
SECTION 1: USE OF SOIL AMENDMENTS/MANAGEMENT TO CONTROL P FLUX

1.1 OVERALL STUDY PLAN SUMMARY

The purpose of this study is to investigate whether internal loading of phosphorus (P) in the STAs (i.e., the flux of soluble P from the soil to the overlying water column) can be reduced by application of soil amendments or management techniques and thereby reduce total P (TP) outflow concentrations. This study will be conducted in three phases with a STOP/GO decision made at the conclusion of each of the first two phases. Phase I will involve (1) data mining and synthesis of past District-supported research relevant to this study, (2) continuation of an existing literature review on technologies for controlling soil P flux in wetlands or lakes and (3) to the extent practicable, assessing the feasibility of implementing any of these technologies at full-scale in the STAs. Phase II will involve screening candidate technologies identified in Phase I through small-scale laboratory or field tests to assess their ability to sequester P and, if warranted, select a subset of technologies for further investigation in Phase III. Phase III will involve conducting large-scale field trials using some form of enclosure at the outflow regions in one or more of the existing STAs and/or within the STA-1W expansion area. The experimental approach for the field trials will be to compare the ability of treated enclosures to reduce outflow TP concentrations with the performance of a control (untreated) enclosure. The field trials will be of sufficient size to minimize uncertainty surrounding the scale-up of the technology/technologies in the STAs. The successful outcome of this study will be to identify a technology or set of technologies that when implemented will sufficiently reduce TP concentrations at the STA outflows in order to achieve the permitted TP Water Quality Based Effluent Limits (WQBELs). These technologies may be applied during construction or during operation of an STA to meet the discharge limits.

1.2 BASIS FOR THE PROJECT

Key Science Plan Question Study Addresses

- 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?

Science Plan Sub-Question Study Addresses

- What are the treatment efficacy, long-term stability, and potential impacts of soil amendments or management?

1.3 BACKGROUND/LITERATURE REVIEW

Biogeochemical cycling of nutrients in wetlands is mediated by a number of factors, one of which is the flux of dissolved nutrients from the soil to the overlying water column. There is a need to evaluate if the flux of dissolved P from the soil in the STAs can be reduced in order to reduce the concentration of TP in water discharged at the outflow of the STAs. Reducing soil P flux during STA startup may shorten the time required for the wetland to achieve its TP startup criterion. The District and other researchers have investigated a number of management approaches to reducing soil P flux, including removing all soil down to the caprock layer, covering the soil with a layer of low-P material (such as limerock), deep tilling the surface soil down into the underlying soil layers and adding soil amendments, either by broadcasting or incorporation.

To date, a number of studies have assessed the efficacy of soil manipulation. The removal of the accrued sediment layer in STA-1W Cell 1B reduced sediment TP concentrations from 1,300 to $<400 \text{ mg kg}^{-1}$ (SFWMD, 2007). The rate of P release from the inverted soils in the littoral zone of Lake Okeechobee was orders of magnitude lower than P release from undisturbed soils, although there were no significant differences in P release from tilled and scraped (topsoil removed) soils (Water and Soil Solutions, LLC, 2009). Muck removal followed by re-vegetation in the inflow cells of the Orlando Easterly Wetland northern flow-train greatly improved the hydraulic performance and P removal effectiveness of the rejuvenated wetland (Wang et al., 2006). Removing the top 30 cm of sediments in Lake Okeechobee decreased the equilibrium phosphorus concentration (EPC_0) from 0.03 to 0.01 mg L^{-1} , indicating that subsurface sediments had greater affinity for P. Dredging significantly reduced P flux under oxygenated water-column conditions, with P flux in the range of 0.1 to $0.35 \text{ mg P m}^{-2} \text{ d}^{-1}$ (Reddy et al., 2002).

In another recent study, physical removal of the accreted organic soil in combination with alum treatments significantly reduced P flux from a municipal wastewater treatment wetland (Malecki-Brown et al., 2009). Because of the difficulties and costs associated with the removal and disposal of soils from a treatment wetland, it was suggested that alum addition alone may be the most cost-effective and efficient means of sequestering P in aging wetlands experiencing reduced P removal rates, but organic soil removal would be a more permanent solution to reducing P flux (Lindstrom and White, 2011).

