Chapter 5C:
Update for the Restoration Strategies Science Plan

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SUMMARY

In accordance with the Everglades Water Quality Restoration Framework Agreement between the U.S. Environmental Protection Agency (USEPA), Region IV, and Florida Department of Environmental Protection (FDEP), dated June 12, 2012 (FDEP and USEPA, 2012) and the Restoration Strategies Regional Water Quality Plan (SFWMD, 2012a), the *Science Plan for the Everglades Stormwater Treatment Areas* (STAs) has been established to investigate the critical factors that collectively influence the total phosphorus (TP) reduction and treatment performance in the STAs (SFWMD, 2013). It is expected that the results from the Science Plan will be used to enhance the design and operations of projects under the Restoration Strategies Program, which will ultimately improve capabilities of the STAs to achieve compliance with the state's water quality criteria for TP. The Science Plan is also intended to fulfill the requirements of the Consent Orders between the FDEP and the SFWMD (dated August 15, 2012) associated with the National Pollutant Discharge Elimination System (NPDES) Watershed Permits and Everglades Forever Act (EFA) Watershed Permits for the Everglades STAs (OGC Nos. 12-1148 and 12-1149, respectively), issued on September 10, 2012.

Pursuant to the Consent Orders, the Science Plan was developed by the South Florida Water Management District (SFWMD or District) in consultation with representatives designated by the FDEP and USEPA (Technical Representatives), on behalf of the state and federal agencies, respectively. Published in June 2013, the complete version of the Science Plan, including the Five-Year Work Plan of the individual studies, is available on the District's website at www.sfwmd.gov/rs_scienceplan. In July 2013, the initial nine proposed studies outlined in the Five-Year Work Plan were reviewed and received approval to move forward by the District's Restoration Strategies Steering Group. During July and August 2013, three technical, public workshops were held with the Technical Representatives to provide an open, collaborative forum for further discussion and refinement of the proposed work of the individual study plans.

This new Volume I chapter provides an update on the Science Plan, with key highlights of the plan as well as ongoing planning and implementation efforts. As the proposed study plans of the Science Plan are further detailed and implemented, it is anticipated that this chapter in future SFERs will integrate and synthesize information to effectively communicate plan findings. The findings will be used to gauge progress toward optimizing phosphorus treatment performance and achieving the Water Quality Based Effluent Limit (WQBEL) for TP (SFWMD, 2012b). This information will then be used to identify needed policy and management actions, key areas of uncertainty, and essential information gaps to direct future Science Plan efforts.

INTRODUCTION

BACKGROUND

As noted in Chapter 5A of this volume, the NPDES and EFA watershed permits and associated Consent Orders require that the District develops and implements a Science Plan to enhance the understanding of mechanisms and factors that affect phosphorus (P) treatment performance, particularly those that are key drivers to performance at low total phosphorus (TP) concentrations (<20 micrograms per liter, or μg/L). The *Science Plan for the Everglades Stormwater Treatment Areas* was structured and developed around six key questions and related sub-questions that were identified by the District's Science Plan Team (SFWMD, 2013). The effort involved reviewing existing knowledge, determining information gaps, and formulating questions regarding phosphorus removal mechanisms and the factors that influence these mechanisms, including physical, chemical, and biological processes. A list of key questions related to the science, operation, and engineering aspects of STA performance was then developed. Analyses of each individual STA was also performed to determine factors affecting phosphorus removal performance, identify areas for further investigation, and list potential engineering refinements for implementation.

Overall, the Science Plan was developed collaboratively by a team of 47 scientists, modelers, and engineers from across the District with participation and valuable input from the six interagency Technical Representatives and scientific experts from the Florida Department of Environmental Protection (FDEP), U.S. Environmental Protection Agency (USEPA), U.S. Department of Interior (USDOI), and U.S. Army Corps of Engineers (USACE). The plan is intended to be a strategic, high-level document that will be revised and updated as needed. Specific implementation of the Science Plan will be guided by the Five-Year Work Plan (Appendix C, SFWMD, 2013), which is currently comprised of nine initial studies. Study plan results may be used to inform the design and operations of water quality projects, which will ultimately improve capabilities to manage for achievement of the WQBELs. Related data and information gathered from these studies will also be incorporated into the development and refinement of the District's operational guidance tools. The complete version of the Restoration Strategies Science Plan, dated June 2013, is available at www.sfwmd.gov/rs_scienceplan. Further information on the Restoration Strategies Program is presented in Chapter 5A of this volume and is available at www.sfwmd.gov/restorationstrategies.

RESTORATION STRATEGIES SCIENCE PLAN

During the technical discussions between the State of Florida and USEPA regarding Everglades water quality, it was agreed that a Science Plan would be developed and implemented by the SFWMD. The Science Plan is intended to increase the understanding of mechanisms and factors that affect phosphorus treatment performance, focusing on those mechanisms and factors that are key drivers to performance at low TP concentrations. Issues identified for potential Science Plan investigation include: effects of microbial activity, phosphorus flux, inflow volumes and timing, inflow phosphorus loading rate and concentrations on phosphorus outflow, phosphorus removal by specific vegetation, and the stability of accreted phosphorus. The Science Plan has been developed collaboratively and in consultation with the Technical Representatives and in coordination with key state and federal agencies and scientific experts. Results from the Science Plan studies could be used to inform the design and operations of water quality projects, which will ultimately improve capabilities to manage for achievement of the WQBEL (FDEP and USEPA, 2012; FDEP, 2012a; FDEP, 2012b).

Purpose, Goals and Objectives

As a strategic, high-level document, the Science Plan provides the overall framework for development and coordination of activities to identify the critical factors that collectively influence phosphorus reduction and treatment performance in order to meet the WQBEL. As such, the plan only includes activities associated with Everglades STA performance, mostly linked to sampling and other supporting information from the STAs. It does not encompass activities related to water quality parameters other than phosphorus or phosphorus source control technologies such as BMPs. Specific implementation of science activities and research studies will be guided by the Five-Year Work Plan.

