Chapter 4C: Advanced Treatment Technologies

INTRODUCTION

As previously described in the 2001 and 2002 Everglades Consolidated Reports (ECRs), the South Florida Water Management District (District or SFWMD) has been evaluating selected water quality treatment technologies ranging from constructed wetlands to chemical treatment for the removal of phosphorus (P) (PEER Consultants and P.C./Brown and Caldwell, 1996; SFWMD, 2001a). The District has performed demonstration studies on eight technologies, as required by the United States Army Corps of Engineers (USACE) 404 permit, to further determine critical design criteria, such as performance efficacy, hydrologic operating characteristics, capital and operating costs and identification of potential environmental impacts. Some of these have the potential to be used in the treatment of "hot spots," as well as regional application. These technologies include the following:

- Periphyton Stormwater Treatment Areas (PSTAs)
- Submerged Aquatic Vegetation/Limerock (SAV)
- Managed Wetland Treatment Systems (MWTS)
- Low-Intensity Chemical Dosing (LICD)
- Chemical Treatment/Solids Separation (Chemical Treatment/Direct Filtration, Chemical Treatment/High-Rate Sedimentation, Chemical Treatment/Dissolved-Air Flotation, Chemical Treatment/Microfiltration)

Demonstration and research projects are ongoing at various locations within STA-1W and adjacent to STA-2. Small-scale mesocosm and pilot-scale studies are located at the north (post-BMP) and south (post-STA) Advanced Treatment Technology (ATT) research sites at STA-1W (**Figure 4C-1**). Intermediate-scale studies are also being performed at the STA-1W test cells (**Figure 4B-1**). **Table 4C-1** presents a brief description and status summary for the District ATT projects, while **Table 4C-2** provides a summary for SAV, PSTA, and Chemical Treatment Solids Separation (CTSS) based on the entire operational project, excluding start-up at each scale tested. Additionally, CTSS, Microfiltration, PSTA and SAV have completed their Supplemental Technology Standard of Comparisons (STSOC). The results for the base case are summarized in **Table 4C-3**. Additionally, various optimal scenarios are discussed in the PSTA and SAV sections of this chapter and in the final reports posted online at the District's Website at http://www.sfwmd.gov. Refer to Chapter 6 of the 2000 ECR (Chimney et al., 2000) for a complete description of the test cells. Additional field-scale projects and studies are located in STA-1W cells 4 and 5, and in an 8-hectare (8-ha) area adjacent to STA-2. Chapter 8 of the 2001 ECR (Coffelt et al., 2001) and Chapter 4C of the 2002 ECR (Jorge et al., 2002) contain complete descriptions of these study sites and demonstration projects. Additionally, the research contracts for managed wetlands, low intensity chemical dosing, and chemical treatment have been completed and were reported in Chapter 4C of the 2002 ECR (Jorge et al., 2002). Copies of past ECRs and all referenced ATT reports are available at the District's Website, referenced above.

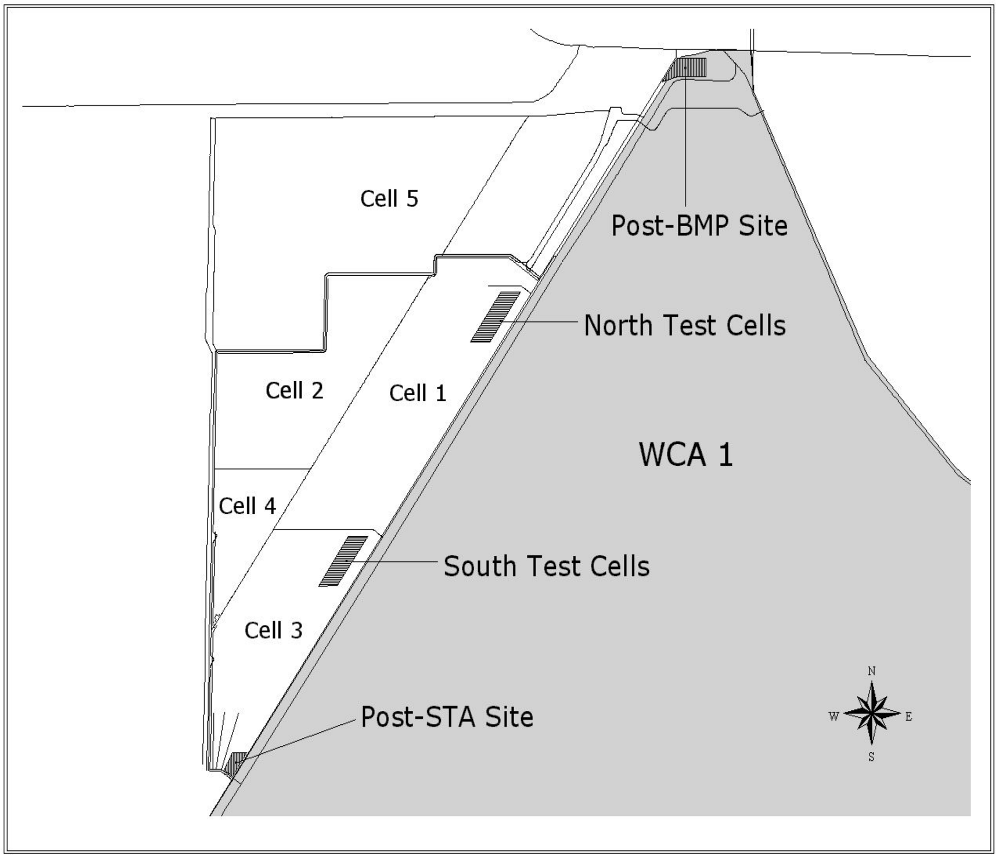


Figure 4C-1. Map showing the relative locations of the north and south test cell research facilities and post-BMP and post-STA sampling locations within STA-1W

Table 4C-1. Status and summary of Advanced Treatment Technologies reviewed by the District

ATT and description	Testing Platform	Limitations/ uncertainties	Future Plans
Submerged Aquatic Vegetation Dominated by submerged aquatic vegetation Peat substrate Limerock berm at outflow area tested	Mesocosm Test Cell Field Scale	Experiments focused on a higher range of HLRs, with little emphasis on the HLRs less than the STA design of 2.6 cm/d. At times inflow TP concentrations were lower than normal due to drought conditions.	Utilize the test cells to test SAV in a treatment train layout with cattail and periphyton vegetation. Continue field scale monitoring and research efforts. FIU continue monitoring vegetation biomass and periphyton species in cell 4.
Periphyton Stormwater Treatment Areas Dominated by spike rush and periphyton Shellrock and peat substrates tested	Mesocosm Test Cell Field Scale	Peat system values include start-up data. Amendment of peat system with calcium was unsuccessful, but addition may have been insufficient in application amount and method. At times, inflow TP concentrations were lower than normal due to drought conditions. Only tested at Post-STA sites. Experiments focused on a higher range of HLRs, with little emphasis on the HLRs less than the STA design of 2.6 cm/d.	Utilize the test cells to test PSTA in a treatment train layout with SAV. Continue research using the 20-acre field-scale platform.
Managed Wetland Treatment Systems Chemical treatment followed by a cattail dominated polishing marsh. Peat substrate	Benchtop Test Cell	At times TP inflow concentrations were lower than normal due to drought conditions. Inordinate amount of floc overflow from treatment plants due to high inflow rate. Experiments focused on a higher range of HLRs, with little emphasis on the HLRs less than the STA design of 2.6 cm/d. Inflow pumping rate about 2.21 L/s.	All research completed.

Table 4C-1. (Cont.)

ATT and Testing Platform	Testing Platform	Limitations/ Uncertainties	Future Plans
Low Intensity Chemical Dosing Low dose of chemical coagulants directly into inflow stream Cattail dominated marsh Peat substrate	Mesocosm Test Cell	Originally tested in STA-1W, Cell 2 in round mesocosms. Test cell project was a short-term project that ran for less than one year to test in a flume type system. At times inflow TP concentrations were lower than normal due to drought conditions.	No future testing is currently scheduled.
Chemical Treatment with Solids Separation (CTSS) with outflow into a wetland Dominated with submerged vegetation Peat substrate	Test Cell	Outflow TP concentration from a submerged aquatic vegetation marsh with inflow TP water column concentrations of less than 10 µg/L. Inflow pumping rate about 1.9 L/s.	Scheduled completion date is December 2003.
CTSS Agricultural runoff treated Urban runoff treated No vegetation Aluminum chloride, poly aluminum chloride, aluminum sulfate, and ferric chloride coagulants tested	Benchtop studies Trailer at STA-1W, Post-STA and Post-BMP scenarios Trailer at Village of Wellington Trailer at S-9 pump station in Basin C-11	Very low inflow rates, 0.4 to 0.8 L/s. Short term project that ran for less than 6 months. Experimental treatment runs often for less than 48 hours. Residual estimate has large uncertainty due to low inflow rates. Testing results includes optimization scenarios.	No future post-STA work is currently scheduled. A request for proposal has been issued to install, operate, and monitor a field-scale (400 gpm) facility located at the Village of Wellington.
Microfiltration No vegetation Tested without coagulants. Test with coagulants	Trailer at STA-1W	Very low inflow rates, 6 to 12 gpm tested Short term project that ran for less than 6 months.	No future post-STA work is currently scheduled.

Table 4C-2. Arithmetic and geometric means of total phosphorus (TP) concentrations along with arithmetic mean of flow-weighted TP concentration values for submerged aquatic vegetation (SAV), periphyton-based vegetation (PSTA), emergent vegetation and chemical treatment (CTSS) systems. Values represent the TP outflow concentration for each technology based on the entire operational period, excluding start-up data

		Total Phosphorus Concentration (ppb)		
Technology	**Platform/period**	**Mean**	**Geomean**	**Flow-weighted mean**
SAV	STA-1W, Cell 4, peat (8/97 through 4/01)	20.0	17.6	21.7
PSTA	South Test Cell 8, limerock (7/99 – 4/01)	12.3	11.9	Constant flow
Emergent	STA-1W, Cell 1, peat (8/97 through 4/01)	39.0	28.0	53.5
Emergent	STA-1W, Cell 3, peat (8/97 through 4/01)	22.0	18.8	28.7*
Emergent	North Test Cell (NTC) 5, Peat (5/00 to 5/01)	31.0	26.0	Constant flow
CTSS	Blue unit @NTC 14 (8 mo) (6/01 to 3/02)	10.0	8.4	Constant flow

*Flow-weighted mean calculation ignores an extreme TP concentration value of 1.10 mg/L for the composite sample for ENR305 collected March 13, 2001.

Each technology has a scientific review panel, and analyses are subject to review by the Florida Department of Environmental Protection (FDEP or Department), other interested agencies, independent peer review, and public input. All studies analyze water samples for a large set of parameters; however, this section will focus on updating the research with respect to removal of P (as the nutrient of most concern). Refer to the "Glossary" for definitions of P speciation used in this report.

Table 4C-3. Cost comparison of full-scale implementation estimates of the various Advanced Treatment Technologies STSOC conceptual designs without inclusion of STA-2 costs or acreage. Outflow TP concentrations represent experimental means achieved. All calculations are based on zero-percent bypass scenarios. Additionally, various optimal scenarios are discussed in the PSTA and SAV sections of this chapter and in the final reports posted at the District's Website

ATT	Outflow TP achieved (μg/L)	Area Required (ha)	50 yr Present Worth ($)	$/pound TP removed	$/1000 gallons treated
		Post-BMP Placement			
CTSS	<=10	2,602[a]	280,000,000	101.00	0.104
SAV	26	1,770	4,167,704	1.80	0.001
		Post-STA Placement			
CTSS	<=10	2,602[b]	301,000,000	264.00	0.134
Microfiltration	20	607	345,000,000	315.00	0.173
SAV	20	1,275	72,933,064	114.00	0.03
PSTA [c]	12	6,198	888,942,000	1,076.00	0.35

[a] Add an additional 690 ha for land application of residuals

[b] Add an additional 369 ha for land application of residuals

[c] Costs include 0.61 m of shellrock

SUBMERGED AQUATIC VEGETATION

The original Submerged Aquatic Vegetation (SAV) with Limerock (LR) technology used indigenous submerged plants to remove P from the water column, along with a LR filter positioned at the end of the system (DBEL, 1999) (**Figure 4C-2**). Removal of P is believed to be accomplished by plant uptake, as well as by adsorption to (or co-precipitation with) calcium carbonate ($CaCO_3$) that precipitates from the water column due to photosynthesis-related pH fluctuations. The LR further removed a small amount of particulate phosphorus (PP) and dissolved organic phosphorus (DOP). The concepts defined in the USACE 404 permit divided periphyton and SAV STAs into two distinct technologies. In an effort to meet the USACE 404 permit requirements, the District embarked on two distinct research efforts defined by the dominate vegetation type present, recognizing that an SAV system will contain various assemblages of periphyton in addition to the dominant submerged macrophytes.

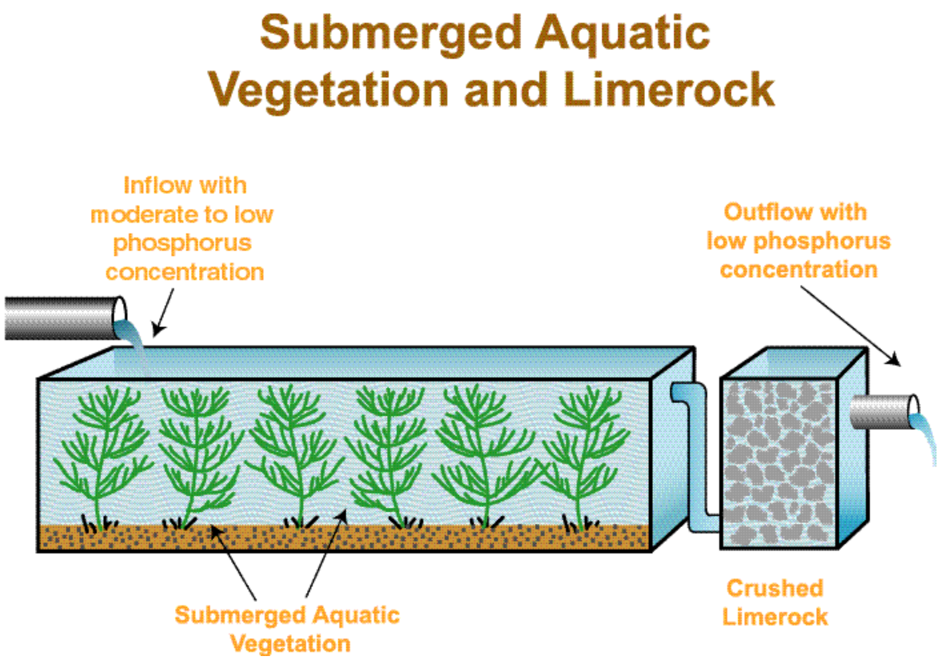


Figure 4C-2. Schematic representation of the Submerged Aquatic Vegetation followed by a crushed limerock filter Advanced Treatment Technology tested at STA-1W

The SAV project was conducted in two phases. During phase I of this project, mesocosms that operated under steady-state conditions were used to evaluate P removal performance of SAV and LR under various hydraulic retention times (HRT), water depths and harvesting regimes (DBEL, 1999). The phase II SAV research program, also known as the Follow-on Study, addresses a number of system processes, as well as operational and management issues at various scales, and continued some of the experiments from phase I (Gu et al., 2001). For a detailed description of the SAV project, refer to DBE (2002a), Chapter 8 of the 2000, 2001 and 2002 ECRs (Gray and Coffelt, 2000; Coffelt et al., 2001, Jorge et al., 2002). United States Environmental Protection Agency (USEPA) Section 319(h) funding was received for this project.

SAV RESEARCH ON CONSTRUCTED SYSTEMS

Test Cell Research

The test cells represent an SAV assessment platform that is intermediate in scale (0.20 ha) compared to the mesocosms (1.7 to 3.7 m^2) and STA-1W cell 4 (147 ha). The main objective of the SAV test cell research was to evaluate whether a scale effect was evident in the P-removal performance of SAV systems by comparison of removal rates at this scale that is intermediate between the small mesocosm and larger field-scale facility. The secondary objective was to evaluate the P-removal performance as a function of hydraulic loading rates and limerock berms.

Two SAV-dominated test cells, NTC-1 and NTC-15, at the north bank of test cells received post-BMP waters from STA-1W cell 1. The two SAV-dominated test cells, STC-4 and STC-9, at the south bank of test cells received post-STA water from STA-1W cell 3. Initially, all four test cells were dominated by cattail and were subsequently converted to SAV by the District in 1998. Baseline monitoring of the SAV-dominated test cells began on September 1, 1999. Additionally, due to the installation of two LR berms at NTC-15 and STC-9 beginning in March 2000, monitoring of NTC-15 was suspended from April 5, 2000 until June 23, 2000; monitoring of the south test cells was suspended from March 14, 2000 until August 4, 2000 due to the removal of *Hydrilla verticillata* (L.f.) Royle., which did not dominate the other SAV test cells. The cell was restocked with SAV vegetation from STA-1W cell 4. The contractor subsequently monitored all SAV test cells until September 14, 2001. The District resumed monitoring of these systems on January 30, 2002. During most of the monitoring period, north test cells were dominated by mixed populations of *Najas guadalupensis* (Spreng.) Magnus, *Ceratophyllum demersum* L. and *Chara spp.*, while south test cells were dominated by *Chara* following the aquatic control of *Hydrilla*. Changes in water depth, hydraulic loading rates, and retention time were made over the course of the monitoring period (**Table 4C-4**).

Table 4C-4. The history of water depths, hydraulic loading rates (HLR) and hydraulic retention times (HRT) during the SAV research performed at the test cells from August 4, 2000 until the end of Water Year 2002

	8/4/00 to 4/5/01 (contractor monitored)			4/6/01 to 9/14/01 (contractor monitored)			1/30/02 to 5/23/02 (District monitored)		
Test Cell	**Depth (m)**	**HLR (cm/d)**	**HRT (d)**	**Depth (m)**	**HLR (cm/d)**	**HRT (d)**	**Depth (m)**	**HLR (cm/d)**	**HRT (d)**
NTC-1	0.74	12.1	6.1	0.60	22.5	2.7	0.31	2.6	8.4
NTC-15	0.96	7.3*	12.9*	0.60	20.5	3.5	0.44	2.6	5.9
STC-4	0.22	5.5	4.5	0.30	5.7	5.3	0.35	2.6	7.4
STC-9	0.45	6.0	7.5	0.45*	6.1	7.5	0.38	2.6	6.8

* Represents the time-weighted average of 5.6 cm/day from August 4, 2000 to March 7, 2001 and 11.2 cm/day from March 8 to June 1, 2001.

SEDIMENT CHARACTERISTIC AND ACCRETION

Sediment cores were obtained from four locations along a longitudinal centerline from each of the four test cells on September 20 and 21, 2001 to characterize the performance of each test cell for P removal. Despite wide variability among the test cell sediment cores (DBE, 2002a), average P mass removal rate and storage were significantly higher in north (post-BMP) than in south (post-STA) test cells (**Table 4C-5**). This increased mass storage was directly related to the increased accrual rate at the north site, and may be indirectly related to the higher mass loading rate at the north site.

Table 4C-5. Bulk density, total P and total Ca concentrations, P storage, and accrual rate for sediments in each SAV-dominated test cell from STA-1W. Sediment samples collected on September 20 and 21, 2001 (modified from DBE, 2002a)

Test Cell	Bulk Density (g/cm^3)	Accrual Rate* (cm/yr)	Total Ca (%)	Total P	
				Conc. (mg/kg)	Storage (g/m^2)
NTC-1	0.117	3.6	16	488	6.4
NTC-15	0.095	2.4	21	527	3.5
STC-4	0.128	1.1	20	521	1.5
STC-9	0.123	1.4	18	496	2.0

* September 1, 1998 to September 20, 2001 for north test cells; March 1, 1999 to September 20, 2001 for south test cells.

P-REMOVAL PERFORMANCE FROM INFLOW AND OUTFLOW WATER

During the entire monitoring period (August 4, 2000 to May 2, 2002), the inflow TP concentration at the north tests cells ranged from 25 µg/L to 189 µg/L, with an inflow mean of 74 µg/L. Generally, both NTC-1 and NTC-15 reduced TP concentrations relative to inflow, except for NTC-1 during the period from January 30, 2002 to May 2, 2002, when mean outflow TP concentrations slightly exceeded inflow. Total P reduction at the north test cells was also estimated at different hydraulic loading rates over time. Preliminary results indicated that mean TP outflow concentrations increased over time at both NTC-1 and NTC-15 (**Table 4C-6**). Field observations for NTC-1 during the third monitoring period indicated that the water surface was covered with *Lemna* and that *Chara* was the dominant SAV in this cell. The shift from *Ceratophyllum* and *Najas* to *Chara*, in combination with the previous high HLRs, may have contributed to the poor P-removal performance in NTC-1 during this period.