A number of studies have been conducted on the effects of soil amendments to reduce P flux. The most common soil amendments are aluminum (Al), iron (Fe), or calcium (Ca) salts that bind P and have been effective in reducing water column TP concentrations in several experiments. Three soil amendments [Al-, Fe- and Ca-based products (polyaluminum chloride, ferric chloride and hydrated lime, respectively)] were tested to determine their ability to reduce P flux from a flooded organic soil in a four-month mesocosm study (CH2MHill, 2003). None of the amendments completely controlled P flux, although polyaluminum chloride and ferric chloride were more effective than hydrated lime.

In a field enclosure study involving the application of wastewater treatment residuals consisting of hydrated lime, gypsum and alum and flooded to a depth of 25 cm, alum residuals strongly reduced P flux to the overlying water column (Hoge et al., 2003). P flux reduction in enclosures with lime and gypsum application was much less. Broadcasting calcium silicate (CaSiO_3) slag on top of the soil to create a surface barrier reduced the flux of soil P up to 84 percent compared to an un-amended soil control. However, incorporation of the material into the soil was only minimally effective at reducing P release (Chimney et al., 2007).

Additional studies generally confirm the results described above (Reddy et al., 1998; Ann et al., 2000). However, ongoing concerns remain about the quantity of amendments necessary to control soil P flux, the length of time that the amendments will remain effective and potential toxicity associated with different chemicals.

1.4 CONCEPTUAL MODEL

The conceptual model for the major pathways involved in P cycling in the STAs is shown in **Figure 1-1**. This figure highlights the flux of soil P to the overlying water column, the pathway that is the focus of this study.

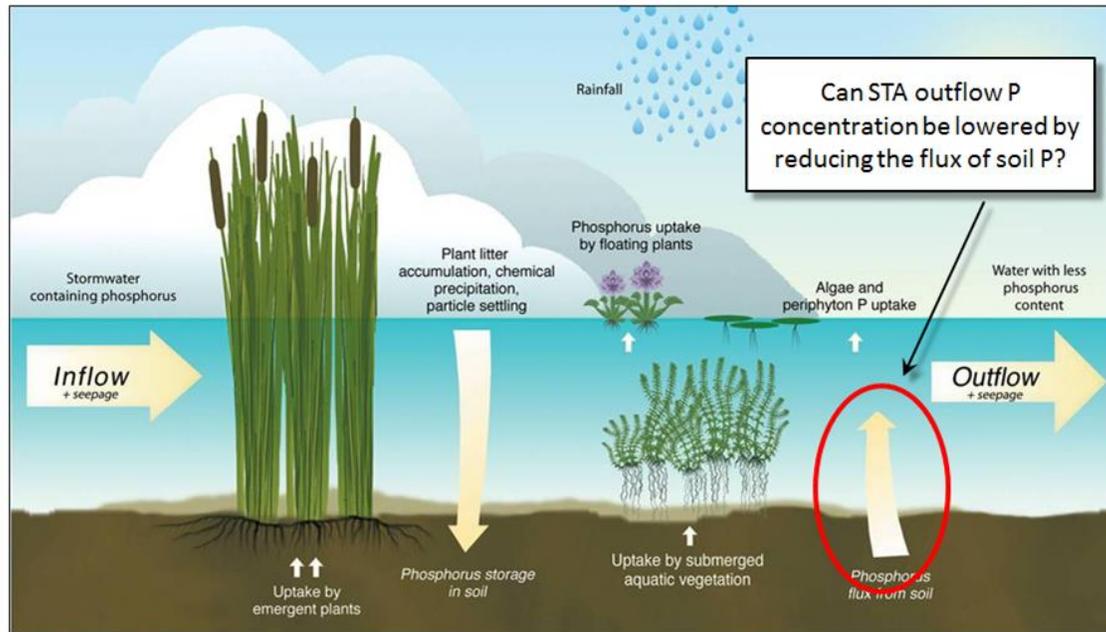


Figure 1-1. A conceptual model showing the major pathways involved in phosphorus (P) cycling in the STAs and the specific pathway that is the focus of this study, i.e., the flux of soluble P from the soil to the overlying water column.

1.5 STUDY PLAN OBJECTIVES

There are two operating hypotheses for this study:

H_0 : Reducing the flux of dissolved soil P to the overlying water column in an operating STA will lower the TP concentration in water discharged at the outflow.