The Framework Agreement states that "…the objective of the Science Plan is to identify the critical factors that collectively govern phosphorus treatment performance; to maximize the understanding that can be gained from existing data, designs and operations; to identify the critical information gaps and research areas that will further treatment objectives in order to meet the WQBEL at each STA" (FDEP and USEPA, 2012). The Consent Orders associated with the EFA and NPDES Watershed permits provide additional details regarding how the Science Plan should be developed and implemented. The Consent Orders state, "after consulting with the [technical] representatives, [SFWMD] shall: (1) identify the critical information gaps and research areas that influence treatment performance; (2) prioritize the science needs; (3) develop and implement the science plan; (4) evaluate the results of ongoing scientific efforts to meet the prioritized science needs; (5) modify the science plan as needed based on results of completed or ongoing scientific studies, and (6) determine how the results of the scientific studies could be implemented to improve phosphorus reductions and treatment performance. Of particular interest is a better understanding of design and operations that sustain outflow concentrations at low phosphorus concentrations (<20 ppb)."

The Consent Orders also identify key areas that likely effect STA performance that should be considered for further scientific studies including (1) phosphorus loading rates; (2) inflow phosphorus concentration; (3) hydraulic loading rates; (4) inflow water volumes, timing, pulsing, peak flows, and water depth; (5) phosphorus speciation at inflows and outflows; (6) effects of microbial activity and enzymes on phosphorus uptake; (7) phosphorus resuspension and flux; (8) stability of accreted phosphorus; (9) phosphorus concentrations and forms in soil and floc; (10) soil flux management measures; (11) influence of water quality constituents such as calcium; (12) emergent and submerged vegetation speciation; (13) vegetation density and cover; (14) weather conditions such as hurricane and drought; and (15) the interrelationships between those factors.

Annual Updates and Reporting

Updates to the Science Plan and other associated documents as needed will be prepared to communicate progress throughout implementation of the plan. The companion Five-Year Work Plan, which guides the specific implementation of activities in the context of an annual budget cycle, will be assessed annually using the adaptive management process outlined in Section 5 of the Science Plan. The Science Plan Team and Restoration Strategies Steering Group will provide input to determine the strategic prioritization for work and projects to be funded in a given year. The annual update for the Science Plan in the SFER is intended to integrate and synthesize information to effectively communicate scientific findings and understanding of the plan results to management and stakeholders. In future SFERs, this will cover the progress of the Science plan implementation and incorporate the status and findings of research, monitoring, and modeling efforts outlined in the Five-Year Work Plan. These updates will summarize comprehensive reporting and analysis of STA science, synthesized to gauge progress toward optimizing phosphorus treatment performance and achieving the WQBEL. Reporting will also describe the current understanding of the various factors and mechanisms controlling TP removal

and analyze the feasibility of implementing potentially viable technologies and approaches. This information will then be used to identify needed policy and management actions, key areas of uncertainty, and essential information gaps, and help direct Science Plan efforts over the next 10 to 12 years of its implementation.

SCIENCE PLAN QUESTIONS AND OTHER AREAS OF INVESTIGATION

SCIENCE PLAN QUESTIONS

The Science Plan was structured and developed around six key questions that were identified by the Science Plan Team. The coordinated effort involved reviewing existing knowledge, determining information gaps, and formulating questions regarding phosphorus removal mechanisms and influencing factors. These include physical, chemical, and biological processes influencing phosphorus reduction in the Everglades STAs (for STA maps, see Figure 5B-1 and Appendix 5B-1 of this volume). A list of key questions related to the science, operation, and engineering aspects of STA performance was developed. Detailed analyses of each individual STA was also performed to determine issues affecting phosphorus removal performance, identify areas for further investigation, and list potential engineering refinements for implementation.

In the Science Plan, the six key questions are as follows:

1. *How can the FEBs be designed and operated to moderate phosphorus concentrations and optimize phosphorus loading rates and hydraulic loading rates entering the STAs, possibly in combination with water treatment technologies, or inflow canal management?*

2. *How can internal loading of phosphorus to the water column be reduced or controlled, especially in the lower reaches of the treatment trains?*

3. *What measures can be taken to enhance vegetation-based treatment in the STAs and FEBs?*

4. *How can the biogeochemical or physical mechanisms be managed to further reduce soluble reactive, particulate, and dissolved organic phosphorus concentrations at the outflow of the STAs?*

5. *What operational or design refinements could be implemented at existing STAs and future features (i.e., STA expansions, FEBs) to improve and sustain STA treatment performance?*

6. *What is the influence of wildlife and fisheries on the reduction of phosphorus in the STAs?*

Each key question was further evaluated after a preliminary literature review and data analyses. This information indicates what is known and unknown relative to the key questions and identified critical information gaps and research areas. A more comprehensive list of sub-questions relative to the key questions was developed. This list was then organized into a set of sub-questions focused specifically on where informational and knowledge gaps exist, as presented in Table 3 of the Science Plan. The level of detail presented for the key questions varies in the initial Science Plan, and additional details may be added in subsequent versions. It should also be noted that in the initial version of the Science Plan, all the sub-questions presented in that table are not covered under the respective key questions, but may be addressed as appropriate in future efforts. In addition, Key Question 6 was not deemed to be the highest priority effort at this time. However, the role of aquatic consumers will continue to be considered by the District as wildlife, fish, and large invertebrates contribute to the phosphorus cycling in the STAs.

An overview and background of the six key questions, as detailed in Sections 3.1.1 through 3.1.6 of the Science Plan, respectively, is presented below.

Science Plan Key Question 1

How can the FEBs be designed and operated to moderate phosphorus concentrations and optimize phosphorus loading rates and hydraulic loading rates entering the STAs, possibly in combination with water treatment technologies, or inflow canal management?