Table 4C-6. P-removal performance at various hydraulic loading rates (HLRs) for SAV-dominated test cells. The hydraulic residence time in days and the ranges of concentration values are presented in parentheses beneath their respective values

NORTH TEST CELLS							
Date	**HLR (cm/day)**		**Inflow TP conc. (µg/L)**	**Outflow TP conc. (µg/L)**		**% TP reduction**	
	NTC-1	**NTC-15**	**NTC**	**NTC-1**	**NTC-15**	**NTC-1**	**NTC-15**
8/4/00-4/5/01	12.1 (6.1 d)	7.3 (12.9d)	56.6 (25-122)	16.6 (8-31)	17.8 (7-32)	70.7	68.5
4/6/01-9/14/01	22.5 (2.7 d)	20.5 (3.5 d)	83.7 (48-149)	34.5 (14-109)	23.1 (14-35)	58.8	72.4
1/30/02-5/2/02	2.6 (25.1 d)	2.6 (22.2 d)	50.1 (40-71)	51.4 (36-67)	26.7 (16-43)	-2.8	46.6

SOUTH TEST CELLS							
Date	**HLR (cm/day)**		**Inflow TP conc. (µg/L)**	**Outflow TP conc. (µg/L)**		**% TP reduction**	
	STC-4	**STC-9**	**STC**	**STC-4**	**STC-9**	**STC-4**	**STC-9**
8/4/00-4/5./01	5.5 (4.5)	6.0 (7.5)	20.1 (13 – 40)	21.4 (13-30)	16.6 (10-22)	-6.5	17.4
4/6/01-9/14/01	5.7 (5.3)	6.1 (7.5)	34.5 (21-51)	22.9 (16-39)	18.2 (14-32)	33.6	47.2
1/30/02-5/2/02	2.6 (12.9)	2.6 (14.8)	25.1 (16-30)	-	21.8 (12-32)	-	9.2

The inflow TP concentrations in the two south test cells ranged from 12 to 55 µg/L, with a mean of 23 µg/L. The overall mean outflow TP concentrations in STC-4 and STC-9 were 19 and 18 µg/L, respectively. The TP reduction at the south SAV test cells was generally lower than at the north site and ranged from –6.5 percent to 47.2 percent (**Table 4C-6**). This reduction in TP removal at the south site relative to north site systems was also observed in the STA-optimization cattail-dominated systems (Jorge et al., 2002).

STA-1W, Cell 4 Sediment Characteristics and Stability

Wetland sediment is the ultimate sink for P removed from the inflow water. It is therefore important to understand internal cycling and mass balance of P. The two objectives of the study of STA-1W cell 4 sediment are to characterize the P storage and sedimentation rates and understand the stability of P under different environmental conditions. The information obtained from these studies will help evaluate P-removal pathways and efficiency by SAV-dominated wetlands.

SEDIMENT CHARACTERISTICS

Sediment cores from STA-1W cell 4 were collected and analyzed at 16 sites along four internal transects from August 9, 2000 to November 9, 2001. Phosphorus removed from the water column in SAV communities became a component of a calcium (Ca)-enriched sediment (~15 to 22 percent Ca). The sediment accrual rate and P content were related to the P loading history for the particular SAV community. Sediment accrual rates in the inflow and outflow regions of STA-1W cell 4 have averaged 1.5 and 0.6 cm/yr, respectively, since the onset of flooding in August 1993. STA-1W cell 4 inflow region sediments contain an average of 11.2 g-P/m^2; outflow region sediments contain 4.5 g/m^2. This difference in P accrual rate and storage from inflow and outflow regions was also found in the SAV community (**Table 4C-7**).

Table 4C-7. Phosphorus accrual rate, P, N, Ca and SAV P storage in the inflow and outflow halves of cell 4 (DBE, 2002a)

Cell Region	Accrual Rate	Sediment (g/m^2)			SAV (g/m^2)
	(cm/yr)	P	N	Ca	P
Inflow	1.5±0.6	11.2±4.3	237±161	1788	0.46±0.36
Outflow	0.6±0.1	4.5±1.6	95±54	1106	0.37±0.27

SEDIMENT STABILITY

Three stations adjacent to the northern levee, and three stations along an east-west transect in the southern region of STA-1W cell 4 were cored using an aluminum corer (inner diameter = 10.1 cm) in June and July 2000. One core from each station was used for P fractionation analyses of the accrued sediment, while the accrued calcareous sediment in the remaining north and south site cores from each station were composited and homogenized to provide substrate for the stability/release assessments. Incubation under amended pH, calcium/alkalinity and anoxic conditions were performed in the dark within a water bath held at room temperature.

Phosphorus fractionations revealed that much of the P sequestered in the STA-1W cell 4 SAV communities was associated with a fairly stable, Ca-bound sediment fraction. Relative to inflow region sediments, the STA-1W cell 4 outflow region sediments were extremely stable and exhibited little P release in response to anoxia, desiccation, and low pH conditions (DBE, 2002a).

SEDIMENT-WATER COLUMN P FLUXES

Microprofiles of pH, redox, SRP, TDP, dissolved Fe, dissolved Ca, and alkalinity were constructed in the inflow and outflow regions of cell 4 using sediment-porewater equilibrators. The equilibrators were inserted into the sediment and allowed to equilibrate for 19 days at the STA-1W cell 4 inflow (October 25 to November 13, 2001) and 18 days at the outflow (November 26 to December 14, 2001). After the equilibration period, samples were extracted by syringe and analyzed for the above-referenced parameters. Flux rates were calculated from the sediment to the overlying water based on Fick's First Law. Results substantiated the stable nature of the STA-1W, STA-1W cell 4 outflow region sediments discussed in the previous section. Porewater SRP concentrations in STA-1W cell 4 inflow region and outflow region sediments averaged 535 and 25 µg/L, respectively. The flux of SRP from sediment to water column was calculated to be 0.10 mg/m^2/d for inflow region sediments, and 0.007 mg/m^2/d for outflow region sediments.

STA-1W, Cell 4 Hydraulic Study

Despite good past performance of STA-1W cell 4, visual observations of water flow indicated that internal short-circuiting occurred along historic agricultural ditches and construction borrow canals. To assess the degree of hydraulic short-circuiting, a tracer study using Rhodamine-WT dye was conducted in December 1999. Results showed that STA-1W cell 4 had a mass recovery of 85 percent, a mean residence time (τ) of 4.4 days, and a variance of 17.2. Approximately 51 percent of the inflow water bypassed the SAV beds and moved rapidly down deep, existing borrow canal areas (DBEL, 2000a). In 2000, actions to improve the hydraulics included plugging the short-circuiting channels, placing cuts in the high-apron areas, and constructing internal levees to compartmentalize the cell and redistribute the flow (DBEL, 2001b). A second tracer study to verify the extent of hydraulic improvement was conducted between November and December of 2002 and indicated that STA-1W cell 4 hydraulic efficiency decreased slightly compared to the first dye study. The mass recovery and mean residence time dropped to 52 percent and 4.9 days, respectively, with a variance of 13.4. The poorer hydraulic performance is mainly attributed to a new short-circuit path along the relic farm canal that lies parallel to flow (DBE, 2002a). The District is currently comparing the TP removal performance of STA-1W cell 4 during these two periods to determine if the compartmentalization affected any change in TP removal.

STA-1W, Cell 5 SAV Monitoring

STA-1W cell 5 was inoculated by the District with SAV collected from other parts of STA-1W in 1999. A quantitative survey of SAV colonization at the 120 monitoring stations established in STA-1W cell 5 has been conducted quarterly since early 2000 (DBE, 2002a).

In addition to the qualitative survey, four quantitative biomass assessments at 25 stations throughout the wetland were also performed between August 2000 and May 2001. *Ceratophyllum* was present at the highest mean standing crop biomass, at 58 g dry wt./m^2, followed by *Najas* (45 g dry wt./m^2) and *Hydrilla* (6.9 g dry wt./m^2). Unlike the standing crops of *Ceratophyllum* and *Najas*, which appeared relatively stable from August 2000 through May 2001, the standing crop biomass of *Hydrilla* steadily increased during the monitoring period (DBE, 2002a). The District has continued monitoring of the vegetation percent cover, biomass, and species type to track changes in vegetation over time. This information will be used in serial comparisons to determine the effect these factors might have on TP removal efficiency.

PROCESS MODEL FOR SUBMERGED AQUATIC VEGETATION

Background and Objective

A dynamic simulation model for SAV systems was developed as part of the District's SAV research contract. This simulation model is hereafter referred to as the Process Model for Submerged Aquatic Vegetation (PMSAV). The goal for PMSAV development was a mathematical representation of essential hydraulic and phosphorus removal processes in SAV systems. The model enables a predictive capability for the performance of future SAV systems that will likely operate with different operational conditions (pulsed inflows, higher influent concentrations, and improved internal hydraulics) than those observed in SAV data sets during past years (DBE, 2002a). The primary objective of this model was to use the predictive capability of PMSAV to design the scale-up exercise required in the Supplemental Technologies Standard of Comparison (STSOC) and was not intended to provide engineering designs for basin-scale decisions.

Some significant features of PMSAV include the following:

- Representation of two P removal pathways: a biologically mediated pathway and a sedimentation pathway. The biologically mediated pathway aggregates plant uptake and co-precipitation processes. The sedimentation pathway models settling of the particulate TP fraction.
- Aggregated representation of sediment burial and recycle processes.
- Inclusion of biomass and sediment storage relationships from mesocosm and test cell data.
- A hydraulic model specifically aimed at modeling the well-documented, detrimental effects of hydraulic short-circuiting in STA-1W cell 4. This feature enables estimation of "intrinsic" rate constants from the STA-1W cell 4 data that would otherwise be tainted if the short-circuit were not explicitly modeled.

The details on the PMSAV model are presented in the SAV Follow-on Study Final Report (DBE, 2002a).

Model Description

PMSAV is comprised of three modeling components: hydrologic, hydraulic, and P-cycling components. The hydrologic component simulates the overall daily water balance in the modeled wetland. The hydraulic component simulates the internal movement of water through the treatment cell using a modified TIS approach. The P-cycling component simulates significant phosphorus processes in SAV wetlands, including biologically mediated removal, sedimentation, sediment recycle, and long-term P burial.

HYDROLOGIC WATER BALANCE

Figure 4C-3 shows a diagram illustrating the wetland water balance (DBE, 2002a). The daily inflow, rain, and evapotranspiration (ET) time series are used as input data sets. Seepage is calculated using the Darcy flow equation that assumes the receiving body (which could be either groundwater or the canal along the western levee) is 0.5 m below the bottom of STA-1W cell 4. Daily outflow is calculated using a form of depth-dependent flow equations suggested by Kadlec and Knight (1996). **Table 4C-8** summarizes the description and values for all constants in the water budget formulation (DBE, 2002a).

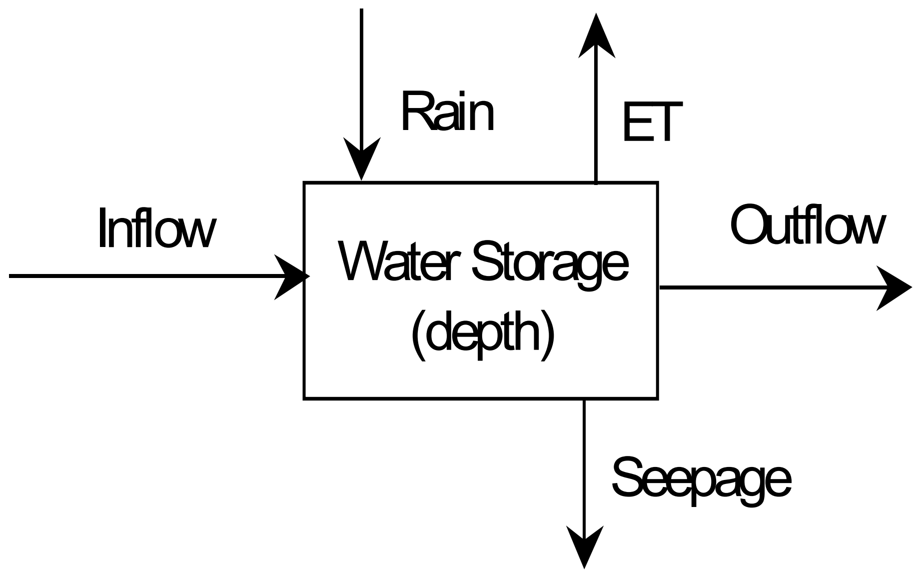


Figure 4C-3. The wetland water balance for the PMSAV model (DBE, 2002a)

Table 4C-8. Summary of coefficients and constants in the SAV hydrologic for STA-1W cell 4 model (DBE, 2002a)

Constant	Description	Unit	Value
A	Wetland surface area	m^2	1.46 E6
w	Average wetland width	m	700.0
d_m	Wetland depth below which there is no outflow	m	0.40
d_s	Assumed stage differential for Darcy seepage flow estimation	m	-0.50
K_{seep}	Coefficient for magnitude of seepage flows	1/d	0.002*
K_o	Coefficient for magnitude of wetland outflows	-	0.75*
a	Exponent for depth dependent hydraulic resistance in outflows	-	3.50*

* Calibrated values for STA-1W, Cell 4

HYDRAULIC PROCESSES

The hydraulic model uses the standard TIS formulation. In the TIS formulation, wetland hydraulic efficiency is modeled as a series of completely-stirred-tank-reactors (CSTRs) (Kadlec and Knight, 1996). The hydraulics component of PMSAV has been formulated with specific features to mathematically model these processes. **Figure 4C-4** shows a schematic diagram of 4 hydraulic processes (DBE, 2002a). Flow is modeled in the wetland, with two parallel pathways: vegetated treatment and non-vegetated short-circuit pathways. The treatment zones are modeled as a three tanks-in-series (TIS) system. The short-circuit zones are presumed to display more plug-flow hydraulics, and are therefore modeled as a 9-TIS pathway shunt that progresses in parallel with the treatment zones. The equations that describe flow through vegetated and open-channel regions suggest that the flow proportioning between treatment and short-circuit zones may be dynamic and depth-dependent. It is likely that flow through the cell's short-circuit behaves as an open-channel and could therefore be described using Manning's equation. **Table 4C-9** summarizes the calibration coefficients used in the equations (DBE, 2002a).

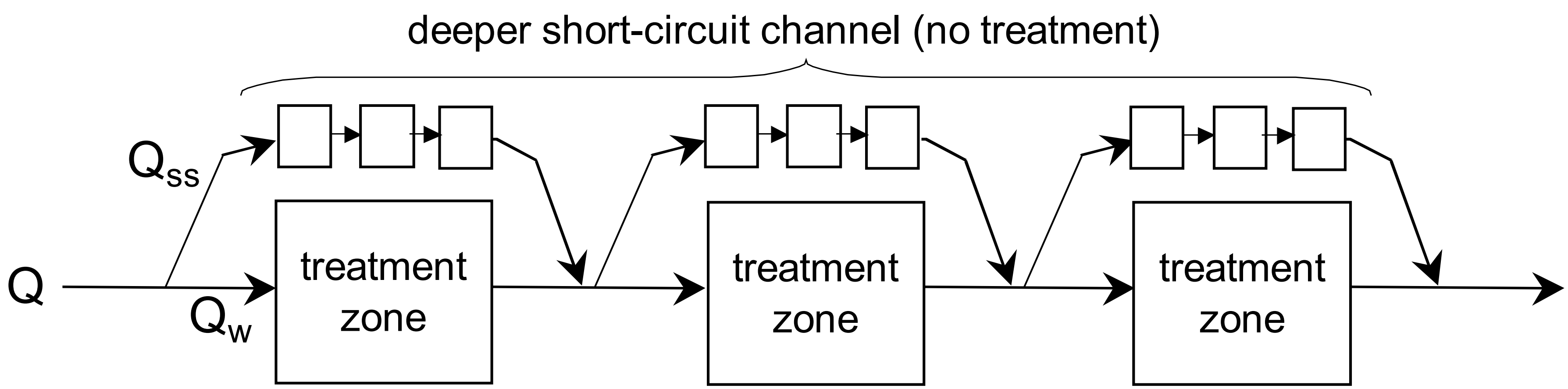


Figure 4C-4. PMSAV hydraulics model includes standard TIS formulation and STA-1W cell 4 hydraulic processes, which accounts for parallel treatment and short-circuiting pathways (DBE, 2002a)

Table 4C-9. Summary of calibration coefficients and parameters for SAV project STA-1W, Cell 4 hydraulic model (DBE, 2002a)

Constant	Description	Unit	Value
f_{area}	Fraction of total wetland area occupied by the short-circuit channel	-	0.08
d_{ss}	Additional depth in short-circuit channel below ground level of treatment region	m	1.20
C	Combined constant that determines short-circuit flow distribution.	-	50.0
f_{flow}	Fraction of total wetland flow passing through the short-circuit channel	-	0.26

P CYCLING PROCESSES

Figure 4C-5 shows a diagram of P removal processes modeled in PMSAV (DBE, 2002a). These processes are modeled in each of the "treatment zones" shown in **Figure 4C-4** (DBE, 2002a). There are three active storage compartments of P modeled in PMSAV: water column, biomass tissue, and active sediment storage. The P stored by burial is also storage, but it is assumed to be an inactive, long-term deposit. SAV biomass is modeled separately from plant P, as PMSAV simulates variable P removal as a function of water column concentration (luxury uptake), implying variable plant P concentrations.

Influent, effluent, rain-based, and seepage flows of P are calculated using daily water flow rates from the water balance model. Simulated biomass growth uses a modified Monod formulation, including a linear growth rate (proportional to biomass standing crop) modified by nutrient (P) limitation. Simulated P limitation uses a standard half-saturation constant formulation. Biomass burial (senescence) is proportional to the square of the standing crop.

Biologically mediated removal is a lumped pathway accounting for both P uptake and co-precipitation processes. Plant P storage assumes an instantaneous removal rate proportional to the product of water column P concentration. The instantaneous uptake rate is a linear equation. At very low ambient P concentrations, P is limiting and uptake occurs to maintain minimum tissue P content. At higher ambient P concentrations, P is not limiting and luxury uptake occurs. It is assumed in the model that P is lost from biomass tissue based on the daily rate of burial and daily average tissue P concentration. The sedimentation pathway includes settling of particulate P. This pathway is modeled as a first-order process proportional to the water column TP concentration. This term can be set to zero when modeling systems with negligible particulate P inflows. P recycled from the active sediment storage is assumed to be linearly proportional to the amount stored. The long-term burial rate from this storage is also assumed linear relative to the storage quantity.

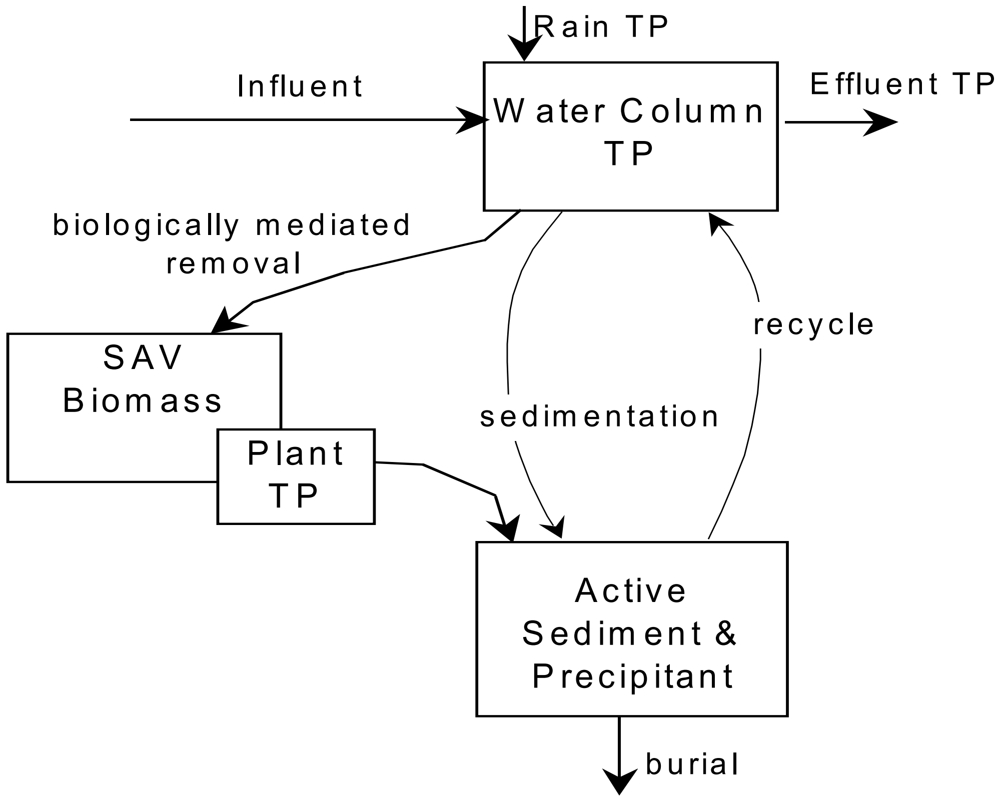


Figure 4C-5. Process diagram for P removal as modeled in PMSAV's treatment zone (DBE, 2002a)

Table 4C-10 summarizes the constants that require calibration in this P cycling processes model (DBE, 2002b).