H_0 : Reducing the flux of dissolved soil P to the overlying water column during startup of a new STA will shorten the time required for the wetland to achieve compliance with the WQBEL.

This study may include a number of separate sub-studies, each of which will focus on a particular aspect of the Key Question and Sub-question. These sub-studies may include, but are not limited to:

- Investigate the use of soil amendments to reduce soil P flux in the existing STAs. The objective would be to reduce the outflow TP concentration.
- Investigate using deep tilling to reduce soil P flux during the start-up of a new STA; the objective would be to reduce the time required for the STA to achieve compliance with the WQBEL.
- Investigate using soil amendments to reduce soil P flux during the start-up of a new STA. The objective would be to reduce the time required for the STA to achieve compliance with the WQBEL.
- Investigate the use of adding a layer of limerock (locally obtained limestone) to cap the soil layer and reduce P flux to the water column in the existing STAs and in the STA-1W expansion area and thereby reduce the outflow TP concentration.

1.6 DETAILED STUDY PLAN AND EXPERIMENTAL DESIGN

1.6.1 Study Plan Description

The purpose of this study is to investigate whether internal loading of P in the STAs can be reduced by application of soil amendments or management techniques and thereby reduce TP concentrations in water discharged from the STA outflows.

This study will be conducted in three phases with a STOP/GO decision for continuing with the study made at the conclusion of each of the first two phases. Phase I will involve (1) data mining and synthesis of past District-supported research relevant to this study, (2) expansion of an existing literature review on technologies for controlling soil P flux in wetlands or lakes and (3) to the extent practicable, assessing the feasibility of implementing any of these technologies at full-scale in the STAs. Phase II will involve screening candidate technologies identified in Phase I through small-scale laboratory or field tests for their ability to sequester P and (potentially) select a subset of technologies for further investigation. Phase III will involve conducting large-scale field trials using some form of enclosure at the outflow regions in one or more of the existing STAs and/or within the STA-1W expansion area. The experimental approach for the field trials will be to compare the ability of treated enclosures to reduce outflow TP concentrations with the performance of a control. The field trials will be of sufficient size to minimize uncertainty surrounding the scale-up of the technology/technologies to the STAs.

1.6.2 Experimental Design and Study Plan Components

This study will be conducted in three phases. **Phase I** will include the following activities:

- Summarize data and findings of past District and DB Environmental, Inc. studies on controlling soil P flux in wetlands.
- Expand the preliminary literature review on technologies for controlling soil P flux in wetlands that was performed during development of the Science Plan. Information gained from the literature review (e.g., technology description, unit costs, treatment efficacy, adverse side effects, etc.) will be compiled into an Excel spreadsheet.
- To the extent practicable, assess the engineering, logistical and economic feasibility of applying any of these technologies at full-scale in the STAs. Where possible, stakeholder and public comments received on this study plan will be addressed during Phase I and will include, but not be limited to, questions concerning the cost of implementation, logistics of applying amendments to the STAs, the long-term treatment efficacy of amendments, potential downstream toxicity and other marsh readiness issues.

The findings from Phase I and any recommendations for continuing the study will be compiled in a summary report. A STOP/GO decision will be made whether to initiate Phase II of the study.

If the Phase I STOP/GO decision is to continue the study, **Phase II** will begin with the preparation of a more detailed research plan. Phase II investigations may use small experimental units, such as soil cores or mesocosms, to characterize the ability of different soil amendments, soil management methods and amendment application methods to reduce the flux of dissolved P from soil to the overlying water column in short-term (days to weeks) trials. Soil used in these trials will be collected from operating STAs or the footprint of the STA-1W expansion area. Findings from Phase II and any recommendations for continuing the study and those technologies to carry forward will be compiled in a summary report. Another STOP/GO decision will be made whether to proceed to Phase III based on the outcome of the Phase II trials.