The Flow Equalization Basins (FEBs) will be evaluated to determine how they will influence performance of the STAs. Kadlec (2011) indicates that storage reservoirs (e.g., FEBs) can be operated to lessen pulse flows and improve wetland performance. This expectation is based on optimizing hydropatterns, reducing flow volumes and velocities, and lowering peak loading rates into the STAs. As reducing flow pulses to the Everglades STAs is a key objective of the water quality projects, storage reservoirs (FEBs) are included for all three project flow paths.

One of the sub-questions concerns how storage in the FEBs should be managed throughout the year so that water can be delivered to the STAs in a manner that allows them to achieve the lowest outflow P concentrations. At present, design information and operational guidance for the FEBs are not available that define the maximum hydraulic inputs to the STAs to prevent deepwater impacts to vegetation, the minimum hydraulic load to prevent dryout, or the optimal P load and concentration for discharges from the basins to the STAs. The operation and performance of the FEBs are important for long-term, sustainable performance of the STAs. Therefore, it is important to determine how storage and outflow hydraulics of the basins should be managed, define the optimal and minimum water depths, and identify how discharge rate and timing should be controlled for consistent STA treatment. It is also necessary to determine how the FEBs should be designed and operated to achieve optimal P loading rates and concentrations for discharges to the STAs.

The FEBs will be managed to the extent possible to maximize STA treatment performance. If continued data analyses warrants, operational hydraulic discharge criteria for the FEBs may be established to maximize STA performance. Operational criteria are needed for a maximum hydraulic loading rate (HLR) to the STAs to prevent deepwater impacts to STA vegetation and a minimum HLR to the STAs. Water quality inflows to the FEBs might be a component of the operation plans. Physical components and operational protocols could potentially be incorporated into the FEB designs and operational plans that would promote settling of sediment and associated particulate phosphorus (PP) to prevent transport into the STAs. For shallow and deep FEBs, designs are needed to optimize settling of suspended material, including PP, to prevent transport into the receiving STA. The design of FEB discharge features should also be investigated to minimize erosion and thereby further reduce P transport into the STAs. Another potential source of P may be the conveyance canals that extend from the FEBs to the STAs. It is important to assess whether sediments in the canals are an important source of TP to the STAs by characterizing the sediment and TP concentrations in canals flowing to the FEBs and STAs, and determining the factors affecting settling and resuspension in these canal reaches. It is also of interest to determine if these conveyance canals should be periodically dredged or lined to remove sediment and associated PP.

Additionally, water quality treatment technologies can be evaluated for potential application to the FEBs. Technologies would need to be evaluated in terms of technical, environmental, and economic feasibilities. The effect of each selected technology on the water quality discharging from the FEBs to the STAs deserves attention, as does the management of residuals generated from each selected technology.

Finally, vegetation could also potentially play a role in enhancing effectiveness of the FEBs in reducing P transport to the STAs. Aquatic plant communities all affect P cycling and accretion based on their physical, chemical, and biological interactions. Water stages in STA cells are currently managed based on target depths to maximize vegetation sustainability and treatment performance. Target depths may also be needed for the FEBs. The FEBs will attenuate peak stormwater flows prior to delivery to STAs and provide dry season flows for STAs. More information is needed on the role of vegetation and means for managing vegetation assemblages optimally in FEBs. Littoral zones might be established in the shallow FEBs to promote P retention, but these also could impede water flows and storage capability. As depicted in Figure 5A-1, the L-8 FEB (Eastern Flow Path) is a deep system with more than 50 feet in potential depth. There is the potential for establishment of floating vegetation in this system. The A-1 FEB (Central Flow Path) and C-139 FEB (Western Flow Path) are shallow systems and both emergent and submerged plants will colonize these systems. Information on biological and operational management of plants in the FEBs is fundamental to the success of the FEBs.

Science Plan Key Question 2

How can internal loading of phosphorus to the water column be reduced or controlled, especially in the lower reaches of the treatment trains?

Water coming into the STAs contains a mixture of inorganic and organic forms of P. Previous findings indicate that, in general, in well-performing STAs the outflow water contain very little to no soluble reactive phosphorus (SRP), and consist primarily of dissolved organic phosphorus (DOP) and PP. Natural and operational factors, such as lack of flow, storm events, and dryout, can cause changes in the composition and concentration of P in outflow water.

Water quality improvements through the use of treatment wetlands are subject to variability due to both natural and anthropogenic factors. Phosphorus cycling and movement along the treatment flow-ways is a function of various chemical, physical, and biological processes including particulate settling, sorption, flux, plant uptake, bioturbation, diagenetic processes at the soil surface, and other abiotic and biotic processes in the water column (Reddy and DeLaune, 2008; Bhomia et al., 2001). The antecedent land use also affects biogeochemical processes and the ability of the wetland to be a sink for phosphorus. For example, soils that were highly enriched from years of farming have been shown to release P to the overlying water column for extended period of time. In STAs with high levels of labile phosphorus, nutrient flux from the soil to the water column may be as important as external inputs in terms of TP concentration and loading. Release of P from enriched soils to the water column can contribute to the challenge of meeting water quality goals in the STAs.

Flux of P from the soil to the water column occurs through diffusion of dissolved P and resuspension of particulate-bound P. The diffusion of DOP and SRP (or dissolved organic P) occurs when the concentration of P in the porewater is higher than the concentration in the overlying water column. Understanding the relative levels of porewater and surface water P concentrations in the different STA flow-ways will help in determining the role of flux in each flow-way and may be useful in developing strategies to minimize flux in the STAs.

The role of microorganisms in the transformation of organic P to inorganic P in the water column and soils has long been recognized (Dunn and Reddy, 2005; Reddy et al., 1999). As the life cycle of microbes is short, nutrient turnover is quick and it is likely that most P uptake is returned as labile DOP and PP, leaving only a small fraction as permanently buried in the sediments. The influence of metallic cations, such as calcium, magnesium, iron, and aluminum has also been studied extensively. Their role in the STAs, particularly at the very low P regions, requires further investigation. Calcium-related P reduction in an alkaline wetland environment may occur via two main pathways: (1) sorption of P on calcareous soil particles, limestone

surfaces, and marl-based detrital material, and (2) co-precipitation with calcium in the water column or porewater (Gumbricht, 1993). Photodegradation may also be an important factor in P cycling under a very low P environment. For example, breakdown of dissolved organic matter may be influenced by the ability of light penetration through the water column. Shallow water condition, reduced water turbidity, and open areas may induce higher photodegradataion. Understanding the role of photodegradation in the STAs may provide some useful information in finding ways to further lower outflow P concentrations.