Table 4C-10. Summary of calibration constants for P cycling processes in the SAV model (PMSAV) (DBE, 2002b). Post-BMP values were generated using the NTC-15 data set, while the post-STA values used data from STA-1W cell 4

Constant	Description	Unit	Post-BMP Value	Post-STA Value
K_g	Intrinsic growth rate	1/yr	5.6	5.6
$K_{P-1/2}$	Half saturation constant for P as limiting nutrient in biomass growth	ug/l	25.0	25.0
K_s	Biomass burial coefficient	m2/g-SAV/yr	0.0035	0.0035
K_u	Luxury uptake coefficient	m3/g-SAV	0.08	0.08
K_c	Sedimentation coefficient	m/yr	20.0	20.0
G	Sediment turnover rate	1/yr	5.0	5.0
B	Sediment burial fraction	-	0.30	0.42

PMSAV Limitations

As with all models, simulation results should be used and interpreted only with a good understanding of the model's strengths and weaknesses. There are several limitations in the formulation of PMSAV and it is important to identify and state them. In terms of P removal processes, the model has two significant limitations. First, total phosphorus was chosen for modeling purpose, rather than a potentially more accurate approach of addressing the P speciation. The data indicated that SRP was removed in SAV systems with relative ease, compared to the more recalcitrant DOP and PP forms. Secondly, while sediment recycle and burial are modeled, internal sediment processes are not.

Further, the data suggest that P recycling from sediment was associated with relative fractions of organic and calcium-bound materials that were present. While including these processes in PMSAV (both speciation and sediment) would have made for a more accurate representation of process understanding, it would also have more than doubled model complexity. It is also important to understand the limitations of the datasets that were used for calibration. The input / output time series of P concentrations are the principle data used for calibration. This data set is supplemented with the measurements of biomass, tissue-P, and sediment that were made (at infrequent intervals) on numerous platforms for SAV systems within the last few years.

Additionally, the model does not account for the large-scale, stochastic natural and human-caused events that have occurred during calibration periods and which could have substantially influenced TP removal on short- and long-term scales.

Model Structure

The differential equations used in the model were expressed as finite difference equations and were coded as a Visual Basic macro within Excel spreadsheets. Input data for the model, including data sets and coefficients, are contained in the spreadsheets. After input parameters, such as calibration coefficients, are entered or changed, the simulation macro is executed with a "run" command, which initiates a sequence of reading values from the spreadsheet, executing the simulation code and returning simulated output to the spreadsheet. Post-processing analysis and graphs of the output data are contained within the same spreadsheet.

Calibration Data Sets and Procedure

The objective of PMSAV calibration was to produce two calibrated models that would be used for post-BMP and post-STA design purposes. Coefficients from the hydrologic, hydraulic and P-removal components of PMSAV were calibrated with measured inflow and outflow data from two SAV systems: STA-1W cell 4 and NTC-15. Additionally, biomass, tissue-P and sediment data from numerous sampling events in SAV mesocosms and STA-1W cell 4 were pooled to provide guidelines for reasonable values of these storages in the P-removal model.

The more detailed information on the calibration data sets and procedures are presented in the *Final STSOC Report* (DBE, 2002b).

STA-1W CELL 4 DATA SETS

Coefficients in the hydrology model were calibrated to STA-1W cell 4 inflow, outflow and depth data for the period of January 1, 1998 through October 9, 2000. Coefficients in the STA-1W cell 4 hydraulic model were calibrated to data collected in the first STA-1W cell 4 dye tracer assessment conducted between December 16, 1999 and January 14, 2000.

P-removal coefficients for the post-STA model were calibrated to STA-1W cell 4 data from the period of January 1, 1998 through September 30, 2001 (1,368 days). Starting the calibration period in 1998 eliminated start-up artifacts that might have been present in the data set for previous years. Ending the calibration period in September 2001 utilized the most complete data available at the time of calibration. Input (G-254) and output (G-256) flow data were used. The entire weekly composite TP samples for influent and effluent TP concentrations were used. A daily inflow time series for TP concentrations was constructed by assuming that the value of a composite measurement applied to all days prior and up to the last measurement date.

NTC-15 DATA SETS

NTC-15 was the largest experimental scale available to represent wetland performance when treating post-BMP stormwater runoff. Therefore, NTC-15 data from the period of July 1, 2000 through September 14, 2001 (440 days) were used to calibrate the model. In April 2000 a limerock berm was constructed in NTC-15. NTC-15 was re-flooded in late-April after berm construction was completed. The calibration period began 2.5 months after re-flooding and concluded with the end of the monitoring period. For post-BMP calibration, only the pre-berm footprint of NTC-15 was used.

Hydrologic data for the model were obtained by field measurements. Data for the NTC-15 hydraulic model were provided by multiple dye tracer studies in the SAV test cells. These studies were performed in late 1999. Inflow and outflow TP data for NTC-15 were also measured. Outflow concentrations from the pre-berm footprint were based on a time series of composite samples collected at three stations located along the upstream width of the berm.

CALIBRATION PROCEDURE

The three PMSAV components were calibrated sequentially. The hydrology model was calibrated first, followed by the hydraulics model and finally the P-cycling model. Calibration proceeded in a similar fashion for each of the three model components (hydrologic, hydraulic, and P removal). Coefficients were manually tuned in a progressive sequence of coarse-to-fine adjustments until desirable calibration was achieved. Each model component had specifically defined calibration criteria, discussed below, that were used to guide coefficient adjustments. Since rigorous mathematical optimization algorithms were not used, the calibration results should be considered "near optimal."

PMSAV Calibration Results

STA-1W, CELL 4 HYDROLOGIC MODEL

There were four criteria for calibrating the hydrologic model to STA-1W cell 4 outflow and depth data:

- The mean simulated wetland depth should be equal to the mean measured depth during the calibration period (± 0.01 m).
- The goodness-of-fit between simulated and measured depth time histories should be maximal. Two graphical goodness-of-fit measures, (cross plots of observed and simulated values and plots of model residuals against simulated values) were used. From these two graphs, two numeric goodness-of-fit values (the coefficient of determination [r^2] and the average absolute residual) were obtained.
- The simulated time histories should be as visually similar to the data as possible.
- Net inflows and outflows in the water budget should balance.

Calibrated values for the hydrologic coefficients are given in **Table 4C-8** (DBE, 2002a).

STA-1W, CELL 4 HYDRAULIC MODEL

The STA-1W cell 4 hydraulic model was calibrated using data from the December 1999 dye tracer assessment. There were three calibration criteria:

- The coefficient of determination (r^2) calculated from a cross plot of simulated versus measured values of effluent tracer concentration should be as high as possible.
- The simulated tracer response curve should have good visual correlation with the measured tracer response curve.
- The dye recovery fraction should be the same as measured for that assessment (72 percent).

Calibrated values for the hydraulic model coefficients are shown in **Table 4C-9** (DBE, 2002a). The STA-1W cell 4 hydraulics model provides an excellent fit to the measured data (r^2 = 0.99), with the combined constant (c) value of 50. Note that the calibrated model suggests that during the tracer assessment period, 8 percent of the STA-1W cell 4 area was occupied by short-circuit pathways, and also that 44 percent of the total wetland flow passed through these pathways. However, a value of 150 for the combined (c) was determined to represent short-circuit flow distribution in the model for the entire post-STA calibration period. This value provided improved fit to TP concentration data, with a short-circuited flow fraction of 44 percent, representing an average value over the post-STA calibration period (a dynamic time history).

POST-STA PHOSPHORUS REMOVAL

There were four criteria for calibrating PMSAV to the STA-1W cell 4 data set:

- The simulated flow-weighted mean effluent TP concentration must equal the measured flow-weighted effluent concentration for the calibration period (± 0.2 μg/L).
- The goodness-of-fit between simulated and measured TP time histories should be maximal. Two graphical goodness-of-fit measures – cross plots of observed and simulated values and plots of model residuals against simulated values – were used. From these two graphs, two numeric goodness-of-fit values – the coefficient of determination (r^2) and the average absolute residual – were obtained.
- The simulated means for PMSAV storages (biomass, plant P, and sediment) must compare favorably with data collected in SAV mesocosms and STA-1W cell 4.
- Since there is considerable scatter in the mesocosms and STA-1W cell 4 data, a loose criterion such that simulated values fall sensibly within the range of observed values was employed.

The post-STA simulation was conducted using a three-year start-up period (February 1995 through December 1997) before the calibration period (January 1998 through October 2001). Initial conditions were prescribed for the beginning of the start-up period (SAV biomass = 10 g/m^2, Sediment P = 0.1 g/m^2). The values for initial conditions affected simulated TP values during the start-up period, but not during the calibration period.

Calibrated values of the key P-removal process parameters for the post-STA PMSAV calibration are shown in **Table 4C-10** (DBE, 2002b). **Figure 4C-6** shows a comparison of the simulated and measured effluent TP time histories (DBE, 2002b). For the calibration period, the simulated flow-weighted mean effluent TP concentration was 21 μg/L (flow-weighted mean), which equaled the observed value. A plot of simulated and observed TP concentrations yielded the (r^2) coefficient of determination of 0.31 (for the calibration period). A plot of the model residuals provided the mean predictive error of approximately 6 μg/L. In general the residuals appear to show a random distribution in relationship to the predicted response (outflow concentration), with no noticeable bias towards either high or low values. This is the desired condition and tends to indicate a well-formulated model. When the mean simulated biomass and plant P and the annual rate of sediment P accumulation was compared to measured values from mesocosm and STA-1W cell 4 data, they indicated that the simulated values correspond to the average values calculated within each of the three wetland tanks. In all cases, the PMSAV simulated values are within the boundaries of observed values and compare well with field measurements.

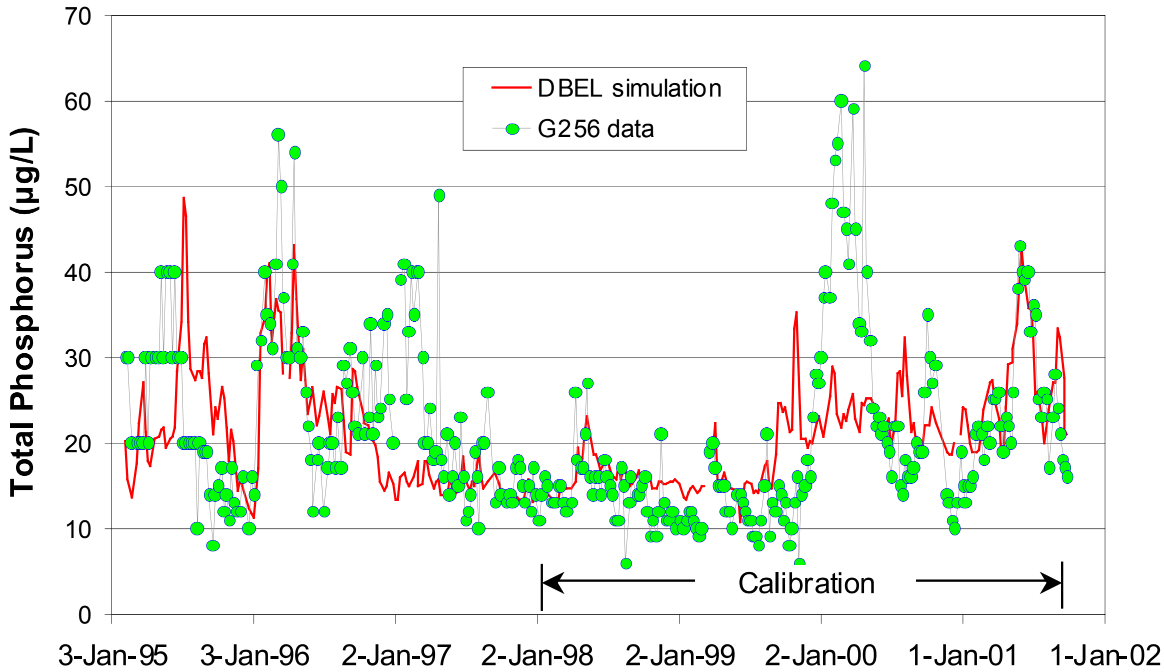


Figure 4C-6. Post-STA calibration of PMSAV to the cell 4 data set (DBE, 2002b)

NTC-15 HYDROLOGY MODEL

The PMSAV hydrology model was modified to accommodate the various weir elevation (stage) changes that occurred throughout the NTC-15 calibration period. Wetland depths were "forced" to match measured NTC-15 depths and outflow water volumes were calculated by difference. As a result, the hydrology model for NTC-15 was not "calibrated", per se, but rather forced to match measured conditions.

NTC-15 HYDRAULIC MODEL

NTC-15 does not exhibit the hydraulic short-circuiting that was evident in STA-1W cell 4. As a result, the STA-1W cell 4 Hydraulic Model was not employed for NTC-15 modeling, but instead used the simpler TIS approach. Data measured in the first tracer assessment on the four SAV test cells indicated their hydraulic efficiency could be represented with TIS values between 1.7 and 3.3 (average value of TIS = 2.5). The specific value for NTC-15 from this assessment was TIS = 1.7, the lowest measured. In the time between the tracer assessments and the model calibration period, NTC-15 was partially drained for limerock berm construction, re-flooded and then restocked with vegetation. Consequently, this data could not be used for hydraulic calibration. Therefore, a value of TIS = 2 was assumed for post-BMP calibration to NTC-15 data.

POST-BMP PHOSPHORUS REMOVAL

The calibration criteria to the pre-berm NTC-15 data were identical, as discussed above, for post-STA calibration. The post-BMP calibration was conducted assuming a steady-state condition in NTC-15. "Steady state" means the system was past start-up, and P removal was due primarily to long-term burial rather than biomass grow-in. Before berm construction (April 2000), NTC-15 had been flooded for more than a year and appeared to be a stable SAV community. During berm construction, NTC-15 was partially drained for a 10-day period and was immediately re-flooded. While there were indications of "burning" on exposed SAV plants during the drained period, there were also indications of healthy and ubiquitous SAV below the "burned" mats. The post-

BMP calibration period using NTC-15 data initiates approximately 2.5 months after re-flooding, and it was assumed that the system was at or close to steady state at that time. To simulate steady-state conditions in PMSAV, the post-BMP calibration model was run for several iterations, where average values of model storages (biomass, plant P, sediment P) from the previous iteration were used as initial conditions for the next simulation. After several iterations this technique achieves steady-state conditions and eliminates sensitivity of calibrated values to initial conditions.

Calibrated values for the post-BMP are shown in **Table 4C-10** (DBE, 2002b). Note that the principal difference between NTC-15 and STA-1W cell 4 calibrations is that the latter had a higher burial fraction coefficient. **Figure 4C-7** shows a comparison of the simulated and measured effluent TP time histories (DBE, 2002b). For the calibration period, the simulated flow-weighted mean effluent TP concentration was 25 µg/L (flow-weighted mean), which equaled the measured value. A plot of simulated and observed pre-berm TP concentrations yielded the (r^2) coefficient of determination of 0.67 (for the calibration period). A plot of the model residuals provided the mean predictive error of approximately 4 µg/L.

When the mean simulated biomass, plant P, and sediment P were compared to measured values from mesocosm and STA-1W cell 4 data, they indicated that the simulated values correspond to the average values calculated within each of the three wetland tanks. In all cases, the PMSAV-simulated values are within the range of observed values and compare well with field measurements.

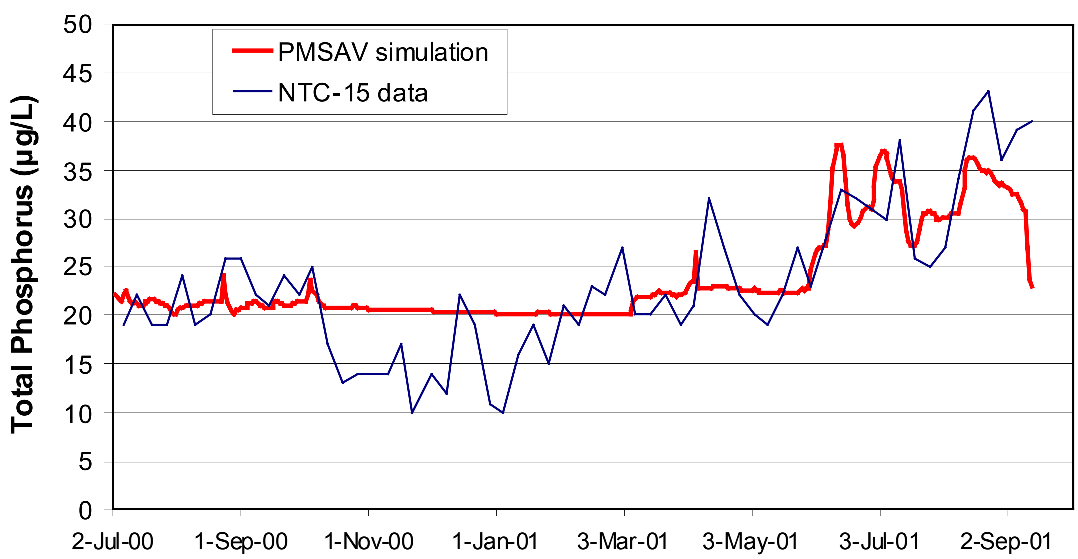


Figure 4C-7. STA-1W, NTC-15 simulated versus measured effluent TP for the PMSAV model (DBE, 2002b)

More detailed information on the PMSAV model calibration is presented in the Final STSOC Report (DBE, 2002b).

Sensitivity Analysis

Table 4C-11 shows the results of a sensitivity analysis of PMSAV TP predictions to coefficient values (DBE, 2002b). The values for post-STA (STA-1W cell 4) calibration coefficients were varied one at a time by +50 percent and –50 percent of their nominal values. These new modified values were used to predict STA-1W cell 4 outflow concentrations. The values in **Table 4C-10** express the percent change in predicted TP outflow as a result of the new coefficient values (DBE, 2002b). Model parameters are listed from least to most sensitive in the table.

Table 4C-11. Sensitivity of simulated TP to +/- 50% change in model coefficients using post-STA calibration for the SAV forecast model and the STA-1W cell 4 data set (DBE, 2002b)

Constant	Description	Value	% Change in Simulated Outflow Concentration	
			-50%	+50%
g	Sediment turnover rate	5.0/yr	- 2 %	+1 %
K_c	Sedimentation coefficient	20.0 m/yr	+ 3 %	- 3 %
c	Short-circuit flow distribution	150.0	+ 12 %	- 5 %
b	Sediment burial fraction	0.30	+ 18 %	- 11%
K_s	Biomass burial coefficient	0.0035 m^2/g-SAV/yr	- 25 %	+ 17 %
$K_{P-1/2}$	Half saturation constant for P as limiting nutrient in biomass growth	25.0 µg/l	- 25 %	+ 18 %
K_u	Luxury uptake coefficient	0.08 m^3/g-SAV	+ 30 %	- 15 %
K_g	Intrinsic growth rate	5.60/yr	+ 60 %	- 28 %

More detailed information on sensitivity analysis is presented in the *Final STSOC Report* (DBE, 2002b). The PMSAV model was designed to provide information needed in the scale-up exercise associated with the SAV Standard of Comparison discussed in the next section.

SAV STANDARD OF COMPARISON

The Supplemental Technology Standard of Comparison (STSOC) was designed to ensure the ATTs could be compared against each other. The STSOC identified nine evaluation concepts (five primary and four ancillary) that were to be addressed:

PRIMARY EVALUATION CONCEPTS

- The level of TP concentration reduction achievable by the technology (as determined from experimental data)
- The level of TP load reduction (as derived from model data)
- Compatibility of the treated water with the natural population of aquatic flora and fauna in the Everglades
- Cost effectiveness of the technology
- Implementation schedule

ANCILLARY EVALUATION CONCEPTS

- Feasibility and functionality of the full-scale design and cost estimates
- Operational flexibility
- Sensitivity of the technology to fire, flood, drought, and hurricane
- Level of effort required to manage, and the potential benefits to be derived from, side streams generated by the treatment process

The full-scale design was based on the STA-2 footprint. Refer to Chapter 8 of the 2000 and 2001 ECRs and Chapter 4C of the 2002 ECR for a more detailed description of the STSOC methodology (Gray and Coffelt, 2000; Coffelt et al., 2001; Jorge et al., 2001). These preliminary estimates were made for comparative purposes only and were not intended to serve as a final design scenario.

SAV/LR Treatment System Performance

Data used for the STSOC analysis were collected from several STA-1W platforms ranging from mesocosms, test cells (0.2 ha), and full-scale SAV wetlands (147 ha to 930 ha). This information was used to document the P removal performance of SAV/LR systems and to define the main biogeochemical, hydraulic and ecological processes that influence the performance and sustainability of SAV wetlands. In this STSOC analysis, SAV/LR systems are used in a post-BMP application (direct treatment of farm runoff with TP of 122 μg/L), as well as in a polishing, post-STA application (treating inflows with TP of 50 μg/L and lower).

Key data on post-BMP performance of SAV/LR were collected in (NTC-15), a 0.2-ha SAV wetland operated at a mean hydraulic loading rate of approximately 11 cm/d. During the STSOC monitoring period, NTC-15 reduced TP concentrations from 73 to 23 μg/L. Mass P removal during the calibration period averaged 2.1 g P/m^2-yr; the mean percentage of P removal by the SAV wetland was 64 percent. Data on post-STA performance was obtained from STA-1W cell 4, a 147-ha (363-ac) wetland that has supported a stable SAV community since at least 1995. Mean TP inflow and outflow concentrations for the wetland for its entire operational period (2/1/95 through 9/30/01) were 52 and 22 μg/L, respectively. Mass P removal by STA-1W cell 4 during this period of record averaged 1.6 g P/m^2-yr, with a mean TP removal rate of 62 percent. The best performance of this system occurred in 1998 and 1999, when it provided a mean flow-weighted outflow TP concentration of 14 μg/L (DBE, 2002b).

