-W004, Task 2b*. Submitted by Soil and Water Science Department, University of Florida, Gainesville, FL, to South Florida Water Management District, West Palm Beach, FL.

Clark M. and K. Glodzik. 2019. *Assessment of Floating Wetland Coverage in STA EAV Cells under Agreement No. 4600003031-W004, Task 3a*. Submitted by Soil and Water Science Department, University of Florida, Gainesville, FL, to South Florida Water Management District, West Palm Beach, FL.

Clark M. and K. Glodzik. 2020. *Data Mining and Atatistical Analysis of Environmental Factors Related to Floating Tussock Formation under Agreement No 4600004016-W001, Task 1*. Submitted by Soil and Water Science Department, University of Florida, Gainesville, FL, to South Florida Water Management District, West Palm Beach, FL.

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

DBE. 2019a. *Deliverable #A1.5 under agreement 4600003883: Studies on Improving the Resilience of SAV in the STAs*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2019b. *Deliverables A2.1 and A2.2: under Agreement 4600003883: Soil Sampling Report and Soil Management Study Sampling and Survey Report 1*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL. Revision date: October 4, 2019.

DBE. 2020a. *Deliverable #A1.4 under agreement 4600004075: Studies on Improving the Resilience of SAV in the STAs*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE. 2020b. *Deliverable #A1.8 under agreement 4600004075: Studies on Improving the Resilience of SAV in the STAs*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

DBE 2020c. *Deliverable A2.3 under Agreement 4600003883: Soil Management Study Sampling and SAV Survey Report 2*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL. Revision date: January 28, 2020.

DBE 2020d. *Deliverable A3.7 Phase I Summary Final Report under Agreement 4600003883: L-8 FEB Surface Water and Groundwater Quality Monitoring.* Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL. Revision date: February 20, 2020.

DBE 2020e. *Deliverable A3.10 Phase II Sampling Report under Agreement 4600003883: L-8 FEB Surface Water and Groundwater Quality Monitoring.*. Submitted by DB Environmental, Inc., to South Florida Water Management District, West Palm Beach, FL.

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

Diaz, O. 2020. Evaluation of Inundation Depth and Duration Threshold for Cattail Sustainability. Pages 5C-13–5C-1. In: R.T. James, C. Armstrong, J. King, K. O'Dell, T. Piccone, and O. Villapando (eds.), Chapter 5C: Restoration Strategies Science Plan, in: *2020 South Florida Environmental Report – Volume I*, South Florida Water Management District, west Palm Beach, FL.

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

Dombrowski, J., M. Powers, J. Wilson, J. King, K. Grace, J. Myles, D. Finn, K. Hellman, I. Eyeington, A. Frye, M. Kharbanda, and M. Chimney. 2020. Appendix 5B-4: Submerged Aquatic Vegetation Coverage in the Stormwater Treatment Areas In: *2020 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Dorn, N.J. 2013. Consumptive effects of crayfish limit snail populations. *Freshwater Science* 32:1298-1308.

Doughty, C.E., J. Roman, S. Faurby, A. Wolf, A. Haque, E.S. Bakker, Y. Malhi, J.B. Dunning, and J.-C. Svenning. 2016. Global nutrient transport in a world of giants. *Proceedings of the National Academy of Sciences of the United States of America* 113:868–873.

Evans, N., J. Trexler, and M. Cook. 2018. Effects of Faunal Communities on the Water Quality in the Everglades STA. Pages 5C-3-36 to 5C-3-45 in: R. Villapando and J. King, 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.

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

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

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

Florida International University. 2019. *Settling and Entrainment Properties of STA Particulates Draft Final Report*. Prepared under Agreement 4600003032-WO02-9500006758 for South Florida Water Management District, West Palm Beach, FL. April 30, 2018.

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

Hogg, E.H., and R.W. Wein. 1988. The contribution of *Typha* components to floating mat buoyancy. *Ecology* 65:1025-1031.

Jerauld, M., J. Juston, T. DeBusk, D. Ivanoff, and J. King. 2019. Internal phosphorus loadingrate (iPLR) in a low-P stormwatert reatment wetland. *Ecological Engineering* 156.

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

King, J., and R. Villapando. 2020. Evaluation of Phosphorus Sources, Forms, Flux, and Transformation Processes in the Stormwater Treatment Areas. Pages 5C-9–5C-12 in: R.T. James, C. Armstrong, J. King, K. O'Dell, T. Piccone, and O. Villapando (eds.), Chapter 5C: Restoration Strategies Science Plan, in: *2020 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Kellogg, C.M., and N.J. Dorn. 2012. Consumptive effects of fish reduce wetland crayfish recruitment and drive species turnover. *Oecologia* 168:1111-112.

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

Morrison, E.S., M.R. Shields, T.S. Bianchi, Y. Liu, S. Newman, N. Tolic, and R.K. Chu. 2019. Mutiple biomakers highlight the importance of water column processes in treatment wetland organic matter cycling. *Water Research* 168:115-153.

Piccone, T., and J. Dombrowski. 2020. Investigation of Stormwater Treatment Area 3/4 Periphyton-Based Stormwater Treatment Area Technology Performance, Design, and Operational Factors. Pages 5C-17–5C-19 in: R.T. James, C. Armstrong, J. King, K. O'Dell, T. Piccone, and O. Villapando (eds.), Chapter 5C: Restoration Strategies Science Plan, in: *2020 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.

Reddy, K.R., L. Vardanyan, J. Hu, O. Villapando, R.K. Bhomia, T. Smith, W.G. Harris, and S. Newman. 2020. Soil phosphorus forms and storage in stormwater treatment areas of the Everglades: Influence of vegetation and nutrient loading. *Science of the Total Environment* 725:138-442.

Schoenebeck, C.W., S.A. Lundgren, and K.D. Koupal. 2015. Using electrofishing catch rates to estimate the density of largemouth bass. *North American Journal of Fisheries Management* 35:331-336.

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 QualityBased Effluent Limit for Total Phosphorus in Discharges from Everglades Stormwater Treatment Areas to the Everglades Protection Area*. South Florida Water Management District, West Palm Beach, FL. June 27, 2012.

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

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

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

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

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

Vanni, M.J. 2002. Nutrient cycling by animals in freshwater ecosystems. *Annual Review of Ecology and Systematics* 33(1):341-370.

Vanni, M.J., A. M.Bowling, E.M. Dickman, R.S. Hale, A. Karen, M.J. Horgan, L.B. Knoll, W.H. Renwick, R.A. Stein, J. Vanni, B. Knoll, J. Horgan, R. Scott, and H. Renwick. 2006. Nutrient cycling by fish supports relatively more primary production as lake productivity increases. *Ecology* 87(7):1696-1709.

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

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

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

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

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

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

Zhao, H., and T. Piccone. 2020. Large scale constructed weltands for phosphorus removal, an effective nonpoint source pollution treatment technology. *Ecological Engineering* 145:105711.