Therefore, it is important to determine the sources (internal/external, plants, microbial, wildlife), forms and transformation mechanisms controlling the residual P pools within the different STAs and if they are they the same as observed in the natural system. In addition, the key physical-chemical factors influencing P cycling at very low concentrations should be evaluated. Vegetation is a major biological mechanism used in the STAs to reduce nutrient concentrations and it is important to assess how different vegetation species moderate P flux and availability. Submerged aquatic vegetation (SAV) decomposition, particularly during low water conditions, may also be responsible for the high flux of PP and SRP. However, this observation has not been strongly demonstrated for effluent DOP. There were no substantial decreases in observed DOP values, underscoring the difficulty in removing DOP in treatment wetlands as plants (and peat soils) were a source of DOP (DeBusk et al., 2004). Additional information is needed on the generation and breakdown of DOP in the STAs, particularly near outflows. Periphyton assemblages can play several roles that lead that lead to increased retention of nutrients. Obtaining additional information on periphyton, with the goal of increasing their role in long-term P storage, is important in improving STA performance.

Science Plan Key Question 3

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

Macrophyte communities and associated periphyton (and microbes as described previously) are the biological backbone of treatment wetlands. In wetlands designed to treat surface water for nutrient removal, macrophytes stabilize sediments, reduce flow velocity, provide contact surface for microbes and algae, take up and translocate nutrients, and provide biological habitat and energy for the system. The role of macrophytes in removal of P in STAs at low ambient concentrations will be evaluated. Although the ecological role of macrophytes in wetlands is generally well known as previously noted, there are many opportunities to gather more specific information on their role in nutrient cycling and removal at low P concentrations in the STAs. New information regarding these processes in STAs can support the development of refined vegetation management strategies to promote lower outflow TP concentrations. The overall goal is to improve STA performance by finding better and more integrated ways to manage macrophyte composition, density, and spatial distribution in the STAs.

To minimize the impacts of deeper water, depth and duration guidance is applied to STA operations. Although using this practical guidance is sound as an interim approach, the optimum inundation depth and duration needed to develop and sustain healthy cattail communities is unknown, particularly for large-scale STA cells. Investigations are needed to gather additional information on the role of depth and water pulses on the sustainability of cattail communities in the STAs. Data will be generated on cattail growing in a range of inundation depths and durations to identify the depth and duration threshold for cattail sustainability in the STAs. This effort should provide specific guidance for better water depth management and result in better initial treatment and more sustainable cattail stands in the STAs.

Different species of aquatic macrophytes can vary in the way nutrients from the water column and sediments are taken up and stored. With this in mind, it may be possible to use individual species to improve STA performance depending upon their physiology and nutrient uptake mechanisms. Certain plant species may be better able to reduce the amount of organic and particulate P near the STA outflows and decrease decomposition rates that result in a high internal loading (Davis, 1991; Kuhn et al., 2002). Investigations will gather information on native vegetation types that are able to grow in low P environments and take up P from the water through enzymes and store it efficiently in their tissues, particularly in belowground components.

The nutrient-poor, oligotrophic Everglades ecosystem is dominated by sawgrass (*Cladium jamaicense*) ridges and water lily (*Nymphaea odorata*) sloughs. These species thrive in very low nutrient environments by being able to take up available P efficiently, particularly organic P, and having life histories that allow them to accumulate much higher tissue P relative to external habitat and retain this nutrient for long periods by slow turnover and decomposition rates (Brix et al., 2010; Davis, 1991; Lorenzen et al., 2001; Miao, 2004; Miao and Zou, 2012). Specific macrophyte species will be evaluated to determine if they can be incorporated near STA outflows to achieve lower outflow TP concentrations.

SAV communities are known to be vital for STA performance and several Science Plan projects are needed to provide better management-relevant information. It is not known what the role of various SAV species is in STA performance, and more information is needed to determine what management actions may be possible to improve and sustain performance of this important aquatic plant community. More detailed and predictive information is needed on SAV dynamics and its influence on P cycling.

Finally, scientific efforts should focus on the role of periphyton in areas dominated by SAV. As floating calcareous mats of periphyton are known to be part of healthy Everglades marshes and are associated with low ambient P levels, it should be evaluated if there are ways to introduce and sustain calcareous periphyton in SAV cells. It is not known why periphyton mats are not more common in the STAs and their value within SAV cells to lower TP concentrations, particularly near outflows, should also be researched further.

Science Plan Key Question 4

How can the biogeochemical or physical mechanisms be managed to further reduce soluble reactive, particulate, and dissolved organic phosphorus concentrations at the outflow of the STAs?

Methods to manage the uptake and long-term storage of P along the treatment train are critical to meeting water quality goals. There is a need to improve the quantitative understanding of the generation and turnover of SRP, PP, and DOP. Inorganic forms of P (e.g., SRP) are known to cycle quickly in aquatic ecosystems. They are readily utilized by STA flora, sorb with calcareous substrates, or co-precipitate with minerals within an STA. Other P forms have longer turnover times, i.e., complex organic and particulate P, and are more resistant to removal or are generated as part of the phosphorus biogeochemical cycle. Generally, DOP in natural waters such as the STAs can range from simple to complex organic molecules. Routine analytical methods to precisely determine the chemical composition of DOP are not completely developed. Instead, DOP is operationally defined as the difference between total dissolved phosphorus (TDP) and SRP. DOP can also be defined by its ability to be broken down by enzymes. PP, which can consist of detritus materials and living organisms (e.g., bacteria, phytoplankton,), is operationally defined as the portion of the total P pool that can be removed by filtration through a 0.45 μm filter. Both DOP and PP are removed in the STAs, and they can also be produced and recycled in the STAs.