Full-Scale SAV Conceptual Design

Using P removal, hydrologic, and hydraulic data from two principal platforms – NTC-15 and STA-1W cell 4 – the designated PMSAV was developed to predict P removal performance and footprint requirements for SAV wetlands treating post-BMP and post-STA waters (DBE, 2002a). STSOC post-BMP design was based on TP inflow and outflow concentrations from NTC-15, with means of 122 μg/L and 26 μg/L, respectively. Based on this data and the STA-2 10-year period-of-record (POR) inflow database stipulated by the STSOC, the PMSAV model predicted that an SAV wetland would require a total of 1,770 ha (4,375 ac) to reduce the post-BMP inflow water to 26 μg/L. STSOC post-STA design utilized inflow and outflow TP levels of 50 and 20 μg/L, respectively, based on performance of STA-1W cell 4 during the entire operational period and the STSOC verification period. Based on this data and on the STA-2 10-year POR inflow database stipulated by the STSOC, the PMSAV model predicted that an SAV wetland would require 1,275 ha (3,150 ac) in addition to STA-2 (2,602 ha) to treat EAA runoff to 20 μg/L.

Because the model simulations indicate that footprint requirements of the SAV wetlands are very sensitive to hydraulic characteristics, additional post-STA and post-BMP design scenarios, with various levels of hydraulic efficiency and varying target outflow concentrations, were developed. An optimum design achieved an outflow TP of 14 µg/L, based on the lowest sustainable effluent concentration (two-year period) from both small-scale (mesocosm) and full-scale (STA-1W, Cell 4) SAV wetlands.

In the optimum post-BMP SAV wetland design using historical STA-2 flow and P load data as input parameters, it is assumed that a full-scale SAV wetland that exhibits good hydraulic efficiency can be deployed. If the TIS could be increased to levels approaching plug-flow, then the total post-BMP area requirement for an SAV wetland that would reduce TP concentrations from 122 to 26 µg/L, with 0 percent bypass, is 1,275 ha (3,150 ac) (DBE, 2002b).

For the optimum post-STA analysis, it was again assumed possible to construct a hydraulically efficient SAV wetland that would be situated after an STA, which in this scenario was STA-2 (2,602 ha). The additional area required for the post-STA SAV wetland to reduce TP concentrations from 25 to 14 µg/L, with 0 percent bypass, was 702 ha (1,735 ac) (DBE, 2002b).

Compatibility of the Treated Water with the Natural Population of Aquatic Flora and Fauna in the Everglades

The STSOC defined compatibility of the treated water with the natural population of aquatic flora and fauna as meeting compliance with Class III water quality criteria, mercury testing, and bio-monitoring (toxicological testing). The SAV technology was in compliance with Class III water quality criteria and did not increase water column total mercury or methyl mercury concentrations (DBE, 2002b). The original STSOC document required specific toxicological tests to be performed as a phase 1 assessment of compatibility. The standard bioassay testing protocol was modified to fit within the STSOC guidelines as required by the FDEP. Bioassay tests were performed following USEPA guidelines, but substituting *C. leedsi* for the fathead minnow, *Pimephales promelas* (EPA/600/4-91/002). Algal Growth Potential (AGP) tests were performed following USEPA guidelines (EPA-600/9-78-018). Specific tests conducted included the following:

- Seven-day Chronic Static Renewal Screen Toxicity Test using the Bannerfin shiner (*Cyprinella leedsi*)
- Seven-day Chronic Static Renewal Screen Toxicity Test using the water flea (*Ceriodaphnia dubia*)
- A 14-day Algal Growth Potential Screen using the unicellular green alga (*Selenastrum capricornutum*)
- A 96-hour Chronic Static Non-renewal Screen Toxicity Test using the unicellular green alga (*Selenastrum capricornutum*)

Subsequent discussions with the USEPA, the FDEP, the Department of the Interior (DOI) and other stakeholders regarding these tests have resulted in the general agreement that standard toxicity tests may not be applicable to determine compatibility of the water with the downstream receiving water. Additionally, the ATTs were designed to reduce P concentrations to levels that limit green algae growth. The validity of this test for the ATTs should be addressed. Therefore, the results of these tests were inconclusive. Currently, the District is in discussion with the FDEP and the DOI to design an experiment that would address this concern.

Implementation Schedule

It is estimated that deployment of the SAV technology within the STA-2 footprint will require approximately 38 months. However, an additional one to three years will likely be required to achieve a fully functional SAV wetland (DBE, 2002b). The duration of this start-up period will depend on the existence of a suitable SAV inoculum within the footprint, on antecedent P levels in the soil (i.e., residual fertilizers), and on the location along the inflow-outflow gradient (i.e., a post-BMP wetland will achieve outflow concentration targets sooner than a post-STA system).

Feasibility and Functionality of Full-Scale Design

With STA-1W cell 4 (147 ha) and cell 5b (930 ha), the District has demonstrated that construction and maintenance of SAV wetlands is feasible at the STA scale. Long-term functionality also has been demonstrated, since STA-1W cell 4 has proven robust and effective in removing TP concentrations down to 22 µg/L for a six-year period. Because STA-1W cell 5 has only been operational since July 2000 and the vegetation biomass is still increasing, the District has not used STA-1W cell 5 to demonstrate long-term functionality.

Operational Flexibility and Sensitivity to Fire, Flood, Drought and Hurricane

Properly compartmentalized SAV wetlands will be less sensitive to wildfires and hurricanes than an emergent macrophyte-based STA. Flood resistance will be comparable to that of existing STAs. Submerged vegetation will be susceptible to drought; the recovery period of the SAV community in the mesocosm study was at least four to six weeks (SAV species specific). By contrast, drydown may be a key strategy for consolidating sediments at the front end of any vegetated STA community. With the exception of gradual sediment accumulation, SAV wetlands will not produce residual byproducts.

Cost Effectiveness

Both the size of the wetland and the 50-year present worth were calculated based on inflow bypass scenarios of 0 percent, 10 percent, and 20 percent. In this conceptual scenario, the bypassed water was not blended with the wetland outflow or incorporated into any hydraulic calculations, such as HLR or HRT. The 50-year present-worth cost for the STSOC post-BMP SAV system that reduced mean TP outflow concentrations to 26 µg/L with 0 percent bypass (without STA-2 costs) is $4,167,704, or $1.80 per pound of P removed (**Table 4C-3**). For the STSOC post-STA wetland used to reduce TP levels from 50 to 20 µg/L with 0 percent bypass, the 50-year present worth cost (without STA-2 costs) is $72,933,064, or $114/lb of P removed. The 50-year present-worth cost for the optimal SAV (an STA completely vegetated with SAV, assumes a nearly plug-flow hydraulic efficient system, and results in mean TP outflow concentrations of 14 µg/L) with 0 percent bypass, is $23,537,214 (without STA-2 costs). The cost of removing P on a "per-pound" basis for the optimal scenario (assuming outflow TP of 14 µg/L with 0 percent bypass, and omitting STA-2 costs) is $9/lb of P removed.

RESEARCH ON NATURAL SAV SYSTEMS

Current research on SAV treatment technology focuses on constructed systems that have been operated from two to seven years (Gu et al., 2001). However, information on long-term P removal performance and water quality conditions is lacking and must be obtained through the investigation of natural SAV systems. Therefore, the District has initiated three studies that aim to obtain information on environmental conditions, P removal performance from surface waters, and sediment in aquatic systems dominated by SAV in Florida, in addition to the District Lake Okeechobee SAV research. Findings from these studies will be helpful in the design, management, implementation and optimization of field-scale SAV-dominated treatment wetlands. Preliminary results of the three studies are summarized below.

Water Quality Conditions in Shallow SAV Lakes

Florida has more than 7,700 lakes that range in size from 4 ha to more than 180,000 ha (Canfield and Hoyer, 1992). Many of these are shallow lakes that are vegetated with SAV. In this investigation, the database from Florida Lakewatch, a citizen's lake monitoring program operated by the University of Florida's Department of Fisheries and Aquatic Sciences, are used. The objectives of this analysis are to reveal community structure (species composition and richness) and to assess relationships between SAV biodiversity, biomass and environmental conditions in Florida SAV-dominated lakes. Information generated from this analysis will be used in creating and managing SAV-dominated wetlands for long-term P removal.

Shallow lakes dominate Florida inland waters, and many of these lakes support the growth of a variety of SAV species. An examination has been made of the physical, chemical and biological conditions of selected SAV lakes using existing data (**Table 4C-12**). The shallow nature of these lakes, high water temperature, and long growth period are among the several key variables that favor SAV growth in this subtropical region. The analysis reveals that eight genera, with approximately 15 species of SAV, inhabit these shallow lakes, which range in size from less than 2 to 2,300 ha. Generally, the SAV community within a lake is occupied predominantly by a single or a few species. *Utricularia* and *Hydrilla* are the most common SAV found in the study lakes. *Ceratophyllum*, *Najas* and *Vallisneria* often dominate lakes with high nutrient concentrations (mean TP = 34 to 53 μg/L), while *Chara*, *Utricularia*, *Potamogeton* and *Myriophyllum* prefer to inhabit lakes with relatively low nutrient concentrations (mean TP = 8 to 13 μg/L). The SAV community found within the STAs is very similar and, with the exception of *Vallisneria* and *Myriophyllum*, contains all these species but generally are dominated by *Najas*, *Ceratophyllum* or *Hydrilla.* Many SAV species grow well in a wide range of water quality conditions, though biomass tended to increase with increasing lake size, pH, alkalinity and calcium concentration (Gu and Newman, in review).

Table 4C-12. Basic statistics of selected environmental variables from 42 study lakes dominated by SAV. Data are taken from Florida Lakewatch (1997)

	Area (ha)	PAC[1] (%)	PVI[2] (%)	SAV (kg wt/m^2)	pH (SU)	Alk (mg/L)	COND (μS/cm)	Color (Pt unit)	Cl (Mg/L)	Fe (mg/L)
Mean	337	74	29	6.0	7.3	38.0	198	20.4	29.9	0.1
Median	111	77	20	4.5	7.4	32.0	153	13.0	21.5	0.0
SD	624	20	24	5.7	1.2	41.3	168	20.8	35.2	0.1
Count	34	42	42	42	39	35	35	33	34	25

	Sulfate (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	TP (mg/L)	TN (mg/L)	CHLA (μg/L)	Secchi Depth (m)	Water Depth (m)
Mean	16.9	10.6	6.5	11.1	3.1	0.021	0.758	12.0	2.4	2.5
Median	11.6	12.5	4.4	7.8	1.6	0.014	0.665	6.0	2.2	2.4
SD	16.8	7.0	9.0	10.3	3.3	0.019	0.389	13.1	1.2	1.4
Count	33	26	26	26	26	42	42	42	41	42

[1]Percent area covered

[2]Percent volume infested

Long-Term P Removal in Natural SAV Systems

The primary objective of this study was to calculate rates of long-term TP removal in selected SAV-dominated systems by analyzing previously collected inflow and outflow water quality data. Specifically, this analysis was designed to answer the following two questions (Knight et al., in review):

1. Have aquatic systems with a history of SAV dominance effectively removed phosphorus and at what rates?
2. How do aquatic systems with a history of SAV dominance respond to changes in TP loading, SAV cover and hydraulic variations?

The overall conclusion of this analysis is that SAV-dominated lakes and rivers typically remove P from the water column, and the likely long-term sink for this P is the newly accreted sediment. These calculated long-term removal rates are higher than those for full-scale wetlands dominated by emergent vegetation. Mass removal rates estimated for SAV-dominated lakes and rivers overlap those from the SAV-dominated constructed wetland and mesocosm studies, but on average are generally lower (**Table 4C-13**). These removals are clearly influenced by inlet P loading rates, both as a function of P inlet concentration and hydraulic loading rate. Based on this analysis, caution is recommended when extrapolating the P removal results from relatively short-term or small-scale studies to the design of full-scale, long-term operating SAV-dominated wetlands (Knight et al., in review).

Table 4C-13. Summary of estimated TP removal performance for select SAV-dominated systems in Florida (modified from Knight et al., in review)

System	HLR (cm/d)	Nominal HRT (d)	Average TP (μg/L)		Mass ($g/m^2/yr$) Loading	Mass ($g/m^2/yr$) Removed	Calc K_1 (m/yr)	C* (mg/L)	Count	Period of Record
Lakes										
Harney	21.6	7.9	72	74	5.68	-0.15	-4.92	0.077	122	1/82-12/98
Hellen Blazes	89.3	2.5	148	134	48.1	7.06	67.21	0.083	84	12/79-9/99
Istokpoga	0.73	218	51	50	0.14	-0.01	0.02	0.018	12	11/72-9/99
Kissimmee	7.3	29	112	61	2.96	1.59	23.44	0.012	14	1/73-7/98
Myakka	16.4	7.3	393	411	23.5	-1.57	-7.50	0.090	52	12/72-9/98
Panasoffkee	1.8	72.6	64	17	0.42	0.20	8.66	0.016	5	5/92-4/93
Poinsett	11.6	9.4	114	82	4.86	0.55	2.33	0.020	138	10/73-5/98
Rodman	8.2	29.3	57	48	1.72	0.17	9.43	0.006	64	9/70-12/98
Sawgrass	73.8	2.0	132	113	35.4	3.92	30.88	0.040	64	12/79-9/99
Seminole	28.9	19.7	54	39	5.66	1.57	32.09	0.025	24	1/72-9/98
Tarpon	1.2	187	121	42	0.52	0.34	4.54	0.010	1	1/96-12/98
Mean	23.7	53.2	120	97	11.7	1.24	15.11	0.036	52.7	
Rivers										
Wekiva	39.6	2.8	193	175	27.9	3.64	28.65	0.058	73	1/80-2/97
Withlacoochee	50.6	2.5	83	65	17.1	3.78	63.24	0.054	35	6/94-6/99
Mean	48.1	2.6	138	120	24.2	3.71	45.94	0.056	54.0	

Sedimentation Composition and P Accrual Rate in an SAV-Dominated Lake

Lake Panasoffkee is a large, shallow, SAV-dominated lake in southwest Florida. The objective of this study was to understand major organic sources and P accrual rates in the Lake's sediment. Two sediment cores and water samples were taken from the lake and were used in ^{210}Pb dating, plant fragment and pollen analysis, P, N and C composition, and stable C isotope ratio analysis (Brenner et al., 2002). The preliminary analyses indicated that the common SAV species (i.e. *Najas, Vallisneria, Potamogeton, Hydrilla, Nymphaea* and *Ceratophyllum*) were present in the lake sediment. Sample analysis has recently been completed and will be reported at a later date.

SUMMARY

Research over the past 12 months has focused on studies of field-scale, SAV-dominated systems (test cells, cell 4 and cell 5 of STA-1W), development of Process Model for SAV (PMSAV), STSOC analysis, and natural SAV systems. Sediment analysis from test cells indicates that P storage and accrual rates were dependent on nutrient and hydraulic loadings, with higher P contents and accrual rates in post-BMP-fed north test cells than in post-STA-fed south test cells. Approximately 70 percent (3.25 to 6.07 g m^2/yr) of TP was removed from the north test cells, indicating that they were extremely effective in P removal under high hydraulic (20 to 22 cm/day) and P (7.5 to 8.3 g m^2/yr). However, only about 20 percent of TP (0.08 to 0.20 g m^2/yr) was removed from the inflow water in the south test cells. It is likely that low inflow TP or SRP concentrations were responsible for the reduced TP removal performance in the south site.

Experiments and analysis of STA-1W cell 4 sediments show that sediment accrual rate averaged about 1.7 and 0.5 cm/yr in the inflow and outflow regions, respectively. Phosphorus sequestered in the SAV community was associated with a fairly stable, Ca-bound sediment fraction. SRP flux from sediment porewater to the water column in the outflow region was a slow process, further demonstrating the sediment's stability.

The studies of natural SAV systems provided important information on P accrual rates, mass balance, and water quality conditions for the evaluation of this ATT. Shallow water depth, high nutrients, pH, calcium concentration and alkalinity favor the growth of SAV species used for treatment in STA-1W. TP removal in natural SAV systems was more effective than systems dominated by emergent plants, but was less effective than the constructed SAV systems.

The STSOC for the SAV/LR provides technology-specific information on P removal performance, cost effectiveness, implementation schedule, and potential toxicity of the technology. This analysis has also addressed secondary evaluation criteria, including feasibility and functionality of design, operational flexibility, sensitivity to natural disasters, and management for any residuals produced by SAV technology.

FUTURE WORK

The District will continue monitoring the performance of the 0.2-ha SAV test cells at STA-1W and will also continue analyzing water quality data from before and after the SAV limerock berms to determine if they are providing any additional TP removal performance. Additionally, the District will continue to optimize the full-scale SAV treatment systems through monitoring and data analysis to improve the P removal performance of these systems.

PERIPHYTON-BASED STORMWATER TREATMENT AREAS

In a periphyton-based Stormwater Treatment Area (PSTA), post-STA water flows over substrate colonized primarily with calcareous periphyton (attached algae) and sparse macrophytes. The latter function primarily as additional substrate and as a stabilizing mechanism for algal mats (**Figure 4C-8**). P is removed from the water column through biological uptake, through chemical adsorption with carbonate associated with the algal photosynthesis and through co-precipitation with $CaCO_3$ within the water column. Findings from the 1996 Desktop Study (PEER Consultants and P.C./Brown and Caldwell, 1996) indicated that the favorable calcitic periphyton could only dominate an STA at very low TP concentrations. Therefore, PSTA research has continued to focus on using PSTAs as polishing cells within, or in addition to, STAs (Jorge et al., 2002).

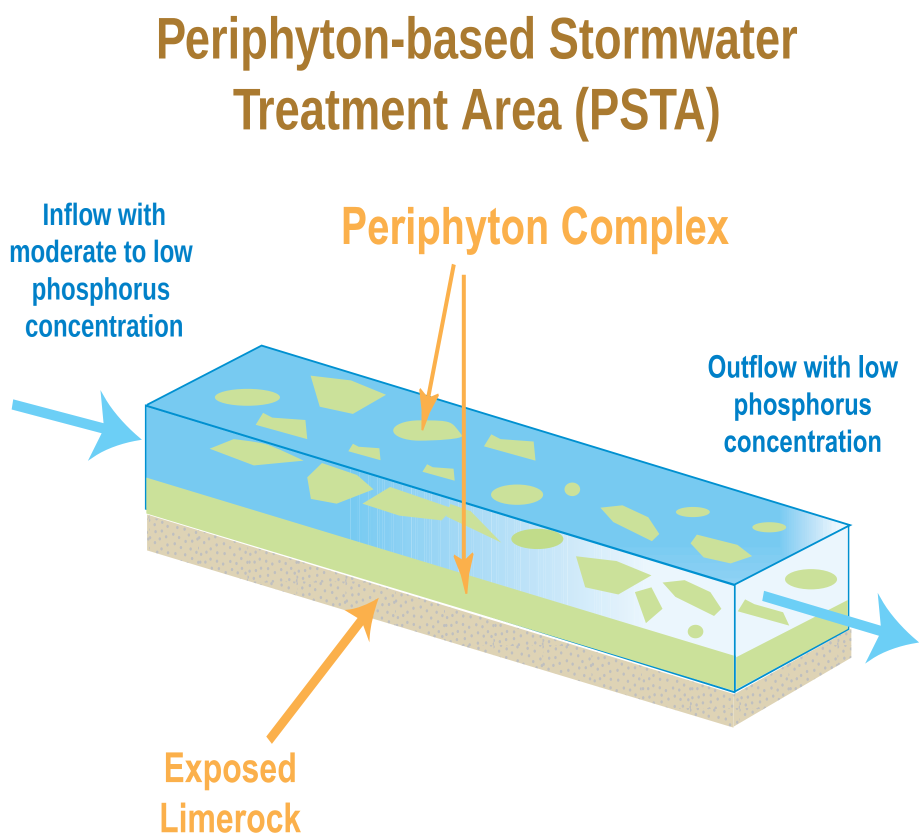


Figure 4C-8. Schematic representation of the periphyton vegetation Advanced Treatment Technology tested at STA-1W and at the field-scale PSTA facility

The PSTA research focus associated with this concept includes the long-term performance and stability of an algal-based system, the level of required maintenance, and macrophyte control needed to prevent shading of the periphyton community (Coffelt et al., 2001). The research has been divided into three phases:

- Phase 1 was an experimental phase and evaluated and provided information to address basic issues associated with viability and treatment performance effectiveness. Experimental platforms included mesocosm tanks and 0.2-ha (half-acre) test cells. For more detailed information on this phase, refer to the 2001 ECR (Coffelt et al., 2001).
- Phase 2 focused on refining the treatments evaluated in Phase 1, and on providing information regarding optimization and validation of the technology. The STSOC analysis was completed at the end of this phase and is summarized below. Routine monitoring of the Porta-PSTAs was completed in early October 2000, while monitoring of the three test cells (STC-03, STC-08 and STC-13) continued through March 2001. For more detailed information on the research performed during this period, refer to the 2002 ECR (Jorge et al., 2002).