If the Phase II STOP/GO decision is to continue the study, **Phase III** will begin with the preparation of a more detailed research plan and a request for engineering support to design and construct the field-scale research facilities. Phase III investigations will involve long-term field trials using the most promising soil amendment(s), soil management method(s) or some combination of both identified in Phase II. Field-trials focused on reducing outflow TP concentration in existing STAs will be conducted in large enclosures constructed in the outflow regions of operating STAs, while field trials investigating reducing soil P flux during STA startup will, by necessity, have to be conducted within the footprint of the STA-1W expansion area. The experimental approach will be to compare reduction in TP concentration at the outflow of treated enclosures with the performance of a control enclosure. If feasible, the inflow/outflow water quality data will be supplemented with *in situ* measurements of soil P flux to the overlying water column. All water quality samples collected during this study will be analyzed by the District's Chemistry Laboratory. To the extent practicable, the enclosures will be operated to mimic the hydraulic conditions experienced in the STAs (i.e., water depth, flow regimes and hydraulic retention time). The success of this study will be defined relative to the WQBEL established for the STAs, i.e., can the treated enclosures produce an effluent that meets the TP concentration limits mandated by the permits and Consent Order. The expected duration of the Phase III field trials will be 4-5 years. The findings from Phase III and any recommendation for full-scale implementation of these technologies in the STAs will be compiled in a summary report.

1.6.3 Data Management

All water quality analyses and the data generated from these procedures will be subject to the District Chemistry Laboratory's QA procedures. The water quality data will be stored in the District's DBHYDRO database.

1.6.4 Reporting

Summary reports, as described above, will be prepared at the conclusion of each phase of the study. Letter reports on the progress of the study will be prepared quarterly. An annual summary of study progress will be included in the annual South Florida Environmental Report (SFER). The summary reports for each study phase also will be incorporated into the annual SFER, if possible.

1.6.5 Study Schedule

Phase I:	Initiate work – FY2014
	Complete work – FY2014
Phase II:	Initiate work – FY2014, if needed
	Complete work – FY2015
Phase III:	Initiate work – FY2015, if needed
	Complete work – FY2020

1.7 LITERATURE CITED

- Ann, Y., K.R. Reddy and J.J. Delfino. 2000. Influence of chemical amendments on phosphorus immobilization in soils from a constructed wetland. *Ecol. Eng.*, 14:157-167.
- CH2MHill. 2003. PSTA Research and Demonstration Project: Field-scale Soil Amendment Study Report. CH2MHill, Inc., Deerfield Beach, FL.

- Chimney, M.J., Y. Wan, V.V. Matichenkov and D.C. Calvert. 2007. Minimizing phosphorus release from newly flooded organic soils amended with calcium silicate slag: A pilot study. *Wetl. Ecol. Mgmt.*, 15:385-390.
- Hoge V.R., R. Conrow, M. Coveney and M. Peterson. 2003. The application of alum residual as a phosphorus abatement tool within the Lake Apopka restoration area. Proceedings of the Water Environment Federation, WEF/AWWA, CWEA Joint Residuals and Biosolids Management, 1500-1513.
- Lindstrom, S.M. and J.R. White. 2011. Reducing phosphorus flux from organic soils in surface flow environment. *Chemosph.*, 85:625-629.
- Malecki-Brown, L.M., J.R. White and M. Sees. 2009. Alum application to improve water quality in a municipal wastewater treatment wetland. *J. Environ. Qual.*, 38:814–821.
- Reddy, K.R., G. Bao, O.G. Olila and D.L. Stites. 1998. Effects of Chemical Amendments on Marsh Soil Chemistry and Nutrient Flux. Soil and Water Science Department, University of Florida, Gainesville, FL, and St. Johns River Water Management District, Palatka, FL.
- Reddy, K.R., J.R. White, M.M Fisher, H.K. Pant, K. Grace and W.G. Harris. 2002. Potential Impacts of Sediment Dredging on Internal Phosphorus Load in Lake Okeechobee. Summary report to the South Florida Water Management District, West Palm Beach, FL. September 2002.
- SFWMD. 2007. Rehabilitation/Conversion in Stormwater Treatment Area 1 West. South Florida Water Management District, West Palm Beach, FL.
- Wang, H., J.W. Jawitz, J.R. White, C.J. Martinez and M.D. Sees. 2006. Rejuvenating the largest municipal treatment wetland in Florida. *Ecol. Eng.*, 26:132-146.
- Water and Soil Solutions, LLC. 2009. Tilling Practices for Phosphorus, Sediment and Vegetation Management in Lake Okeechobee, Phase I. Final Report, January 2009.