In general, during periods when the STAs are performing well, most of the SRP rapidly is reduced to below detection levels, leaving PP and DOP as the predominant P species in the outflow water. However, there are some periods in well-performing STAs (e.g., following stagnant condition or during high-flow storm events) when a significant amount of SRP is detected at the outflow. It is important to determine if this SRP is being produced near the outflow or is being moved through the STA without substantial cycling.

Many biogeochemical and physical mechanisms can reduce PP and DOP concentrations. PP can be reduced through grazing by fauna, incorporation into biological assemblages (e.g., floating periphyton mats), filtering by emergent and submerged aquatic vegetation, decomposition (desorption), and sedimentation or settling. DOP can be taken up by periphyton or microbial organisms, and microbial transformation may make this pool more readily available for uptake by emergent and submerged vegetation, phytoplankton, and bacteria. It can also be reduced through photodegradation (Sharma et al., 2004), co-precipitation with minerals, and sorption (e.g., excess iron or aluminum provides sorption sites).

Key sources at the STA outflows can consist of P from the inflow that has not settled or been sequestered by wetland biogeochemical mechanisms, or P associated with suspended particulates including plankton, bacteria, and detritus generated within the STA. However, knowledge gaps exist regarding the composition and origin of residual P at the STA outflows and on the cycling of P, including PP and DOP as water flows along the STA flow-ways. This information is important to better understand and manage the composition and concentration of P in the outflows from the STAs and distribution canals in order to meet water quality goals.

Science Plan Key Question 5

What operational or design refinements could be implemented at existing STAs and future features (i.e., STA expansions, FEBs) to improve and sustain STA treatment performance?

Operational or design refinements could influence phosphorus treatment performance in existing and future STAs and these need to be researched further. The FEBs can help achieve low outflow TP concentrations from the STAs and investigation of their role is in Key Question 1. High flow rates may increase transport of sediment and floc and increase outflow TP concentrations. Therefore, it is worthwhile to investigate extending the time period that inflow occurs to help achieve lower outflow levels. Managing STA inflow rates can minimize impacts to STA vegetation from deep water and help to sustain treatment performance in the emergent cells. Determining thresholds for vegetation changes could help guide inflow management.

Canal P cycling is another area of interest relative to STA performance. Changes in TP concentrations have been observed in inflow canals between the STA inflow pump stations and inflow structures at the upstream side of the STA flow-ways. There is also some evidence that TP concentrations may increase as water moves from the treatment cell flow-ways to permit compliance discharge structures. During times when velocities are high, sediment resuspension could result in elevated TP in STA inflow water or STA outflow collection canals. Quantifying resuspension thresholds could support lower TP discharge concentrations. During severe droughts, water levels in some canals are significantly lowered to the extent that portions of the canal sediments are exposed for periods of time. When re-wetted, the effects of sediment P flux to the overlying water column or release of P from wetting/drying cycles of portions of canal sediment could also influence the water TP concentrations observed at the STA inflow and outflow structure sampling locations. Operational studies to minimize the TP release from canals are needed.

Short-circuiting of flows within the STAs reduces contact with the treatment system and hydraulic retention time (HRT) and can reduce treatment performance. Short-circuiting exists in STAs for various reasons but sometimes is caused by erosive velocities associated with inflow structures. Wider and deeper STA inflow distribution canals and energy dissipaters will be explored to minimize flow velocity and short-circuiting near inflow structures. Over broad areas of the STA marsh, bulrush (*Scirpus acutus*) plantings have been successful in reducing open water in SAV cells and increasing the percent cover of vegetation in these cells. Quantifying improvements in TP removal efficiency as a result of these plantings will be attempted in relation to reducing short-circuiting. Also, other structural measures— such as stilling basins, inflow culverts, box culverts, spreader canals, or broad-crested weirs— can be examined to improve flow distribution, reduce short-circuiting, and enhance treatment performance. Such structural issues regarding short-circuiting and flow distribution apply to both existing and future STAs.

In STA cells, variations in topography may still exist that affect hydraulics and the ability to maintain target stages to sustain vegetation. Topographic variability occurring in several existing STA cells is thought to contribute to their poor performance. With this in mind, future STA designs may benefit from analysis to define the optimal degree of topographic accuracy for new and existing treatment cells.

Operational activities for the STAs are necessary to maintain optimal conditions for vegetation and sustain treatment performance. Occasionally, individual cells need to be drawn down (or dried out in some instances) to allow for construction access, planting, or to rejuvenate vegetation. SAV cells need to remain hydrated even during drought periods. The FEBs are expected to reduce the frequency of dryout but they may still occur. As a result, flexibility to transfer water between STA cells and flow-ways will be explored. This can be done by increasing the number of permanent or mobile pumps, or through structural changes.

The exchange of P between the soil and the water column occurs due to a combination of physical, chemical, and biological processes including macrophyte mining, bioturbation, chemical diffusion, and hydraulic gradients that induce upward or downward movements of water in wetland soils. The magnitude of the exchange of water (and the associated dissolved or particulate P) between the soil and water column depends in part on the hydraulic conductivity, surface area, and gradient between the aquifer and surface water. The gradient and resultant upward or downward movement of water through the soils can potentially be manipulated to effect a change in flow between the soil and water column. Within the STAs where the rate and frequency of water level changes may be controlled, there may be an opportunity to use this principle to lower TP concentrations in the water column. Where soil pore water TP concentrations are high relative to water column concentrations—which is the case in most SAV cells—alternating or persistent soil to water column (upward) flow may be less desirable than persistent water column to soil (downward) flow for achieving the lowest possible TP concentration in the water column. Based on current data, there is solid performance in STA cells where the average water table is relatively high compared to surrounding water tables suggesting that upward diffusion of phosphorus may be reduced by inducing downward advection flow. Quantitative studies are needed to support this potential management option.