- Phase 3 is an 8.1-ha (20-acre) demonstration of the PSTA technology using the information gained in Phases 1 and 2. In Phase 3, large-scale issues, such as construction techniques, effects of cell configuration, and seepage are evaluated in addition to phosphorus removal performance. With the support of Everglades National Park, construction of the 20-acre field site was completed in June 2001. At least two years of field-scale testing will be required to obtain information on the feasibility and function of this concept for scale-up design and operation. Data collection at this scale began in August 2001 and will continue into fiscal year 2003. Data collected within this water year is presented below.

The following sections incorporate data gathered in Water Year 2002 (WY02) and includes the PSTA Forecast Model, the STSOC and the research conducted to date at the field-scale facility.

PSTA FORECAST MODEL

Computer models provide a useful tool for gathering information that cannot otherwise be obtained from experiments. Methods for forecasting PSTA performance range in complexity from single- to multiple-parameter models. One- and two-parameter models were developed, and their calibration results (k_1 and k-C* models) were presented in the PSTA Research and Demonstration Project Phase 1 Summary Report (CH2M HILL, 2000b). Subsequently, an interim PSTA Model was developed and was partially calibrated to provide a more complete and mechanistic method for performance forecasting. This interim model was prepared to provide insight into the ongoing PSTA research, but was subsequently deemed to be more complex than could ultimately be supported by experimental data generated by this study. The interim model was described in the PSTA Research and Demonstration Project 5th Quarterly Report (CH2M HILL, 2000a). A final PSTA Forecast Model was developed, is presented in the PSTA Research and Demonstration Project Phase 1 and 2 Summary Report, and is discussed below (CH2M HILL, 2002a). The primary objective of this model was to use the predictive capability of the model to design the scale-up exercise required in STSOC. The model was not intended to provide engineering designs for basin-scale decisions.

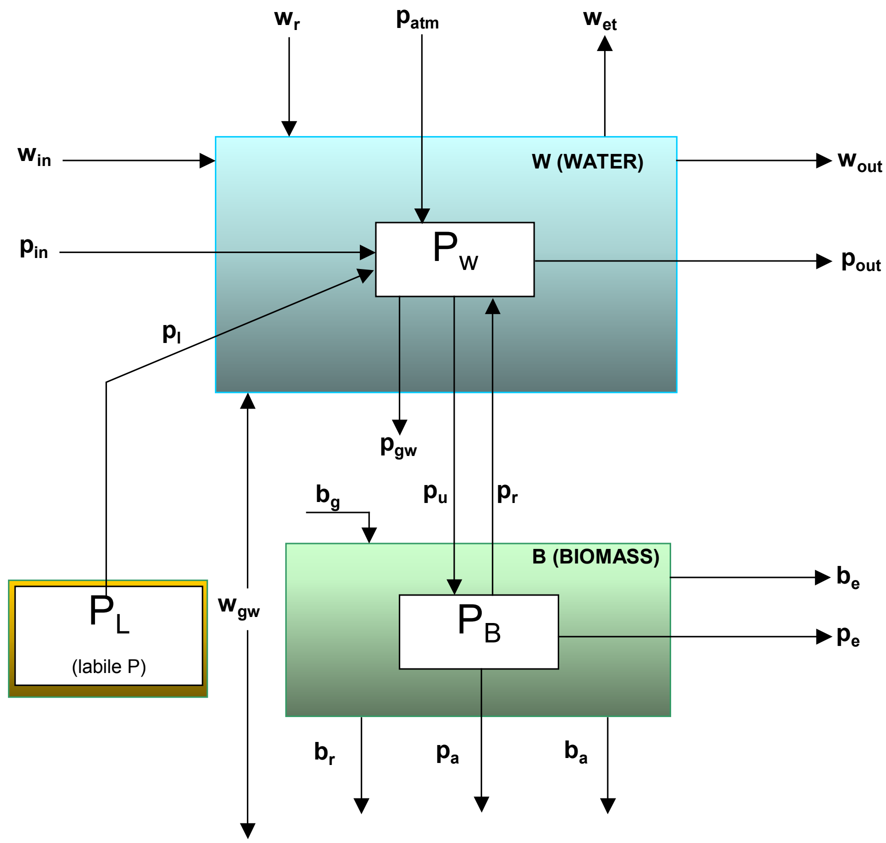
Model Description

The final PSTA Forecast Model was described in an earlier project report (CH2M HILL, 2000a) and includes the following modifications from the previously developed interim model:

- Inclusion of external forcing functions to provide the best understanding of processes that control the natural periphyton-based treatment system, including sunlight (seasonally variable), rainfall (both direct and through stormwater inputs), and atmospheric inputs/outputs (ET and atmospheric P loads)
- Simplifications of the final model to only include predictions of TP data
- Addition of more dynamic water balance with stage-storage relationships
- Consideration of human management influences (construction, water pumping and depth control, biomass removal, maintenance and related actions)

The final model is described in greater detail in the PSTA Research and Demonstration Project Phase 1 and 2 Summary Report (CH2M HILL, 2002a).

Figure 4C-9 shows a diagram representing hydrologic and P removal processes used in the PSTA Forecast Model, along with the major state variable equations and definitions of variables (CH2M HILL, 2002a). The model consists of four principal component storages: water, TP in the water column, periphyton biomass and TP in the biomass. In addition, an initial storage of labile P (PL) is included to allow simulation of start-up releases of TP from pre-existing soils and decaying vegetation. Each of these state variables is described in detail in the following paragraphs. The project Phase 1 and 2 Summary Report (CH2M HILL, 2002a) provides details on the equations used to calculate each pathway or storage component and identifies the data sources available for model calibration. The final model uses Microsoft Excel as an operating platform.



$$\dot{W} = w_{in} - w_{out} + w_r - w_{et} - w_{gw}$$
$$\dot{P}_W = p_{in} - p_{out} + p_{atm} - p_u + p_r - p_{gw} + p_l$$
$$\dot{B} = b_g - b_r - b_e - b_a$$
$$\dot{P}_B = p_u - p_r - p_a - p_e$$
$$\dot{P}_L = - p_l$$

$\dot{W}$ = water state variable
w_{in} = pumped water supply to system
w_{out} = measured outflow from system
w_r = rainfall
w_{et} = evapotranspiration
w_{gw} = groundwater flow

$\dot{P}_W$ = TP in water column state variable
p_{in} = aerial loading rate of TP to water column
p_{out} = TP in outflow from system
p_{atm} = bulk atmospheric deposition of TP
p_u = TP uptake by biomass
p_r = TP returned from biomass to water column
p_{gw} = TP in groundwater

$\dot{B}$ = biomass (ash-free dry weight) state variable
b_g = biomass growth rate
b_r = biomass respiration rate
b_e = harvested biomass export rate
b_a = biomass accretion rate

$\dot{P}_L$ = Labile TP state variable
p_l = TP input from initial labile storage

$\dot{P}_B$ = TP in biomass state variable
p_a = TP accretion in sediments
p_e = TP exported with harvested biomass

Figure 4C-9. PSTA forecast model diagram (CH2M HILL, 2002a)

WATER COLUMN

The water column (W) component is represented by a general water balance equation. The water "state" at any time is the difference between the sum of the flow inputs (pumped inflow and precipitation) and outputs (flow over the weir, ET, and groundwater exchange). No groundwater interactions were used for water budgets for the test cells because the cells were lined. For model calibration, the pumped inflow and outflow over the weir were measured in the field. Water outflow in the model is based on the weir design. The model provides either a horizontal or a v-notch weir. The v-notch weir expression was used to calibrate the model with data from the test cells. The horizontal weir with variable width was used for simulation of larger-scale PSTA systems.

The model utilizes a single, well-mixed tank hydraulic framework. This is based on the single-cell configuration of all the research test units. Actual tracer data from the mesocosms indicated that their tracer residence time distributions could best be described as between 1.4 and 4.1 tanks-in-series (TIS). A 1.8-TIS model was constructed and tested, and it was determined that this model framework did not provide a better fit to the actual operational data than the single, well-mixed tank model. Based on treatment wetland theory, it is currently assumed that higher performance is likely at higher numbers of TIS (Kadlec and Knight, 1996).

WATER COLUMN TP

TP in the water column is described as the concentration resulting from the net effects of the inflow and outflow concentrations, bulk atmospheric deposition, uptake by the biomass, losses to groundwater, and a return from sediments and biomass. Because this is a single, well-mixed tank model, PW (phosphorus water) is equivalent to the outflow TP concentration.

BIOMASS

The biomass (B) component consists of the ash free dry weight (AFDW) (total organic content) of the benthic periphyton mat, epiphytic algae, tychoplankton and detritus. Macrophytic plants are not explicitly included in the model because of the inherent population variability and the limited resources devoted to their measurement. The biomass state variable depends on periphyton growth and respiration rates, algal export from the system measured as total suspended solids (TSS), and accretion of algal solids in the detrital layer.

Periphyton growth is calculated as a function of incident solar radiation (I) using a Monod (Michaelis-Menten) expression, water column TP concentration with a Monod expression, and periphyton biomass. Periphyton respiration is modeled as a quadratic drain (proportional to the periphyton biomass squared). A linear (first order) expression was initially used but was found to result in model instability. The quadratic expression has been found to be an effective model to describe the growth of a variety of ecological plant communities.

Periphyton accretion is a first-order expression based on the total periphyton biomass. Periphyton export includes only periphyton removed by harvesting.

BIOMASS TP

TP in the biomass (PB) depends on uptake from the water column, internal recycling, and losses to respiration (back to the water column), accretion of biomass, and export of biomass in the outflow water. Measured effluent concentrations for TSS were used to derive the export rates.

Periphyton TP uptake is proportional to the product of the water TP (PW) and the amount of periphyton biomass (B). TP lost as a result of periphyton respiration is proportional to the product of the periphyton decay rate multiplied by the concentration of TP in B. Both the TP accretion rate and the export rate are based on the same relationship.

LABILE TP STORAGE

Start-up data from most of the mesocosms indicated that there were initial storages of labile TP (PL) in the antecedent soils that entered the water column upon flooding. These initial storages are modeled as a tank that is initially full of TP, with a single outlet to the water column. This addition to the model helped duplicate the observed start-up behavior not only at the beginning of the project, but also at the mid-point, when the sediments in the peat-based test cell were highly disturbed.

PSTA DRYOUT

The shellrock test cell (STC-03) was operated with a variable water regime that included a drawdown to determine the effects of periphyton dryout. The model was found to be unstable as water levels declined to near dryout conditions. Consequently, a decision was made to incorporate some logic switches to capture the main effects of dryout. Two types of switches are included in the model. The first switch reduces the rates of biomass growth and decay by 90 percent when water depth falls below 1 cm. The second switch stops calculating PW when water levels are less than 15 cm. This switch is necessary to prevent mathematical integration problems associated with zero values.

Calibration Data Sets and Procedure

Data from STC-03, STC-08 and STC-13 for the 24-month operational period were used to calibrate the final model. Each of these cells is approximately 0.2 ha. The Porta-PSTA mesocosms were not used for model calibration because of their relatively small scale and because of the multitude of treatment variables.

The model was calibrated using period-of-record (POR) and optimum performance period (OPP) data from the three test cells. These systems were operated for slightly more than two years. The POR included data from March 1999 through March 2001. The OPP varied slightly for the three test cell treatments. For treatment STC-13 (peat), the OPP included data from July 1999 through January 2000 and from July 2000 through March 2001. For STC-08 (shellrock, constant water regime) and STC-03 (shellrock, variable water regime), the OPP used for calibration was from July 1999 through March 2001. The optimum performance period does not include start-up data from the beginning of the experiment during the stabilization and grow-in phase, nor does it include start-up data immediately following the shutdown and replanting of the peat-based PSTA system.

Calibration was conducted to obtain the best overall fit of the actual and model data by varying the rate constants (i.e., coefficients). Goodness-of-fit was determined by calculating the sum of squares of the differences between individual records. The solver routine in Excel was used to automatically optimize adjustable coefficients to provide the lowest total sum of these individual sums of squares (CH2M HILL, 2002a). POR and OPP average values for the actual data and the model were also calculated and were referred to during model calibration. Various calibration runs were performed and the effects of individual and grouped input parameters on each state variable were examined. The final value selection for the coefficients was based on the best overall fit to all the state variables in the model.

Calibration Results

The following eight coefficients were calibrated for the model:

- P_W,
- k_g (d^{-1}) periphyton biomass growth rate constant
- k_{si} ($E/m^2/d$) half saturation constant for solar radiation I (PAR)
- k_{sp} ($g\ TP/m^3$) half saturation constant for periphyton uptake of water column TP
- k_r (m^2/g AFDW/d) periphyton biomass respiration rate constant
- k_a (1/d) periphyton biomass accretion rate constant
- k_u (m^3/g AFDW/d) periphyton TP uptake rate constant
- k_l (d^{-1}) TP release rate constant from labile storage

The above coefficients are described in greater detail in the *PSTA Research and Demonstration Project Phase 1 and 2 Summary Report* (CH2M HILL, 2002a).

PSTA mesocosm data were analyzed to develop initial estimates for some of these coefficients. Only the shellrock treatment data were reviewed for this range-finding effort. These correlations were found to be unsatisfactory for precise model calibration. Therefore, the final calibration of the model used the Excel Solver routine to adjust all coefficients at one time to minimize the sum of squares for all the major state variables simultaneously.

Figure 4C-10 illustrates a representative PSTA Forecast Model calibration worksheet for test cell 8 (shellrock, constant water depth) (CH2M HILL, 2002a). An additional worksheet was developed and used to overlay model and actual values for a visual assessment of goodness-of-fit. The ability to correlate the model output to actual data from multiple measured parameters provided significant aid in calibration.

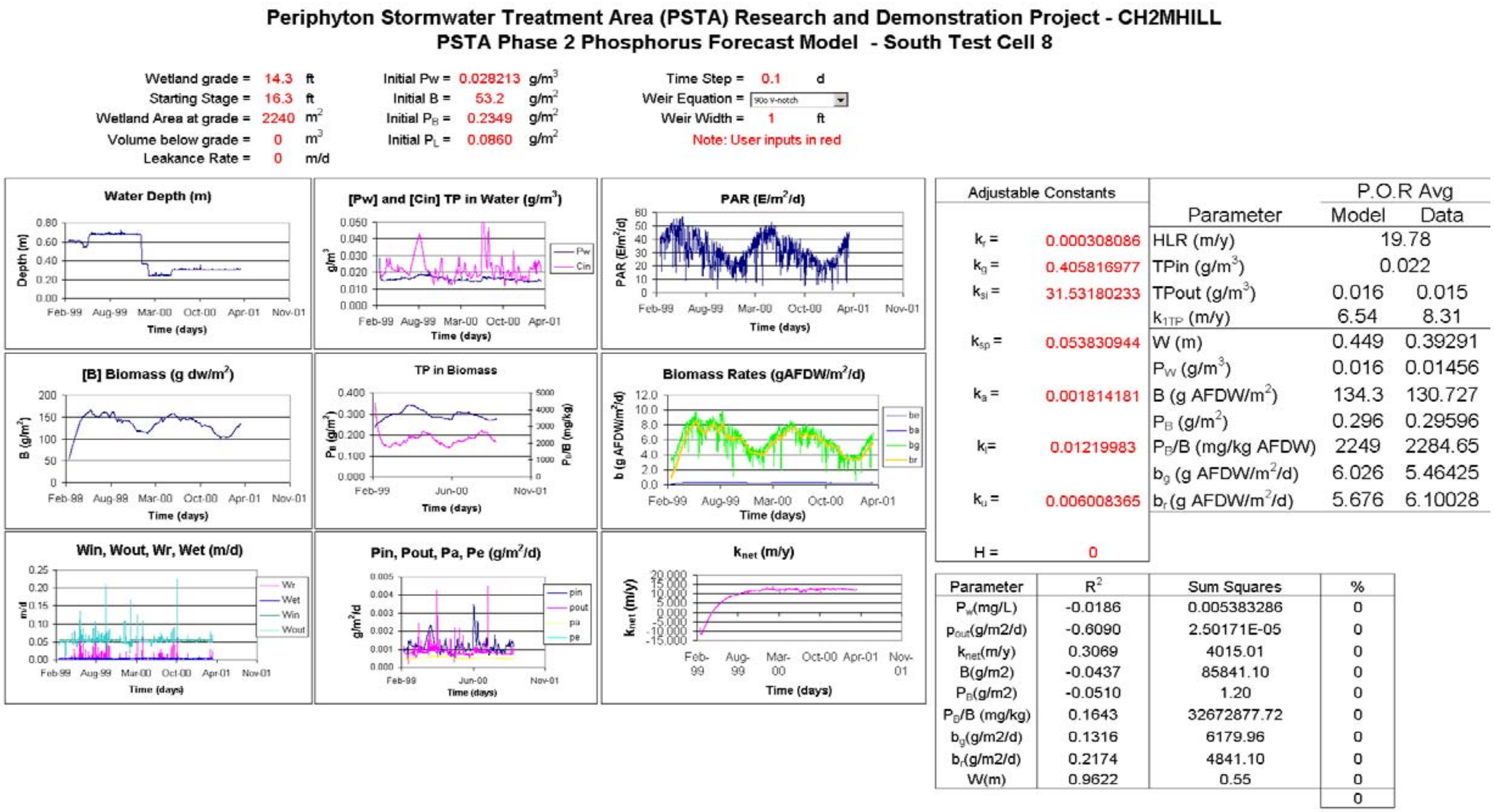


Figure 4C-10. Example PSTA Model Calibration Spreadsheet Illustrating PSTA Test Cell 8 Input Parameters and Model Output (CH2M HILL, 2002a)

Figure 4C-11 shows calibrated model fits for each of the three test cells for the POR data sets (CH2M HILL, 2002a). Comparisons between actual data and model output were performed for W, TP_{out}, k_{1TP}, and b_g. All the general trends in the actual data are reasonably well simulated by the model.

A set of values, for all seven coefficients, representing the initial conditions was developed. This was done for each of the calibration data sets and for both the POR and the OPP. A relatively small range in calibrated model coefficients was found among the three test cells. However, there were noticeable changes between the calibrations for the POR and the OPP.

Sensitivity Analysis

Table 4C-14 shows the results of a sensitivity analysis of the model's calibration coefficients for the shellrock test cell (Test Cell 8 OPP) (CH2M HILL, 2002a). Each coefficient was tested at one-half and at twice its calibrated value. The coefficients that consistently resulted in the largest changes in k_{1TP} and TP_{out} were k_u and k_r. The biological state variables and rates of productivity and respiration were also most affected by changes to the biomass growth and respiration rates (k_g and k_r, respectively) and the light half saturation constant (k_{si}).

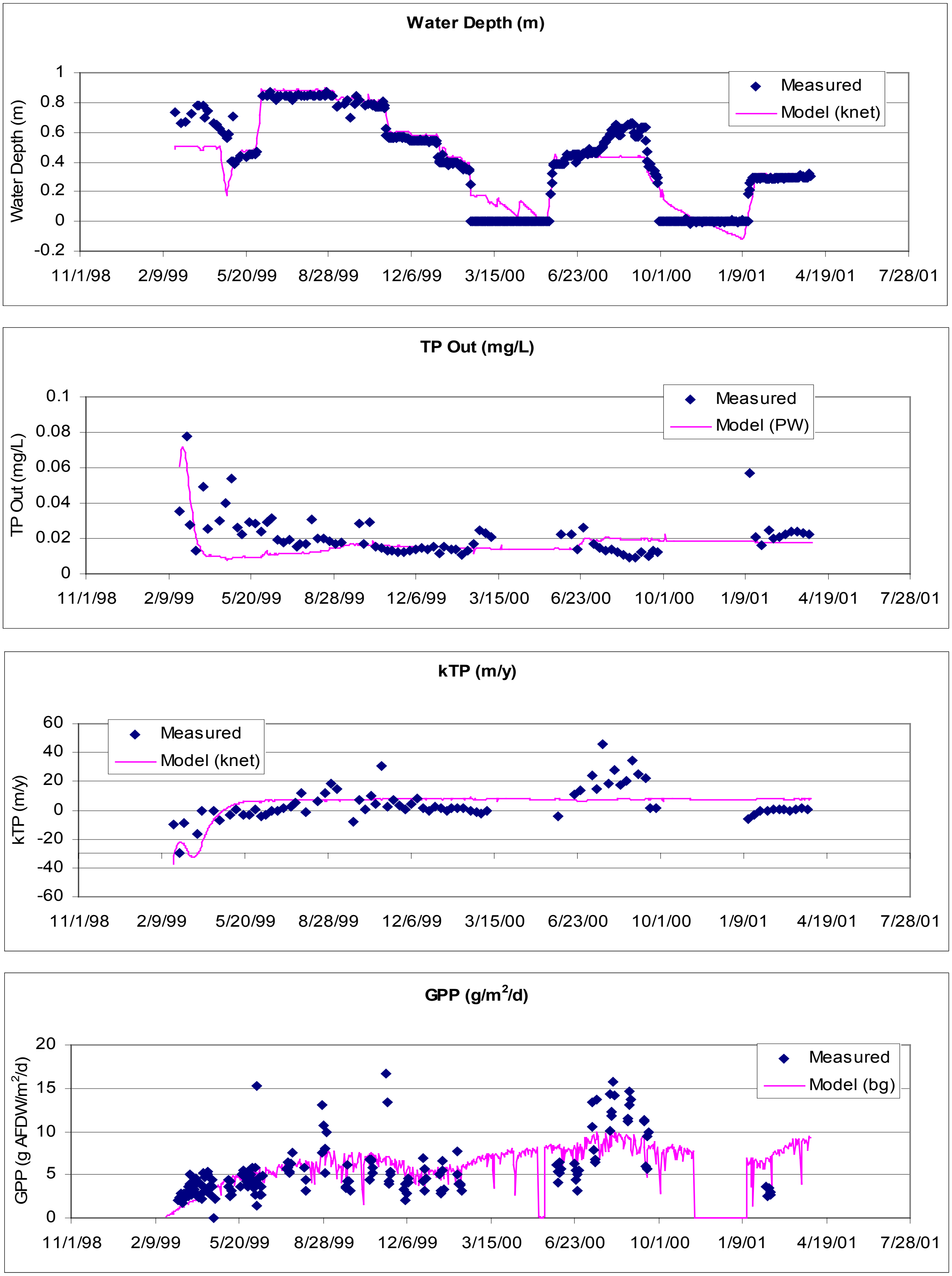


Figure 4C-11. Detailed comparison of PSTA model estimates and actual data from PSTA test cell 3 – shellrock, variable water regime (CH2MHILL, 2002)

Table 4C-14. Sensitivity of model calibration coefficients for PSTA south test cell 8, which had a shellrock base and was operated with a constant inflow loading rate and water depth

Adjustable Constants	Initial Value	Percent Adjustment	Adjusted Value		HLR (m/yr)	TP_{in} (g/m³)	Tp_{out} (g/m³)	k_{1TP} (m/y)	W (m)	B (g AFDW /m²)	P_B (g/m²)	P_B/B (mg/kg AFDW)	b_g (g AFDW/ /m²/d)	b_r (g AFDW/ /m²/d)
				Actual Data Averages	19.8	0.022	0.012	11.8	0.38	128	0.268	2115	5.5	6.6
				Model Averages	19.8	0.022	0.012	11.9	0.41	136	0.296	2261	6.3	6.2
				Delta ? (%)	0.0	0.0	-0.7	1.1	9.8	6.3	10.4	6.9	14.6	-5.9
		50%	0.000488	Model	19.8	0.022	0.015	7.4	0.41	92	0.251	2844	4.3	4.3
K_r	0.000325			Delta ? (%)	0.0	0.0	25.1	-37.6	9.8	-28.1	-6.7	34.5	-22.2	-34.8
		-50%	0.000163	Model	19.8	0.022	0.007	21.6	0.41	265	0.360	1396	12.3	11.7
				Delta ? (%)	0.0	0.0	-39.0	83.1	9.8	107.4	34.2	-34.0	122.5	78.6
		50%	0.230	Model	19.8	0.022	0.012	12.1	0.41	204	0.298	1516	14.3	13.9
K_g	0.154			Delta ? (%)	0.0	0.0	-1.6	2.6	9.8	59.2	11.1	-28.3	157.6	111.1
		-50%	0.077	Model	19.8	0.022	0.013	11.4	0.41	70	0.291	4420	1.6	1.7
				Delta ? (%)	0.0	0.0	1.9	-3.2	9.8	-45.2	8.5	109.0	-70.4	-74.1
		50%	100.11	Model	19.8	0.022	0.012	11.8	0.41	102	0.295	3034	3.6	3.5
K_{si}	66.7403			Delta ? (%)	0.0	0.0	0.3	-0.4	9.8	-20.3	9.7	43.5	-35.7	-46.5
		-50%	33.3702	Model	19.8	0.022	0.012	12.1	0.41	207	0.298	1469	14.6	14.2
				Delta ? (%)	0.0	0.0	-1.6	2.7	9.8	62.2	11.1	-30.5	164.4	116.8
		50%	0.00213	Model	19.8	0.022	0.011	13.9	0.41	134	0.265	2054	6.2	6.0
K_a	0.00142			Delta ? (%)	0.0	0.0	-10.0	17.8	9.8	4.7	-1.2	-2.9	12.9	-8.7
		-50%	0.00071	Model	19.8	0.022	0.014	9.8	0.41	138	0.334	2514	6.4	6.4
				Delta ? (%)	0.0	0.0	10.8	-17.2	9.8	8.0	24.5	18.9	16.3	-3.0
		50%	0.0129	Model	19.8	0.022	0.012	11.9	0.41	136	0.296	2261	6.3	6.2
K_l	0.0086			Delta ? (%)	0.0	0.0	-0.7	1.1	9.8	6.3	10.4	6.9	14.6	-5.9
		-50%	0.0043	Model	19.8	0.022	0.012	11.9	0.41	136	0.296	2261	6.3	6.2
				Delta ? (%)	0.0	0.0	-0.7	1.1	9.8	6.3	10.4	6.9	14.6	-5.9
K_u		50%	0.01228	Model	19.8	0.022	0.009	17.2	0.41	136	0.335	2564	6.3	6.2
	0.00818			Delta ? (%)	0.0	0.0	-23.7	45.4	9.8	6.3	24.9	21.2	14.6	-5.9
		-50%	0.00409	Model	19.8	0.022	0.018	4.6	0.41	136	0.215	1630	6.3	6.2
				Delta ? (%)	0.0	0.0	44.0	-61.3	9.8	6.3	-20.0	-22.9	14.6	-5.9

PSTA STANDARD OF COMPARISON ANALYSIS

As previously described in the SAV Standard of Comparison sub-section, the STSOC analysis was designed to ensure that the ATTs could be compared against each other. In addition to TP, TDP, and SRP, additional parameters were analyzed for a period of five weeks (the STSOC verification period). The PSTA Forecast Model was used to address sustainability, produce a preliminary full-scale design based on the STA-2 footprint, and define the remaining uncertainties with this technology. Refer to Chapter 8 of the 2000 and 2001 ECRs, and Chapter 4C of the 2002 ECR for a more detailed description of the STSOC methodology (Gray and Coffelt, 2000; Coffelt et al., 2001; and Jorge et al., 2002). Due to the small scale of these platforms, these preliminary estimates were made for comparative purposes only and were not intended to serve as final design scenarios.

Methodology

Two 0.2-ha test cells, one peat and one shellrock-based, were selected for the STSOC analysis because they were the largest platforms available to date. These test cells were operated with depths of 60 cm during the entire Phase 1 research beginning February 1999 and were reduced to 30-cm depths for the Phase 2 research in April 2000. During this time, the cattails were removed from the peat-based test cell and the sediment was amended with lime. The HLR during the entire research period remained at about 6 cm/d; the HRT for the Phase 2 research was 5 days. The optimal performance period (OPP) was defined as the entire period of record (POR) without system start-up, achieved a mean TP outflow concentration of 12 μg/L, and was used for the STSOC phosphorus analysis (CH2M HILL, 2002a).

To comply with the STSOC methodology, additional STSOC tests were performed in the peat and shellrock PSTA test cells for a five-week period beginning on February 27, 2001 and ending on April 3, 2001. **Table 4C-15** illustrates the parameters and methods used during the STSOC analysis. Water quality and mercury samples were taken at the head cell outflow leading into the PSTA test cells and at the outflow from these cells. Water samples were taken weekly. Periphyton samples were collected for mercury analysis on weeks 2, 4 and 5, while fish were sampled at the beginning and end of the five-week period. These samples were analyzed for both filtered and unfiltered total and methyl mercury at ultra-trace levels (Rawlik, 2001). Biomonitoring samples were collected on March 5, 2001 and were repeated on April 24, 2001. A summary of the results has been provided below. Refer to section 4 of the *PSTA Research and Demonstration Phase 1 and 2 Summary* report for more detail (CH2M HILL, 2002a).

Table 4C-15. The PSTA Standards of Comparison (STSOC) water quality parameters and the frequency of collection during the STSOC verification sampling period (CH2M Hill, 2002a)

Parameters	Units	Analytical Method	Method Detection Limit	Sampling Frequency
		Group A		
TP	mg/L as P	EPA 365.4	0.001	24 hr composite/ 3 per week
		Group B		
TDP	mg/L as P	EPA 365.1	0.001	Twice per week grab[a]
DRP	mg/L as P	EPA 365.1	0.0004	Twice per week grab[a]
Turbidity	NTU	EPA 180.1	0.1	Twice per week grab[a]
Color	CU	EPA 110.2	5	Twice per week grab[a]
		Group C		
TSS	mg/L	EPA 160.2	2	One per week
TOC	mg/L	EPA 415.1	1	One per week
Alkalinity	mg/L as CaCO3	EPA 310.1	1	One per week
TDS	mg/L	EPA 160.1	3	One per week
Sulfate	mg/L	EPA 375.4	1.5	One per week
Chloride	mg/L	EPA 325.2	0.2	One per week
TKN	mg/L as N	EPA 351.2	0.1	One per week
Nitrate/Nitriteb	mg/L as N	EPA 353.2	0.004	One per week
NH3	mg/L as N	EPA 350.1	0.003	One per week
		Group D		
Dissolved Al	µg/L	EPA 202.2/200.7c	4.5	5 times
Dissolved Fe	µg/L	EPA 200.7	4	5 times
Dissolved Ca	mg/L	EPA 200.7/60.0	0.013	5 times
Dissolved Mg	mg/L	EPA 200.7/60.0	0.01	5 times
Dissolved K	mg/L	EPA 258.1	0.04	5 times
Dissolved Na	mg/L	EPA 200.7	0.15	5 times
Reactive Silica	mg/L	EPA 370.1	0.2	5 times
		Group E		
Conductivity	µs/cm	NA	NA	Twice per week
DO	mg/L	NA	NA	Twice per week
pH	units	NA	NA	Twice per week
Temperature	°C	NA	NA	Twice per week

NA = Not applicable; field readings will be collected *in situ*. NS = Not specified in the STSOC guidelines

°C = degrees Celsius. TDP = total dissolved phosphorus. TDS = total dissolved solids. TSS = total suspended solids

[a]Twice per week grab collected to meet Department filtering requirements and short holding times (48 hours).

[b]To be consistent with current monitoring at the PSTA Test Cells, nitrate/nitrite will be reported instead of each component separately.

[c]Aluminum samples below approximately 100 µg/L are analyzed by EPA 202.2 (GFAA); samples above approximately 100 µg/L are analyzed by EPA 200.7 (ICP).

Results

As required by the STSOC, nine evaluation concepts were addressed and summarized in this section (**Table 4C-16**). The cost effectiveness on a dollar-per-pound-of-P-removed basis presented in **Table 4C-16** included all the costs presented in **Table 4C-17**. The STSOC also requires the use of the best available data related to P removal performance, flexible engineering and operational components to attain maximum P removal levels, and development of costs associated with the conceptual engineering design. The possible environmental effects of each technology in terms of disposal of byproducts and effects on downstream waters were also addressed. (CH2M HILL, 2002a). Information regarding all these concepts as they relate to the PSTA technology can be found in the *PSTA Phase 1 and 2 Final Report* (CH2M HILL, 2002a). The following discussion will focus on the first four primary evaluation concepts.

LEVEL OF TP CONCENTRATION AND LOAD REDUCTION ACHIEVABLE BY THE TECHNOLOGY

The mean flow-weighted outflow concentration from the peat-based system during the OPP was 17.9 μg/L, with 25.4 percent mass P removed from the system. Very little mass removal occurred from the peat-based system when TP inflow concentrations were less than about 25 μg/L. However, 46.2 percent of the P mass was removed from the shellrock system during the OPP, with a mean flow-weighted outflow concentration of 12.2 μg/L. For purposes of the STSOC assessment, the long-term minimum achievable average TP of 12 μg/L from the shellrock test cell was used for the PSTA conceptual design. (CH2M HILL, 2002a)

COMPATIBILITY OF THE TREATED WATER WITH THE NATURAL POPULATION OF AQUATIC FLORA AND FAUNA IN THE EVERGLADES

The STSOC defined compatibility of the treated water with the natural population of aquatic flora and fauna as meeting compliance with Class III water quality criteria, mercury testing, and biomonitoring (toxicological testing). The PSTA technology passed all the Class III standards with the exception of dissolved oxygen (DO), which is naturally depressed in the Everglades (CH2M HILL, 2002a). Additionally, except for two occasions, both the shellrock and peat-based PSTA treatments showed no evidence of significantly increasing mercury concentrations in the outflow water or in the periphyton relative to the inflow. The total mercury during the two excursions was comprised primarily of inorganic particulate mercury (CH2M HILL, 2002a; Rawlik et al., 2001). The shellrock-based PSTA system did not increase mercury concentrations in mosquitofish. Unfortunately, there was a lack of mosquitofish in the peat treatment at the time of collection and, therefore, no samples were taken.

The STSOC document required that specific toxicological tests be performed as a Phase 1 assessment of compatibility. This was previously described in the SAV STSOC section of this chapter. Subsequent discussions with the USEPA, the DOI and other stakeholders regarding these tests have resulted in the general agreement that standard toxicity tests might not be applicable to determine compatibility of the water with the downstream receiving water. Additionally, the ATTs were designed to reduce P concentrations to levels that limit green algae growth, and the validity of this test for the ATTs should be addressed. Therefore, the results of these tests were inconclusive. The District is currently involved in discussions with the FDEP and the DOI to design an experiment that would address this concern.

Table 4C-16. A summary of the Standards of Comparison (STSOC) evaluation concepts for the PSTA full-scale scenarios results (CH2M Hill, 2002a)

Criterion	No Bypass	10% Bypass	20% Bypass
Mean Outflow TP Concentration of 12 µg/L			
Level of P Concentration Reduction[a]	76 percent	67 percent	60 percent
Total Phosphorus Load Reduction[a]	76 percent	67 percent	60 percent
Compliance with Water Quality Criteria	YES	YES	YES
Cost-Effectiveness ($/lb)	$1,076	$1,078	$1,096
Implementation Schedule	72 MONTHS	72 MONTHS	72 MONTHS
Feasibility and Functionality of Full-Scale Design	HIGH	HIGH	HIGH
Operational Flexibility	HIGH	HIGH	HIGH
Sensitivity to Fire, Flood, Drought, and Hurricane	NO	NO	NO
Residual Solids Management	NONE	NONE	NONE
Mean Outflow TP Concentration of 20 µg/L			
Level of P Concentration Reduction[a]	60 percent	53 percent	47 percent
Total Phosphorus Load Reduction[a]	60 percent	53 percent	47 percent
Compliance with Water Quality Criteria	YES	YES	YES
Cost-Effectiveness ($/lb.)	$699	$705	$718
Implementation Schedule	72 MONTHS	72 MONTHS	72 MONTHS
Feasibility and Functionality of Full-Scale Design	HIGH	HIGH	HIGH
Operational Flexibility	HIGH	HIGH	HIGH
Sensitivity to Fire, Flood, Drought, and Hurricane	NO	NO	NO
Residual Solids Management	NONE	NONE	NONE

Notes:

[a] Concentration and load reductions are based on the PSTA Forecast Model simulations and include the TP contribution of bypassed flows.

All information in this table is based on assumptions as stated in the text and incorporates uncertainties related to model forecasts, limited experimental testing, and full-scale operational experience.

Table 4C-17. The costs of full-scale implementation of the PSTA project STSOC conceptual design without the STA-2 costs (CH2M Hill, 2002a)

Cost Component	12 µg/L			20 µg/L		
	0% bypass	10% bypass	20% bypass	0% bypass	10% bypass	20% bypass
Capital Costs	$843,798,569	$737,832,446	$663,697,737	$408,514,840	$357,406,344	$321,886,004
Operating Costs	$1,581,898	$1,483,448	$1,417,593	$1,367,755	$1,292,178	$1,255,048
Demolition/ Replacement Costs	$20,691,746	$16,867,324	$15,739,170	$20,935,504	$16,971,599	$14,797,671
Salvage Costs	($73,210,339)	($63,342,812)	($56,483,392)	($32,050,978)	($27,407,667)	($24,378,828)
Lump Sum/ Contingency Items	$761,200	$811,200	$811,200	$761,200	$811,200	$811,200

COST EFFECTIVENESS OF THE TECHNOLOGY

STSOC guidelines were used to develop the unit costs for this technology (**Table 4C-17**). Several scenarios were evaluated, including two levels of TP outflow concentrations, bypass scenarios ranging from 0 percent to 20 percent, and total costs with and without the cost of STA-2 included. The size of the wetland and its 50-year present worth were calculated based on several inflow bypass scenarios of 0, 10, and 20 percent. In this conceptual scenario, the bypassed water was not blended with the wetland outflow, nor was it incorporated into any hydraulic calculations, such as HLR or HRT. The generated values were based on the assumptions used in the model, the thickness of the experimental limerock cap, effects of seepage, and actual TP inflow concentration. The 50-year present worth for a PSTA system with a 61-cm limerock cap, treating water to an outflow TP concentration of 20 µg/L and excluding the cost of STA-2, would be about $455 million, with a unit cost of about $700/lb of TP removed. To attain 12 µg/L, the estimated present worth cost was about $889 million, with an estimated unit cost of $1,080/lb of TP removed.

The detailed costs include land acquisition, limerock capping of the sediment and an assumption of an inflow TP concentration of 50 µg/L as the main factors affecting total cost for a PSTA system. Each of these factors is briefly described in the following bullets:

- The land area requirements were based on a one-TIS model for PSTA hydraulics. However, the latest test cell tracer studies indicated that the system might be operating as a four-TIS system, indicating improved hydraulics over the model assumptions. Therefore, additional model simulations of the shellrock system were performed, with TIS values ranging from 1 to 4, and indicated that the required area needed to reach 12 µg/L could possibly be reduced from 6,192 ha (15,300 ac) to 2,873 ha (7,100 ac), respectively (**Table 4C-18**).

- The cost of the limerock cap alone may represent as much as 80 to 90 percent of the capital costs. If a more cost-effective method of sealing the peat-based soils existed, this would represent a substantial cost savings (**Table 4C-19).** As a follow-up to these findings, the District has begun an evaluation of alternative soil amendments at the mesocosm scale.
- The STAs were designed to achieve a yearly mean outflow TP concentration of 50 μg/L. However, the mean outflow TP concentration from STA-1W has been less than 25 μg/L. Therefore, the PSTA Forecast Model was employed to determine what effect a lower inflow TP concentration would have on the land area required for a PSTA system to achieve various operation scenarios. Reducing the inflow TP concentration from 50 μg/L to 25 μg/L would result in a 35% and 16% land area reduction when meeting a target mean TP outflow concentration of 12 μg/L and 20 μg/L, respectively (**Table 4C-18**).

Table 4C-18. PSTA Forecast Model sensitivity analysis detailing the effects of different hydraulic efficiencies (Tanks in Series [TIS]) on the estimated conceptual PSTA areas for the post-STA-2 data set with a 50 μg/L inflow concentration

	Estimated Required Area (ha)	
No. TIS	Outflow TP = 20 μg/L	Outflow TP = 12 μg/L
1	2,670	6,192
2	1,862	3,602
3	1,659	3,116
4	1,578	2,873

Table 4C-19. The PSTA project Standards of Comparison (STSOC) conceptual cost comparison with and without shellrock capping for the 12 and 20 μg/L outflows, with 0, 10, and 20 percent bypass with a 50 μg/L inflow concentration (CH2M Hill, 2002a)

Target	12 μg/L			20 μg/L		
Percent Bypass	**0**	**10**	**20**	**0**	**10**	**20**
Treatment Area (ha)	6,198	5,358	4,772	1,929	1,589	1,406
Treatment Area (ac)	15,316	13,241	11,791	4,767	3,926	3,473
With 2-ft Shellrock						
50-year Present Worth (millions $)	889	778	703	455	399	361
$/Pound TP Removed	1,076	1,078	1,096	699	705	718
$/1000 gallons	0.35	0.34	0.35	0.18	0.17	0.18
With 1-ft Shellrock						
50-year Present Worth (millions $)	561	495	451	314	278	254
$/Pound TP Removed	679	686	703	482	492	505
$/1000 gallons	0.22	0.22	0.22	0.12	0.12	0.13
With Lime Soil Amendment						
50 yr Present Worth (millions $)	234	212	198	173	158	147
$/Pound TP Removed	283	294	309	265	279	292
$/1000 gallons	0.09	0.09	0.10	0.07	0.07	0.07

Notes:
50-year present worth in millions of dollars
Assumes lime addition = $1,300/acre

PSTA FIELD-SCALE PROJECT

The PSTA field-scale site has four 2.02-ha (five-acre) cells. The original design described in the 2001 ECR consisted of three five-acre cells: two with limerock fill over peat and one scraped to bedrock (Coffelt et al., 2001). Based on encouraging preliminary test cell data, the site design was revised to include a fourth peat-based cell to assess long-term viability and provide construction cost estimates of a field-scale peat based PSTA system. While the two limerock cells are operated at the same depths and hydraulic loading rates, the nominal velocity and aspect ratio are different due to construction of an internal sinusoidal levee placed within cell 2 (**Figure 4C-12**). The total area of cell 2 was increased beyond the 2-ha footprint to account for the internal levees, resulting in a treatment area of 2.02 ha. The objective of this design is to discern if velocity effects P removal performance in PSTA systems. Methods and performance results, to date, are presented in this section.