Science Plan Key Question 6

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

A wealth of ecological literature confirms the central role of consumer populations in material cycling in most ecosystems, including productive wetlands such as the Everglades STAs. The interaction of consumers with P cycling and peat accretion provides a direct linkage between faunal activities and STA performance. The overall challenge is to review available literature and information on the STAs to decide what ecological interactions may be important and conduct the studies necessary to make decisions on potential management and operational means to lower outflow concentrations through cascading biological interactions involving consumers. The central information need is to get quantitative estimates of faunal densities and interactions and then to ascertain whether these linkages are positive or negative to performance and whether fauna are sources or sinks of TP for the STAs.

To better understand how fish and wildlife may influence nutrient reduction in STAs, species densities over the year must be determined as a first step. Aerial surveys for waterfowl, wading birds, and other avifauna would be helpful. Subsurface sampling is essential for fish and macro-crustacean population levels and locations. Various types of submerged aquatic surveys (e.g., fyke nets, gill nets, throw traps) should be considered. While the potential role of consumers on STA performance may be concentrated near STA outflows, some initial studies should focus on areas across nutrient, vegetation, and food resource gradients in the STA. Eventual studies of management strategies may focus more on areas within about one kilometer of STA outflows.

Over 200 bird species have been identified in STA-5 alone and the STAs support bird densities over 30 times that of the natural marsh when averaged across all seasons (Gawlik and Beck, 2010). Coots and many dabbling duck species forage on SAV, and by the time the spring migration of blue-winged teal occurs, the biomass of SAV is often greatly reduced. Fish-eating birds, especially wading birds (e.g., herons, egrets, and storks), are also common in the STAs and may play an important role in the redistribution of nutrients. The export, import, and recycling of their feces may play an important role in STA P dynamics and outflow concentrations. Together, these observations and additional examples from the literature provide strong justification to gather more definitive information on avifauna influences on STA performance and determine TP export or import by birds.

In addition to more conspicuous avian species, there are high densities of small omnivorous and herbivorous fishes in the STAs. The role of direct grazing and predation of fish in the STAs remains largely uncertain, but examples from the literature suggest that fish are major players in plant growth and composition and in nutrient cycling. While it is known that other submerged aquatic wildlife species (e.g., crayfish, grass shrimp, apple snails, and other aquatic macroinvertebrates) utilize the STAs, it is expected that the STAs as eutrophic to mesotrophic wetlands will provide ample food and habitat to support relatively high densities of shrimp, crayfish and other benthic invertebrates. The role of all invertebrates in P cycling in the STAs needs quantitative study.

Alligators are very abundant in the STAs and yet there have been no quantitative studies of their abundance or impacts on the functionality of the STAs. When concentrated near outflows, alligators could be significant in P recycling and their role in physical disturbance of the sediments and vegetation could influence water column P concentrations strongly. As a result, when working toward very low P outflow concentrations, additional information on direct and indirect effects of alligators on water column P concentrations would be valuable, particularly near outflows. Also, the role of alligators in P mass balance in the STAs would help guide future studies and management strategies.

The consideration of potential management actions for aquatic consumers will be considered after more quantitative information is available. Information from the literature should provide some management options and landscape-level approaches both within and outside of the STAs could be considered. For example, selective clearing in the STA could change species distributions and abundance to favor lower TP concentrations. Reshaping internal canals and surgically creating transecting channels may allow modification of fish predation patterns and cascading interactions with P recycling and retention. Altering landscapes outside the STAs may attract waterfowl or wading birds away from the STA daily or seasonally and thereby alter the P mass balance. Quantitative information on fauna in STAs can support the development of other novel management strategies to promote lower outflow TP concentrations, such as modifying plant habitats, conducting selective removal, attracting individuals away from the STA, managing seasonal depths, or physically modifying the STA. The overall goal is to improve STA performance by finding better and more integrated ways to manage fish and wildlife composition, density, and spatial distribution in the STAs.

Finally, there are legal considerations for wildlife in the STAs that deserve attention. Birds protected by the Migratory Bird Treaty Act or the Endangered Species Act establish a direct linkage between avian presence in the STAs and operational limitations that can influence STA performance. Black-necked stilts (*Himantopus mexicanus*) are a migratory bird species that overwinter in the STAs and are known to nest on the ground within drying portions of STA cells. As this species is protected by the Migratory Bird Treaty Act, operational steps have been taken to minimize the flooding of nests and these operations have the potential to affect the overall functionality of these treatment wetlands. Consequently, quantitative information is needed on the influence of operational modifications implemented in compliance with the Migratory Bird Treaty Act or the Endangered Species Act on STA performance and treatment capacity.

SCIENCE PLAN SUB-QUESTIONS TO GUIDE STUDY PLAN DEVELOPMENT

Although many potential areas of investigation were identified during the generation of sub-questions, implementing all of these for hypothesis testing at the same time is not feasible. Consequently, this information was further evaluated with the goal of determining a proposed initial suite of studies or research to be included in the Five-Year Work Plan. Specifically, the Science Plan Team evaluated the areas of investigation and sub-questions considering testability, feasibility, timeliness, and importance in reaching the WQBEL based on the following criteria:

- **Testability**. Can a study be realistically designed and conducted around the question to get reliable results? What is the uncertainty factor?

- **Feasibility**. Can information learned from the study be realistically implemented? Would study results be transferable and applied at the scale needed?

- **Timeliness**. Is it short-term, quick win versus long-term? Can the study be completed in time to support decisions, and is it in the critical path of other studies, etc.?

- **Importance**. Does it have the potential of reaching the WQBEL objective, and will it be sustainable and resilient over the long-term?