Methodology

HYDROLOGY

Water flows by gravity from STA-2 cell 3 into the inflow canal of the PSTA Field-scale Project and is pumped into each cell (**Figure 4C-12**). Water supply to the PSTA field scale becomes reduced when stages in STA-2 cell 3 fall below 11.7 NGVD. The experimental design depth target is 0.30 m for each cell; however, low water levels in STA-2 cell 3, combined with pump failures, have resulted in periodic interruptions in flow that have periodically resulted in lower depths (**Figure 4C-13).**

The water balance is calculated by direct measurement of the pumped inflow, outflow and rainfall. Inflow measurements were estimated using water level recordings within the cells until November 8, 2001, when flowmeters were placed on the inflow distribution system of each cell. Outflow calculations are based on a weir equation for flow over a 24-inch horizontal weir with end constrictions. Evapotranspiration is estimated from a District station located at STA-1W, and storage is estimated from beginning and ending water level records in the cells (CH2M HILL, 2002a).

The field-scale system represents the first opportunity to examine the effects of seepage on a PSTA system. Leakance tests, which measured changes in static water level over time, were performed during four time periods: during construction in September 2000, February 2001, April 2001 and August 2001. Additionally, tracer studies were used to establish the general location and extent of horizontal and vertical seepage in the system. Hydraulic tracer studies were conducted in cells 2 and 4 in March 2002, but were delayed until August 2002 in cells 1 and 3 due to low water levels in STA-2 cell 3.

In this study, lithium (Li) and rhodamine dye were used concurrently. Lithium was used to measure the HRT, while rhodamine dye was used to quantify seepage through the levees and to qualitatively note any visible seepage losses. In addition to lithium measurements conducted at the outflow, lithium was also measured at the inflow and at sample sites located along the four transects positioned transversely to the flow path. These measurements were made to account for possible seepage back into the inflow canal from the inflow deep zone in each cell and to quantify where any vertical seepage losses were occurring. When completed, this data will be used to correct the phosphorus mass balance calculations for seepage losses.

Tracer spikes were prepared to yield average, well-mixed concentrations of about 500 μg/L as Li and rhodamine in the high velocity cell (cell 2), and 250 μg/L in the remaining cells. The tracer solution was applied to each cell over a period of about 10 minutes by pouring the contents into the inlet distribution system. Automated samplers were deployed at the inlets and outlets of each cell and were programmed to collect 125-ml samples at varying intervals beginning at the time of initial tracer application. During the course of the experiment, grab samples were also collected at four transects transverse to the flow path, at wells located along the outer levees, and in the center of each cell to document the passage and fate of the tracer. Daily outflow rates were calculated by the measurement of water height over the horizontal weir. The data from these tracer studies is currently being analyzed, and the results will be summarized when the analysis is complete.

CHEMICAL ANALYSES

Water, sediment and vegetation are collected at various intervals at the inflow, midpoint and outflow in each cell, with TP, TDP and SRP water quality analyses performed weekly at the inflow and outflow of each cell (**Table 4C-20).** Additionally, wells surrounding the project perimeter and located in the center of each cell were sampled monthly for a subset of parameters, as described in **Table 4C-20** (CH2M HILL, 2002b).

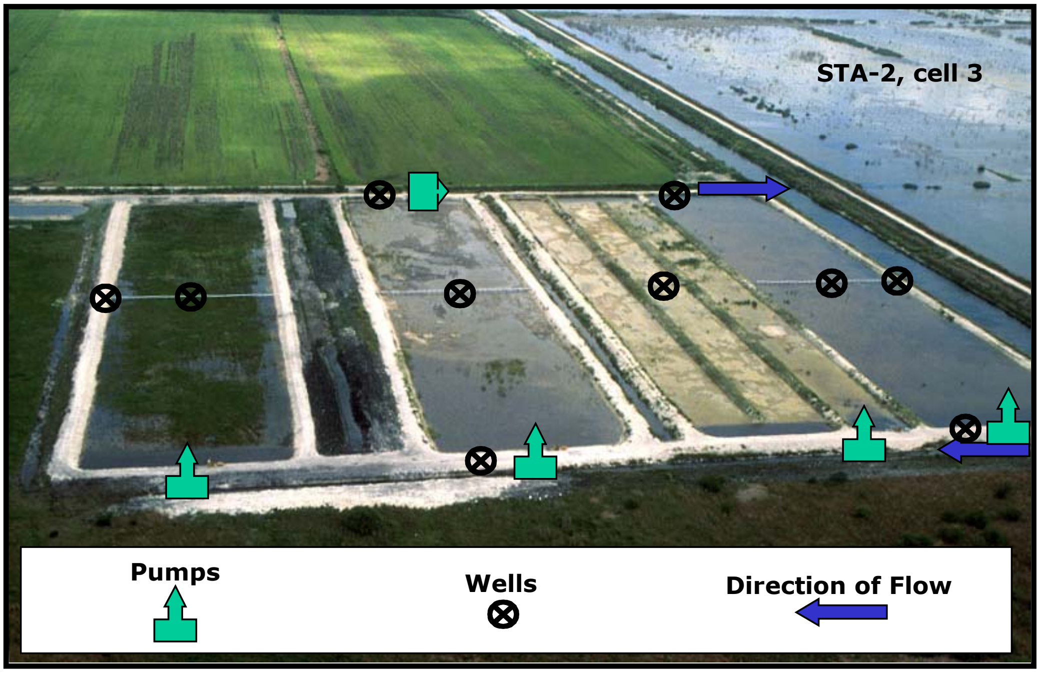


Figure 4C-12. The field-scale research facility. Water flows by gravity into the inflow canal from STA-2 cell 3 and is pumped into each cell. The outflow is collected and flows into the STA-2 seepage canal. Water quality samples are collected at the inflow, midpoint and outflow in each cell. Wells are located around the perimeter and in the center of each cell

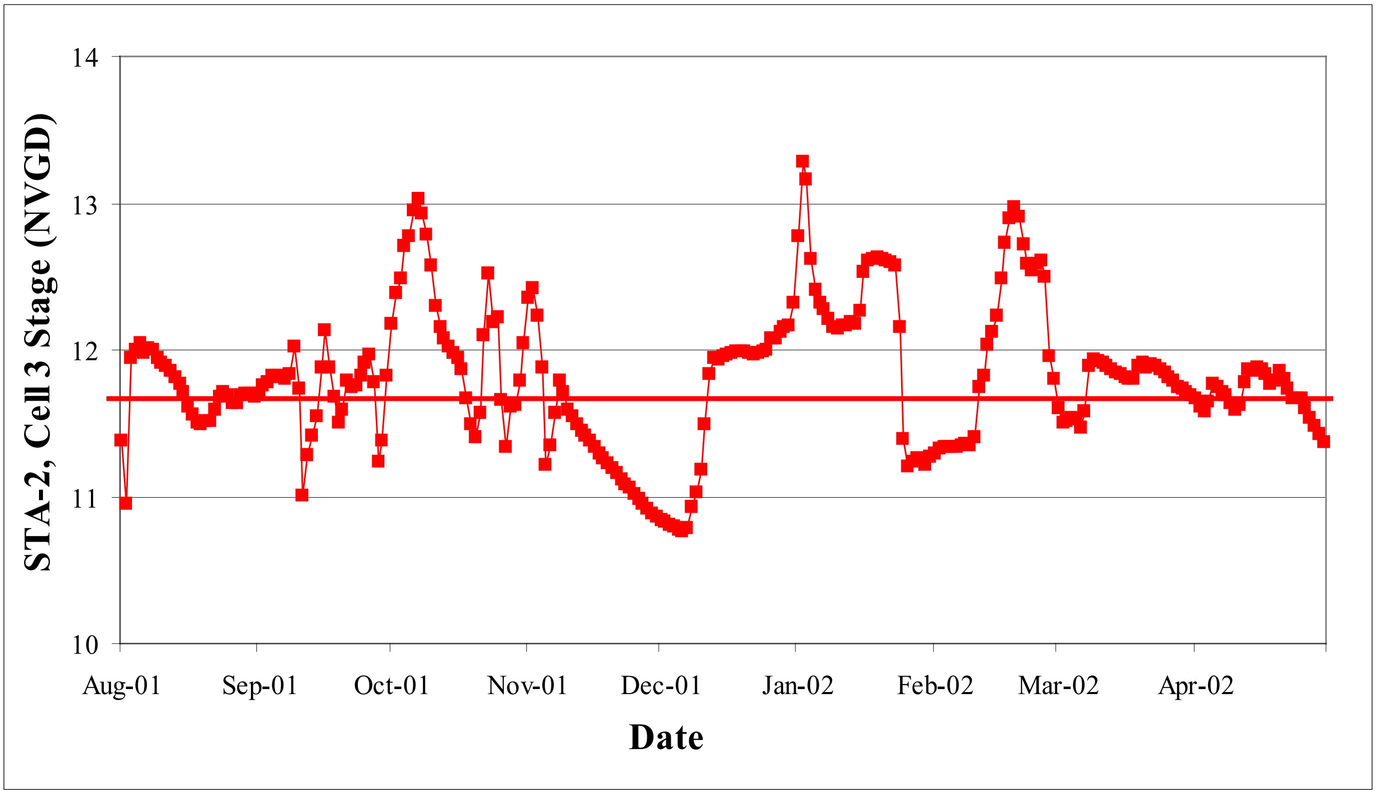


Figure 4C-13. A time series of the stage in STA-2 cell 3 from August 2001 to April 2002. Ground level in this cell averages 9.6 NGVD. Water supply to the PSTA field scale becomes reduced when stages in STA-2 cell 3 fall below 11.7 NGVD. The arrows indicate the time interval when the water level within STA-2 cell 3 fell below 11.7 NGVD

Table 4C-20. Parameters collected and frequency of collection at the PSTA project field-scale facility

Parameter	Sampling Locations and Frequency					
	Piezometers	Inflow Canal	Inflow	1/2	Outflow	Outflow Canal
	Field Meter Readings					
Flow	NA	NA	Pump	NA	Calc	NA
Water Stage	W	C(I)	W	C(I)	W	C(I)
Water Temperature	M	W	W	C(I)	W	NA
Dissolved Oxygen	NA	W	W	C(I)	W	NA
pH	M	W	W	C(I)	W	NA
Conductivity	M	W	W	C(I)	W	NA
Total Dissolved Solids	M	W	W	C(I)	W	NA
Turbidity	M	W	W	C(I)	W	NA
PAR	NA	NA	NA	M	NA	NA
	Water Quality Analyses					
Total Phosphorus	M	W	M	M	W	NS
Dissolved Reactive Phosphorus	NS	W	M	M	W	NS
Total Dissolved Phosphorus	NS	W	M	M	W	NS
Total Nitrogen	NS	NS	M	M	M	NS
Ammonia N	NS	NS	M	M	M	NS
TKN	NS	NS	M	M	M	NS
Nitrate + nitrite N	NS	NS	M	M	M	NS
Total Suspended Solids	NS	NS	M	M	M	NS
Total Organic Carbon	NS	NS	M	M	M	NS
Calcium	NS	NS	M	M	M	NS
Alkalinity	NS	NS	M	M	M	NS
Chlorides	NS	NS	M	M	M	NS
	Biological Analyses					
Periphyton Cover	NS	NS	NS	M	NS	NS
Macrophyte Cover	NS	NS	NS	M	NS	NS
Periphyton Dominant Species	NS	NS	NS	Q(a)	NS	NS
Biomass (AFDW)	NS	NS	NS	Q(a)	NS	NS
Calcium	NS	NS	NS	Q(a)	NS	NS
Chlorophyll a, b, c phaeophytin	NS	NS	NS	Q(a)	NS	NS
Total Phosphorus	NS	NS	NS	Q(a)	NS	NS
Total Inorganic Phosphorus	NS	NS	NS	Q(a)	NS	NS
Non-reactive Phosphorus	NS	NS	NS	Q(a)	NS	NS
TKN	NS	NS	NS	Q(a)	NS	NS
Accretion (net organic/inorganic)	NS	NS	NS	Q(a)	NS	NS

Table 4C-20. (Cont'd.) Parameters collected and frequency of collection at the PSTA project field-scale facility

Parameter	Sampling Locations and Frequency					
	Piezometers	Inflow Canal	Inflow	1/2	Outflow	Outflow Canal
		Sediments (Start and End)				
Total Phosphorus	NS	NS	NS	S/M/E	NS	NS
Total Inorganic Phosphorus	NS	NS	NS	S/M/E	NS	NS
Non-reactive Phosphorus	NS	NS	NS	S/M/E	NS	NS
Phosphorus sorption/desorption	NS	NS	NS	S/M/E	NS	NS
TKN	NS	NS	NS	S/M/E	NS	NS
Total Organic Carbon	NS	NS	NS	S/M/E	NS	NS
Bulk Density	NS	NS	NS	S/M/E	NS	NS
Solids (percent)	NS	NS	NS	S/M/E	NS	NS
		System Level Parameters				
Gross Primary Productivity	NS	NS	NS	C(I)	NS	NS
Net Primary Productivity	NS	NS	NS	C(I)	NS	NS
Community Respiration	NS	NS	NS	C(I)	NS	NS

(a) Three replicate samples taken along the boardwalk of each cell.

W = weekly M = monthly C(I) = continuous interval NA = not applicable

Q = quarterly NS = not sampled S/M/E = start, mid-point and end of sampling

Results

HYDROLOGY

Mean HLR for scrape-down and peat-based cells (cells 3 and 4) were the lowest at 5.5 cm/d Cell 1 (caprock) had a slightly higher HLR of 7.5 cm/d, while by design, cell 2, the higher-velocity cell, had the highest HLR of 11.7 cm/d (**Table 4C-21**) (CH2M HILL, 2002c). The leakance rates performed in March 2001 indicated high leakance in cells 1 and 2, with rates of 6.7 cm/d and 10.7 cm/d, respectively. As a result, the levees of these cells were rebuilt. A reduction in leakance has been noted over time, with leakance rates ranging from a low of 2.2 cm/d to a high of 4.0 cm/d for all four cells (**Table 4C-22).** The high leak rates are easily confirmed when comparing the total inflow and outflow volumes for each cell during the operational period. Cell 2 had the largest water loss from the system, with a difference between inflow and outflow volumes of 1,196 m^3/d (**Table 4C-21**). However, cell 3 had outflow volumes greater than inflows and leakance tests, indicating that this system might experience periods of seepage into, as well as out of the system.

Table 4C-21. Mass phosphorus inflow, outflow, percent retention, HLRs and HRTs for the PSTA field-scale facility from August 2001 to April 2002

	Cell 1 Shellrock	Cell 2 Shellrock High Velocity	Cell 3 Scrape Down	Cell 4 Peat
Flow				
HLR (cm/d)	7.41	11.56	5.54	5.49
HRT (d)	4.05	2.59	5.41	5.46
Inflow (m^3/d)	1500.2	2339.8	1122.0	1111.6
Outflow (m^3/d)	727.5	1143.8	1719.0	368.0
TP Mass Balance				
Inflow (g/m^2/year)	0.501	0.750	0.355	0.390
Outflow (g/m^2/year)	0.247	0.304	0.439	0.128
Removal (%)	50.77	59.42	-23.56	67.30

Table 4C-22. The estimated leakance rates (cm/day) for the PSTA Project field-scale facility based on the change in static water levels in the cells (CH2M HILL, 2002b)

PSTA Field-scale Cells	September - December 2000	February 2001	August - September 2001
Shellrock (cell 1)	6.7	5.3	4.0
Shellrock high velocity (cell 2)	10.7	7.8	3.5
Scrape down (cell 3)	3.4	Note A	2.2
Peat-based (cell 4)	Note B	Note B	3.2

A: Water levels in cell 3 did not drop significantly for this period, and thus leakance could not be estimated.

B: The cell was not constructed during initial leakance measurements.

NUTRIENT REMOVAL EFFICIENCY

Mean inflow TP concentrations were 19 µg/L over the nine month period of record (POR), extending from August 2001 through April 2002, and ranged from 8 µg/L to 47 µg/L. Cells 1 and 4 had mean TP outflow of 19 µg/L, while Cells 2 and 3 had mean TP outflows of 15 µg/L, and 14, µg/L, respectively (**Figure 4C-14**). The phosphorus species were evenly split between total dissolved and total particulate fractions in both the inflow and outflow. Soluble reactive phosphorus was at the detection limit in the inflow before entering treatment and remained below the detection limit at the outflow.

The phosphorus removal performance was negatively affected by the periodic interruptions in the inflow water source. The mass of TP entering the systems ranged from 0.36 $g/m^2/y$ to 0.75 $g/m^2/y$, with Cell 2 (with the highest HLR) receiving the greater load of phosphorus (**Table 4C-21**). The TP percent removal ranged from –24 percent to 67 percent for Cells 3 and 4, respectively. The negative percent removal in the scrape-down cell (Cell 3) may be due to the influence of seepage into the cell (CH2M Hill, 2002c). The high TP reduction in the peat cell (STA-1W, Cell 4) may be attributed to increasing plant biomass within the system during this time.

The means, minimum and maximum concentrations for other parameters measured during the POR are detailed in the Phase 3 Interim Report 1 for the PSTA project (CH2M HILL, 2002b).

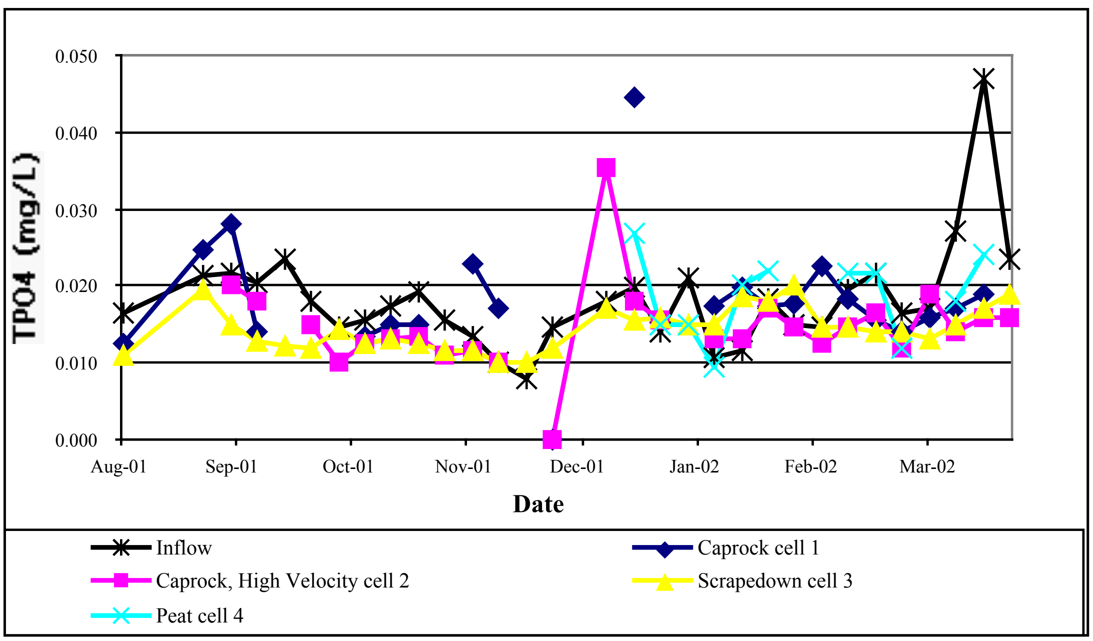


Figure 4C-14. Total phosphorus time series in the inflow and at the outflow from each field-scale cell. Sampling started in August 2001 and continued through the remaining eight months of the water year

SUMMARY

Research has shown that mean outflow TP concentrations of 12 μg/L can be sustained for more than a year in a 0.2-ha shellrock-based PSTA wetland system with mean TP inflow concentrations of 23 μg/L. The preliminary data from the 8.1-ha field-scale system indicated that seepage into and out of these systems could be a significant factor in their phosphorus removal effectiveness. The STSOC methodology was applied along with the theoretical STA-2 10-year POR data, and the PSTA Forecast Model was used to estimate land area required and cost estimates for constructing a full-scale PSTA system. Several factors influence the size and cost of any treatment area, including the inflow concentrations, the hydraulic efficiency of the system, and the sediment nutrient concentration. The cost estimates of the PSTA system were most sensitive to the depth of limerock added to the sediment and the cost of the required land area.

The PSTA field scale has experienced high seepage rates, which will affect the final P-mass budget calculated for these systems. The field-scale cell 3 wetland experienced seepage in and out of the system and had a net export of phosphorus from the system, though it had the lowest mean outflow TP concentration of the field-scale cells. Tracer studies are underway in an attempt to quantify the seepage values and provide reliable estimates of actual P treatment within the system.

FUTURE RESEARCH

The District will continue monitoring the performance of the 8.1-ha field-scale system and the three 0.2-ha PSTA test cell wetlands. Additionally, the District has begun mesocosm research to determine the optimal soil amendments and depths for sealing peat sediments.