In collaboration and consultation with the Technical Representatives, eight sub-questions were selected as the basis for developing the proposed study plans. The selection process was semi-quantitative and utilized best professional judgment of the Science Plan Team, Technical Representatives, and federal agency experts and consultants during multiple meetings and workshops. In addition, several opportunities for public and stakeholder participation and review of the sub-question evaluation process and the selected sub-questions were provided at Long-Term Plan Communications Meetings, Water Resources Advisory Commission Meetings,

and during the Draft Science Plan public review period, prior to publication of the Science Plan in June 2013. The initial Five-Year Work Plan includes seven study plans (derived from the sub-questions listed below) as well as study plans for two other areas of investigation discussed in the *Other Areas of Investigation* section. The eight selected sub-questions are as follows:

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

2. Would changes in canal management or design improve STA and FEB performance?

3. What are the treatment efficacy, long-term stability, and potential impacts of floc and soil management?

4. What are the sources (internal/external, plants, microbial, wildlife), forms, and transformation mechanisms controlling the residual P pools within the different STAs and are they comparable to what is observed in the natural system?

5. What are the key physical-chemical factors influencing P cycling at very low concentrations?

6. What is the role of vegetation in modifying P availability to the low P environment, including the transformation of refractory forms of P?

7. How does water depth affect sustainability of dominant vegetation?

8. Can *Cladium jamaicense, Nymphaea odorata,* and periphyton mats enhance P uptake and removal in SAV cells?

The remaining sub-questions (Table 3 of the Science Plan) or any new ones generated as the plan is implemented will continue to be evaluated and prioritized annually through an adaptive management process outlined in Section 5 of the Science Plan. From this process, new studies not currently on the schedule will be identified, prioritized, designed, and added as the plan progresses.

OTHER AREAS OF INVESTIGATION

An overview and background of the two other areas of investigation, as detailed in Sections 3.4.1 and 3.4.2 of the Science Plan, is presented below.

STA Water and Phosphorus Budget Improvements

An accurate water budget for an STA (or individual cell) is necessary for developing a phosphorus budget and ultimately for understanding phosphorus treatment performance of each STA. STA water budgets are comprised of several components including structure flows (inflows and outflows), rainfall, evapotranspiration (ET), seepage, change in storage, and residual (error). Recently, the STA Water Budget Application has been used to compute water budgets for entire STAs and individual cells. Using this automated tool, water budgets can be computed on a daily, monthly, seasonal, annual, or multiyear basis. For water budget calculations, inflow, outflow, ET, rainfall, and stage data are obtained from the District's hydrometeorologic database (DBHYDRO) and seepage through levees is estimated with seepage coefficients and stage differences. Water control structure flows are the largest component of the water budgets, accounting on an average year for about 70-80 percent of the annual water budget, while rainfall and ET are roughly 10 to 12 percent (Abtew e al., 2013a). In dry years, especially during drought when inflow and outflow structures are mostly closed, seepage, ET, and rainfall account for larger percentages.

Annual water budgets for each STA typically have less than 10 percent error, whereas individual cell water budget errors can be much larger, i.e., 40-50 percent (Abtew et al., 2013b). The primary source of such error is often attributed to estimates of structure inflows and outflows and seepage. Flow-way or cell water budgets can have large error terms because flow-way inflow and outflow structures and cell-to-cell structures are typically culverts, which are difficult to

estimate for flow, particularly when operating under low head difference conditions that are prevalent in the STAs.

In some cases, further improvements in cell water budgets may require structural retrofits, operational changes, enhanced monitoring, equipment installation, field investigation (e.g., surveying), as well as development and maintenance of additional DBKEYs as needed and as resources permit. To improve STA water budgets, errors in all budget components should be reduced to the maximum extent practicable. Agency efforts are under way to evaluate sources of error in the STA water budgets and develop recommendations for reducing such errors and improving water and phosphorus budget accuracy for both entire STAs and individual cells. A test case for improving STA water budgets is under way for STA-3/4 Cells 3A and 3B. These results may be applied to other STA water budgets. Once the water budgets are improved, revised phosphorus budgets may also be developed using the improved water budgets.

STA Water Quality Monitoring

STA performance and compliance calculations are comprised of both structure flows and TP concentrations. In accordance with the issued permits, the calculation of the WQBEL requires TP concentrations measured at representative outflows. Water quality measurements are generally collected using grab samples and flow-proportional composite samples. A third measurement of TP, time-proportional composite samples, is a variation on the composite when flow data are not available. Using these data in combination with structure flows allows for the calculation of TP flow-weighted mean concentrations for WQBEL compliance.

In general, quality control of samples is monitored through a comprehensive program that tracks equipment cleaning, maintenance and the ability to replicate results in the field and laboratory and ensure that monitoring data are of high quality (SFWMD, 2011; SFWMD 2012c). While sampling failures are rare (i.e., usually less than 1 percent of samples collected), an issue for end users of water quality data has been the frequent occurrence of data sets in which grab and composite estimates are significantly different—in other words, clarification is required as to which sampling approach is more accurate. The observed differences between grab and composite samples may be well explained by brief, localized events that affect the composite results. With this possibility in mind, the District has recently deployed remote analyzers that can both sample and analyze TP in the field at specified time intervals (Struve et al., 2005). These experimental data are relatively similar to the associated grab samples, thereby validating both these methods but raising further question about flow composite sampling. Remote analyzer data reveal several short-term events in which trends in TP levels were briefly interrupted by spikes of elevated concentrations. It is presumed that these spikes were ephemeral events where debris impacted the sample collection equipment and briefly influenced the measured concentrations. Composite samples may be greatly impacted by debris as well as perhaps by organisms that can accumulate on sampling equipment.

Given the implementation of the WQBEL and sensitivity of compliance calculations to relatively small changes in concentrations, focused research that uses various methods to examine the impacts of sampling method, trigger method, frequency, and data analysis and calculations would aid in better understanding this issue. Efforts will include samples collected using grabs, flow composites, time composites, and the remote analyzer, along with newly available breakpoint flow data, as well as in situ conductivity and turbidity to detect ephemeral events. It would also be helpful to collect samples to evaluate surface biological growth on the deployed equipment over time. To minimize logistical issues of implementing this research, a pilot program will be carried out at one of the discharge structures for STA-1W to leverage existing research and compliance monitoring at the site. Based on these results, other key structures throughout the STAs could be evaluated.