CHEMICAL TREATMENT/SOLID SEPARATION (CTSS)

During the past few years, the District has evaluated in a pilot scale the use of several chemical treatment processes identified in the Desktop Study for the precipitation and removal of TP. Results of these research studies with post-BMP and post-STA waters at the ENRP (Gray and Coffelt, 2000; Coffelt et al., 2001; HSA, 2000) showed that two of the four chemical alternative treatments evaluated – microfiltration and high rate solids separation (CTSS) – were successful in achieving less than 10 μg/L TP outflow concentrations. For a detailed summary of the CTSS technology and research results, refer to Chapter 8 of the 2000 and 2001 ECRs (Gray and Coffelt, 2000; Coffelt et al., 2001) and Chapter 4C of the 2002 ECR (Jorge et al., 2002).

CTSS TESTING AT URBAN BASIN, C-11 WEST

Background

In the 2002 ECR, the District reported results from the CTSS pilot-testing unit located within the Wellington basin (Jorge et al., 2002). However, the Wellington basin has more horse farms, larger lot sizes, and less paved surface than might be typical for most urban basins in South Florida. Additionally, the mean TP concentrations found in the runoff from Wellington basin was 187 μg/L and 19 μg/L for the C-11 West basin during the time of the CTSS pilot tests. Therefore, the water quality of the runoff will be different, requiring different coagulant and polymer dosages. The C-11 West basin annually discharges approximately 240.5 hm^3 (195,000 ac-ft) of stormwater directly into Water Conservation Area 3B (WCA-3B), with an average annual TP concentration of 17 µg/L (SFWMD, November 2001). As a follow-up to the CTSS pilot testing performed using agricultural stormwater runoff, the District placed a pilot unit at the S-9 pump station in the C-11 West basin, located in south central Broward County.

Testing Program

Testing within the C-11 basin was conducted over the course of seven independent pumping events in response to rainfall that occurred between August 27 and November 1, 2001, using the same equipment and configuration described in detail in the 2002 ECR (Jorge et al., 2002). During all trials, a concentration of 0.5 mg/l of Cytec 130 polymer was added to the incoming waters during testing. The feed flow rate, the corresponding clarifier loading rate, and the aluminum chloride coagulant dose were varied in each individual trial and are detailed in **Table 4C-23**.

Grab inflow and outflow water samples were periodically collected about every two to four hours and were analyzed for SRP, TDP and TP. Composite samples of the solid residual were collected to determine solids production rates and were analyzed for toxicity characteristic leachate procedure (TCLP) evaluation of solids. In addition, 24-hour composite samples were also collected for a complete water quality analysis, including nutrient and heavy metal characterization.

Bioassay tests were performed following USEPA guidelines, but substituting *C. leedsi* for the fathead minnow, *Pimephales promelas* (EPA/600/4-91/002). Algal Growth Potential (AGP) tests were performed following USEPA guidelines (EPA-600/9-78-018). Bioassay and AGP tests indicated there was no significant identifiable impact that could be attributed to the CTSS treatment system. Specific tests conducted include the following:

- Seven-day Chronic Static Renewal Screen Toxicity Test using the Bannerfin shiner (*Cyprinella leedsi*)
- Seven-day Chronic Static Renewal Screen Toxicity Test using the water flea (*Ceriodaphnia dubia*)
- A 14-day Algal Growth Potential Screen using the unicellular green alga (*Selenastrum capricornutum*)
- A 96-hour Chronic Static Non-renewal Screen Toxicity Test using the unicellular green alga (*Selenastrum capricornutum*)

Subsequent discussions with the USEPA, the DOI and other stakeholders regarding these tests have resulted in the general agreement that standard toxicity tests may not be applicable to determine compatibility of the water with the downstream receiving water. Additionally, the ATTs were designed to reduce P concentrations to levels that limit green algae growth, and the validity of this test for the ATTs should be addressed. Therefore, the results of these tests were inconclusive. Currently, the District is involved in discussions with the FDEP and the DOI to design an experiment that would address this concern.

Table 4C-23. CTSS testing conditions and results at C-11W using aluminum chloride as a flocculant and 0.5 mg/L of polymer Cytec 130 as a coagulant

Date	Clarifier loading rate (gpm/sq. ft.)	Dose (mg/L as metal)	TP concentrations Influent (mg/L)	Effluent (mg/L)
8/27/2001	0.14	13	0.011	0.013
9/5/2001	0.28	16	0.012	0.010
9/20/2001	0.14	23	0.018	0.005
10/2/2001	0.35	18	0.020	0.005
10/30/2001	0.35	14	0.032	0.005
10/31/2001	0.42	19	0.019	0.007
11/1/2001	0.28	18	0.015	0.004

Results

WATER QUALITY

With the exception of the first trial, which showed an outflow TP concentration slightly greater than the inflow TP concentration, the outflow TP concentration of the experimental runs produced outflow TP concentrations less than or equal to 10 μg/L (**Table 4C-23**). The lowest aluminum chloride concentration used during testing that yielded a TP outflow concentration less than or equal to10 μg/l or less was 14 mg/l AlCl as aluminum. The trial run performed on October 31, 2001 had the highest clarifier loading rate of 0.42 g/sq ft/min of projected plate area and produced a TP outflow concentration of 7 μg/l.

Due to the presence of unreacted aluminum ions in the processing stream, the mean outflow aluminum concentration of 1.0 mg/L was greater than the mean inflow aluminum concentration of 0.21 mg/L. Additionally, the mean inflow Cl concentration increased from 66 mg/L to a mean outflow Cl concentration of 145 mg/L.

On average, the CTSS treatment process removed 99 percent of the fecal coliform bacteria from the inflow water. Additionally, alkalinity, color, iron, reactive silica, TKN, TOC and turbidity were reduced relative to inflow concentrations due to the acidic nature of the aluminum salts and also due to the precipitation and coagulation reactions occurring within the pilot testing facility. Ammonia, nitrogen, calcium, chromium, lead, magnesium, nitrate, potassium, selenium, sodium, sulfate, biological oxygen demand, total suspended solids, and zinc did not show any significant difference between the pilot unit inflow and outflow concentrations.

WATER RESIDUALS

The TCLP analyses were performed on representative samples of the water residuals collected from the clarifier underflow on November 1, 2001. All analytical results on the residual solids were well below respective allowed limits for TCLP parameters, so by this definition the CTSS residual solids are non-hazardous. A licensed waste disposal contractor hauled the water residual solids offsite.

CONCEPTUAL DESIGN AND COSTS

Flow data used in developing facility conceptual designs was obtained from historical information for the S-9 pump station for the 10-year period from 1990 to 1999 (SFWMD, 2001). During this period, the S-9 pump station was pumping for 1,993 days, with a mean flow rate of

343 MGD (flow days only). The mean plus one standard deviation of flow was equal to 522 MGD. The mean inflow TP concentration of 16 µg/L used in developing this full-scale design was based on District historical data.

The full-scale facility was designed to achieve a flow weighted average effluent total P concentration of 10 µg/L with 0 percent flow diversion. The design criteria was established by optimizing the size of the water treatment plant required to treat incoming stormwater runoff compared to the size of a flow equalization basin (FEB) that would store high volumes of waters resulting from short-duration, high-intensity rainfall events. The facility would treat the water stored in the FEB during the subsequent hours and days following a storm event. Using a fill and draw hydraulic model to evaluate various plant versus FEB sizes, the optimum plant size was designed, with 70 MGD of treatment capacity and a 300-acre FEB. This combination produced a mean flow-weighted TP outflow concentration of 10 µg/L.

Assumptions and conceptual design used in developing the treatment system and the capital and operating costs were detailed in the STSOC and are detailed in previous reports on CTSS (Jorge et al., 2002). The District provided unit costs for selected capital, operation and maintenance (O&M), replacement, and salvage items. The cost estimate data were developed from equipment supplier quotations and prior engineering experience.

Table 4C-24 details the area and costs generated from the full-scale design estimates for the Wellington and C-11 West basins. The full-scale facility treatment costs and the 50-year present-worth costs were calculated using a net discount rate of four percent. The total lump sum, 50-year present-worth cost (capital and O&M) of the 70-MGD facility is estimated at $124,878,036.

Table 4C-24. Cost comparison of full-scale implementation estimates of the Wellington and C-11 West urban basin conceptual designs. Outflow TP concentrations represent experimental means achieved. All calculations are based on zero-percent bypass scenarios

Urban Basin	Outflow TP achieved (µg/L)	Area Required (ha)	50-year Present Worth ($)	$ per pound of TP removed	$ per 1,000 gallons treated
Wellington	<=10	83[a]	100,100,000	134	0.185
C-11 West	<=10	123[b]	124,887,036	746	0.085

[a] Add an additional 29 ha for land application of residuals

[b] Add an additional 186 ha for land application of residuals

CHEMICAL TREATMENT/SUBMERGED AQUATIC VEGETATION RESEARCH

Project Background

CTSS was tested in sequence with an emergent vegetation-dominated wetland as part of the managed wetland project. This research indicated emergent wetlands might provide some additional treatment benefit through buffering the pH and alkalinity of the CTSS inflow (CH2M HILL, 2001; Jorge et al., 2002).

District research on Submerged Aquatic Vegetation (SAV) has demonstrated that these systems might be more effective than cattail-dominated wetlands at removing P, but their buffering capacity might be diminished due to their alkaline water chemistry. Therefore, the District has been monitoring the performance of a CTSS unit followed by an SAV-dominated wetland (CTSS/SAV).

Objectives

Findings from previous research on the CTSS process had demonstrated the technical effectiveness of using chemical coagulants plus polymers, followed by clarification to reduce TP levels in post-BMP waters to concentrations below 10 μg/L. However, this research has been carried out using a loading rate of about 22.7 L/min to 30.3 L/min (6 to 8 gpm) and for a period of continuous sampling not greater than two weeks. The objectives of the CTSS/SAV project were as follows:

- Demonstrate that a CTSS unit operating for a period greater than two weeks and at a loading rate of about 75.7 L/min (20 gpm) could consistently reduce TP concentrations to 10 μg/L or less
- Demonstrate that an SAV system was efficient at buffering the pH and alkalinity of the CTSS inflow
- Demonstrate that the SAV wetland could effectively capture and trap any solids overflow from the CTSS system
- Demonstrate whether the wetland released phosphorus from the sediment into the overlying water

Project Design and Study Site

The CTSS/SAV demonstration project is located at the STA-1W north test cell site, test cell 14 (NTC-14). The chemical treatment equipment used for the recently completed managed wetland research was refurbished and reconfigured for this demonstration project so it could treat up to 75.7 L/min (20 gpm) of water. The CTSS received inflow water directly from the north site head cell. The water was pumped into a mixing tank, where 20 mg/L of aluminum chloride (AlCl) was added and mixed in a rapid-mix tank for about 30 seconds (flocculation). From the rapid mix tank, the water overflowed by gravity into a coagulation tank, where 0.5 mg/L of Cytec polymer was added and was slowly mixed for 60 minutes to form and protect the integrity of the flocs. The chemically treated water overflowed them into a laminar clarifier, where the flocs were separated and settled as water residuals. The treated water overflowed from the clarifier into a holding tank, and then was fed by gravity into the test cell through an inflow distribution manifold. Water residuals were pumped periodically to an onsite storage tank and were removed from the test cell area. Hydraulic loading rates to the wetland, the appropriate coagulant (aluminum chloride), and polymer (Cytec polymer) dosages were selected based on previous District research (HSA, 2000; Jorge et al., 2002). NTC-14 contained a dense growth of cattails prior to this project and was converted to an SAV-dominated wetland through several sequential steps. First, the cell was drained and the cattail stalks were cut to just above the sediment (rhizomes were left in place). Following cattail removal the wetland was reflooded and stocked with about 1 kg of SAV (wet weight) per square meter of wetland area. The SAV used for stocking NTC-14 was harvested from the outflow region of STA-1W cell 4.

For the six months following inoculation, the wetland was loaded with untreated water from the north test cell site head tank, which contains water pumped in from STA-1W cell 1. During this period the SAV biomass in the system increased and reached about 75 percent areal coverage. After six months the wetland began receiving water that had been processed by the CTSS unit. The unit began operation on May 5, 2001, and following a short start-up period it began discharging to the STA wetland on June 11, 2001.

Results

During the period from June 11, 2001 to May 25, 2002, the mean TP inflow concentration into and out of the CTSS unit was 73 µg/L, and 8.8 µg/L, respectively. The mean TP outflow concentration from the SAV wetland was 15 µg/L, which was greater than the inflow concentration (**Table 4C-25**). However, the TDP and SRP concentrations from the wetland were 3 µg/L and 8 µg/L, respectively, which were lower than the respective inflow concentrations. Alkalinity and TKN were also sequentially reduced as follows: CTSS inflow concentrations were > wetland inflows, which were > wetland outflow concentrations (**Table 4C-26**). Mean total aluminum (TotAl) and chloride concentrations from the CTSS unit were higher than inflow TotAl and chloride concentrations due to the addition of 20 mg/L of aluminum chloride as a coagulant. The SAV wetland reduced the chloride relative to CTSS outflow, but chloride was higher than CTSS inflow water (**Figure 4C-15**). The SAV wetland reduced mean TotAl concentrations to 0.035 mg/L, which was only slightly higher than mean CTSS inflow concentrations; however, the wetland TotAl outflow concentration has been steadily increasing over time (**Figure 4C-16**).

Table 4C-25. Mean TP, DRP and SRP treatment plant inflow and outflow concentrations, along with concentrations from the wetland outflow for the CTSS/SAV Project at STA-1W test cell 14 from June 11, 2001 to May 25, 2002

Parameter		Inflow (Post BMP)	After Chemical Treatment (to Test Cell)	Effluent from Test Cell
TP (µg/L)	Average	73	8.8	15
	(min/max)	(22-139)	(4-22)	(8-32)
DRP (µg/L)	Average	43	6	3
	(min/max)	(9-108)	(1-56)	(1-5)
SRP (µg/L)	Average	49	10.7	8
	(min/max)	(17-114)	(3-6.6)	(6-13)

Table 4C-26. Mean TKN, ALK, Cl, and Total Al treatment plant inflow and outflow concentrations along with concentrations from the wetland outflow for the CTSS/SAV project located at STA-1W, test cell 14 from June 11, 2001 to May 25, 2002.

Parameter		Inflow (Post BMP)	After Chemical Treatment (to Test Cell)	Effluent from Test Cell
TKN (mg/L)	Average	2.6	1.6	1.4
	(min/max)	(1.4-3.1)	(0.7-2.9)	(1.0-1.9)
Alkalinity (mg/L)	Average	291	164	115
	(min/max)	(187-336)	(60-332)	(88-153)
Chloride (mg/L)	Average	160	266	234
	(min/max)	(97-210)	(160-336)	(155-302)
Total Al (mg/L)	Average	0.023	1.01	0.035
	(min/max)	(0.010-0.058)	(0.12-2.58)	(0.003-0.11)

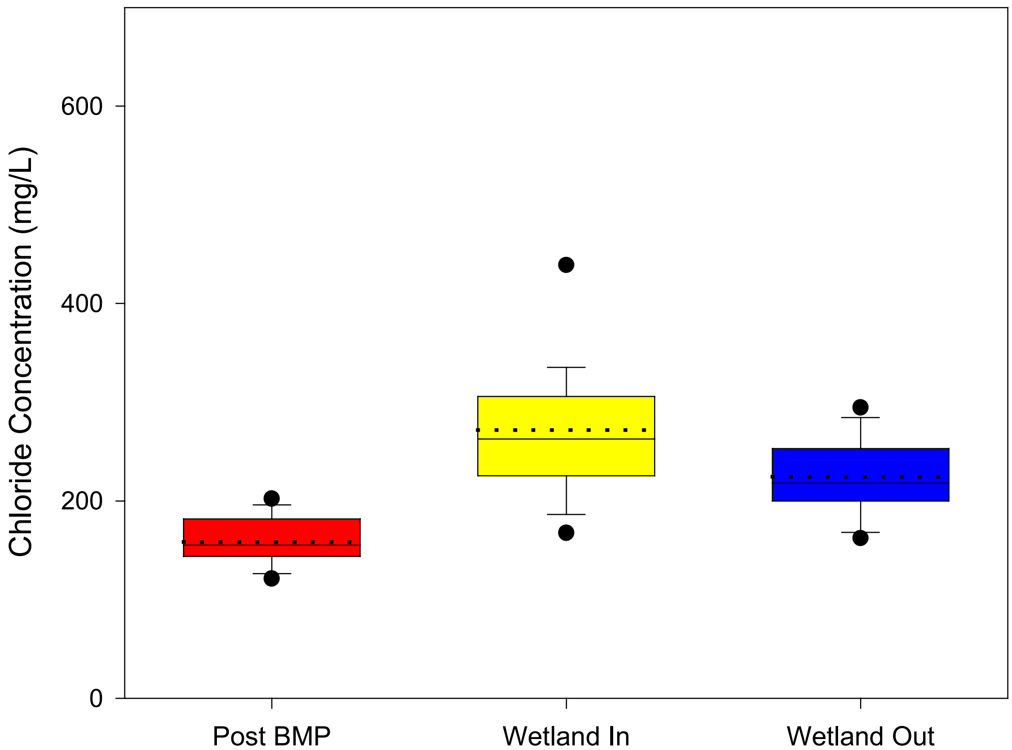


Figure 4C-15. Chemical treatment unit inflow (post-BMP), outflow (wetland in), and NTC-14 wetland outflow chloride concentrations for the CTSS-SAV demonstration from June 11, 2001 through May 25, 2002 at the STA-1W north test cell site

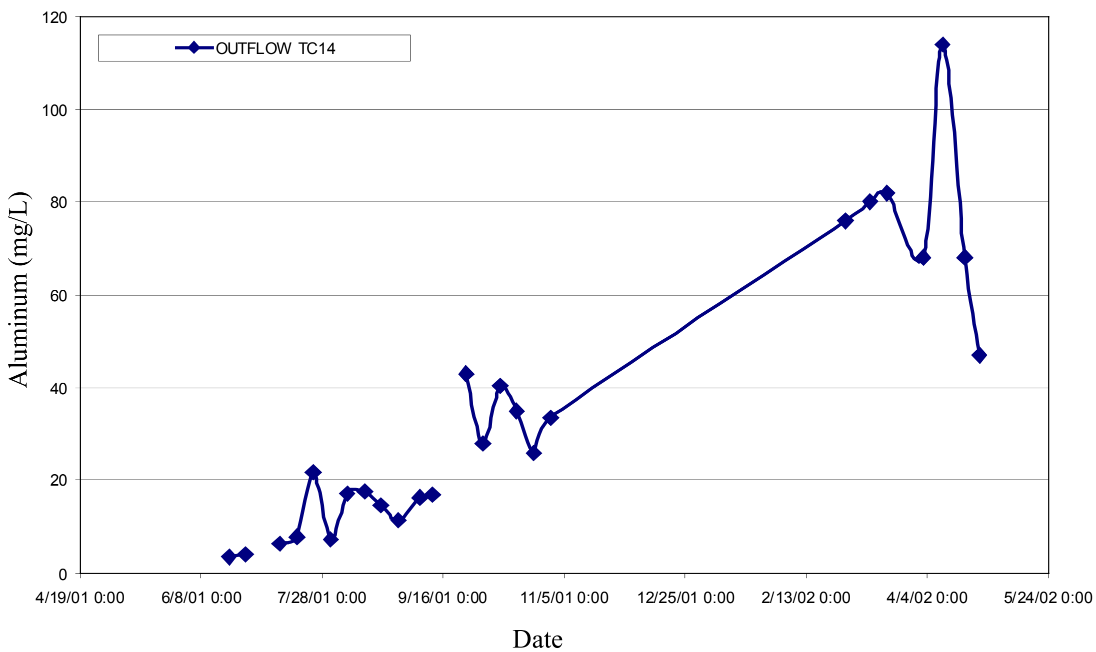


Figure 4C-16. Time series of weekly total aluminum concentrations from STA-1W NTC-14 outflow for the period from June 11, 2001 through May 25, 2002. This wetland is receiving source water from a chemical treatment plant that is being used to remove the TP from the test cell inflow water prior to discharge into NTC-14

Chemical addition did not adversely affect the reduction performance of the natural SAV wetland with respect to TOC, heavy metals, temperature, silicone oxide, sodium, manganese, potassium, TSS, hardness, DOC, pH, conductivity, calcium and sulfate (**Appendix 4C-1**). While not an objective of this experimental design, the District recognizes that increases in chloride and aluminum concentration in the wetland outflow relative to the chemical treatment unit require additional research to determine if these constituents would impact the Everglades ecosystem. The District is involved in discussions with the FDEP and the DOI to design an experiment that would address this concern.

Future CTSS/SAV Work

The District continues to operate and monitor the CTSS pilot unit SAV wetland complex at the STA-1W north test cell facility. Therefore, the District has weatherproofed and upgraded the CTSS pilot unit to increase the unit's automation.

FUTURE RESEARCH

The District will continue investigation of all promising technologies in an effort to further reduce outflow phosphorus concentrations from the Stormwater Treatment Areas. The monitoring of the Periphyton-based Stormwater Treatment Area and Submerged Aquatic Vegetation test cells located at STA-1W will also continue, along with monitoring of the Periphyton-based Stormwater Treatment Area field-scale site. In addition, the District has entered into a cooperative agreement with the University of Florida to investigate several methods of mineralizing the dissolved organic phosphorus in effluent from Stormwater Treatment Areas in an effort to further reduce outflow phosphorus concentrations.

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