RESEARCH AND STUDY PLAN DEVELOPMENT

The next step in the process was the development of nine conceptual study plans derived from the eight sub-questions selected for investigation and two additional areas of investigation that were determined to be important during development of the Science Plan. These proposed plans lay out the framework for the initial phase of Science Plan implementation and comprise the Five-Year Work Plan, as presented in Appendix C of the Science Plan. All data collection, analysis, and management performed under the proposed studies will be done in accordance with Sections 7 and 8 of the Science Plan, respectively.

As discussed in Section 5 of the Science Plan, adaptive management will also be a key aspect of performance management and will be used by the District's Science Plan Team during science/research project planning, design, and implementation to identify uncertainties early in the planning process to facilitate progress and communicate to management to obtain buy-in on the approach to addressing those uncertainties and documenting management decisions. The Science Plan requires an adaptive management process to address uncertainties by incorporating robustness and flexibility into program/project planning and implementation, and by testing hypotheses, linking science to decision making and adjusting implementation, as necessary, to improve the probability of achieving the plan's objectives.

As the proposed study plans are refined and executed, review of results along with regular evaluation of progress and data will be conducted with input from the Technical Representatives. Continuing workshops will be held with the Technical Representatives and federal agency experts and consultants to improve the study plans, refine experimental design, and specify data analysis procedures. This will allow for more rapid dissemination of information and prompt assessment of the potential need for specific steps to take if mid-course corrections are necessary. Such a continuing feedback loop will ensure that the most relevant and promising studies move forward in the process. In a parallel effort, technical staff will also coordinate closely with the Restoration Strategies Steering Group and construction and engineering teams to ensure that relevant information from the study plans are considered and incorporated into the design-build-operate activities associated with the Restoration Strategies capital projects as appropriate.

SCIENCE PLAN IMPLEMENTATION

Implementation of the initial study plans in the Science Plan will be guided by the Five-Year Work Plan. The Work Plan provides an overview of nine study plans proposed to be conducted over the first five-year planning cycle, along with project schedules. It describes a suite of studies, including background information, study hypotheses and objectives, proposed methodology, activities and milestones, and estimated schedules. The initial suite of studies, along with the corresponding key questions and sub-questions that the studies address, are presented in Appendix C, Table C-1, of the Science Plan. **Table 5C-1** lists the proposed studies and their estimated schedule over the next five-year planning horizon. More details on each of the individual study plans are provided in Appendix C of the Science Plan.

Since the initial publication of the Science Plan in June 2013, all nine studies have been reviewed and have received approval to move forward by the District's Restoration Strategies Steering Group. During July and August 2013, three technical, public workshops were held with the Technical Representatives as an open, collaborative forum to further discuss and obtain input for refining the proposed work efforts for each of the planned studies. With the implementation of the Science Plan scheduled to begin in September 2013, the current conceptual plans are continuing to evolve into detailed study plans. As these study plans are further detailed and implemented, it is anticipated that this chapter in future SFERs will integrate and synthesize information to effectively communicate related findings.

Table 5C-1. Estimated schedule for the nine proposed studies over the initial five-year planning horizon.
[Light blue shaded areas represent proposed work and dark blue shaded areas indicate proposed location.
Note that information in this table continues to be reviewed/updated and is subject to revision.]

STUDY NAME	2013	2014	2015	2016	2017	2018
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
1. Use of Soil Amendments/Management to Control P Flux Management	Phase I - Data Analysis / **Office**	Phase II - TBD based on Phase I / **Field Test**	Phase III - TBD based on Phase II results to include detailed research plan and test facility / **Research in Test Cell Facility**			
2. Evaluation of P Removal Efficacy of Water Lily and Sawgrass in a Low Nutrient Environment of the STAs		Phase I - Mesocosm Extension	Phase II - Field Implementation/Site Prep/Planting/Monitoring/Reporting / **STA cell (TBD)**			
3. Development of Operational Guidance for FEB and STA Regional Operation Plans	Data Gathering / **Office**	Hypothesis Testing/Field Testing/Analytical and Modeling Tool Development/ Application of Toolset/ Development of Regional Ops Model / **Office/ Field Testing within STAs**				
4. Evaluate P Sources, Forms, Flux, and Transformation Processes in the STAs	Develop/Procurement/ Set up / **Office/begin field**	Data Collection Sampling for Sub-Studies 1,2,3,4 / **STA Transects (2 yrs)/WCAs (2 yrs)/Core or Microcosm Sites (2 yrs)/Test Cell or Field Mesocosms (4 yrs)**				
5. Investigation of STA-3/4 PSTA Performance, Design and Operational Factors		Plan and Design/Continue Data Collection/ Core-Mesocosm/Biomarker-Isotopes / **STA-3/4 PSTA/Lower and Upper SAV/Cells 2B and 3B**	PSTA Dryout/Reflooding / **STA-3/4 PSTA Complex**	Final Report / **Office**		
6. Evaluation of the Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow TP Concentrations		Phase I - Data Analysis / **Office**	Phase II - Study Plan Design Initiation / **Field Work - Various Canal Sediment Sampling**			
7. Evaluation of Impacts of Deep Water Inundation Pulses on Cattail Sustainability	Study Plan/Procurement/Data Mining/Boardwalk-Plot Set Up / **Office/1W Test Cells**	**STA-1W Test Cells/STA-2** Data Collection/Sampling of In Situ Study and Test Cells / **STA-1W Test Cells**		Data Analysis and Reporting		
8. STA Water and Phosphorus Budget Improvements	Phase I - Data Analysis / **STA-3/4**	Phase II - Planning and Data Analysis; Phase III (TBD) / **All STAs**				
9. Evaluation of Sampling Methods for TP	Develop/ Procure/ Set Up / **STA-1W G-310 Discharge**	Data Collection / Data Analysis and Reporting / **Office**				

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