Chapter 4C: Advanced Treatment Technologies

INTRODUCTION

As previously described in the 2001 Everglades Consolidated Report (ECR), the South Florida Water Management District (District or SFWMD) has been evaluating selected water quality treatment technologies, ranging from constructed wetlands that require fairly low maintenance, to full 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 the 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 for both on-farm treatment of hot spots and regional application. These technologies include:

- Periphyton Stormwater Treatment Areas (PSTAs)
- Submerged Aquatic Vegetation (SAV)/Limerock (LR)
- Managed Wetlands Treatment Systems (MWTS)
- Low-Intensity Chemical Dosing (LICD)
- Chemical Treatment/Solid 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 Stormwater Treatment Area (STA) 1W and adjacent to STA-2. Small-scale mesocosm and pilot-scale studies are located at the north (post-Best Management Practices [BMP]) and south (post-STA) Advanced Treatment Technology (ATT) research sites at STA-1W (**Figure 4C-1**). Larger-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 of the best performing experimental period for each ATT project at each scale tested. 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 a 20-acre area adjacent to STA-2. Refer to Chapter 8 of the 2001 ECR (Coffelt et al., 2001) for a complete description of these study sites and demonstration projects.

Each technology has a scientific review panel and analyses are subject to review by the Florida Department of Environmental Protection (Department), other interested agencies, professional peers and the public. All studies analyze water samples for a large set of parameters; however, this chapter will focus on updating the research with respect to P as the nutrient of most concern. Refer to the glossary for definitions of P speciation used in this Report.

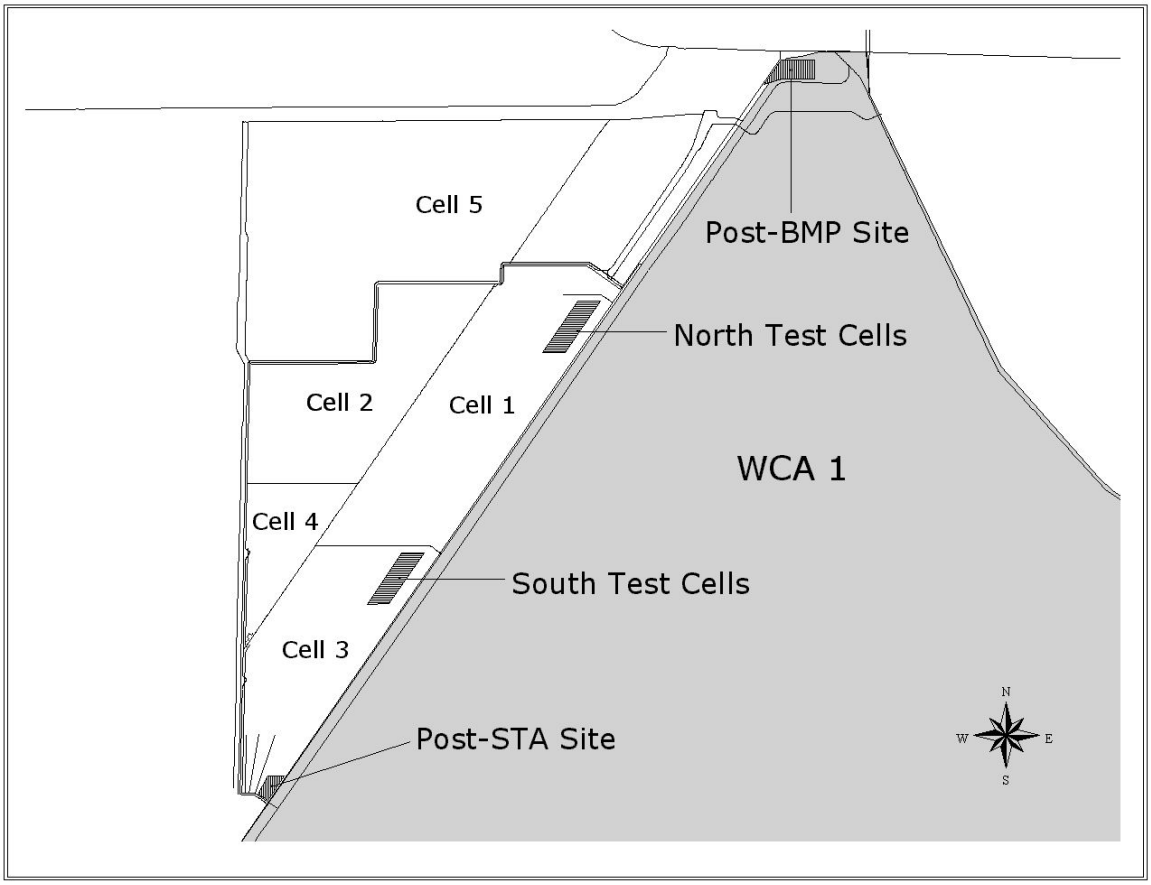

Figure 4C-1. Map showing the relative locations of the north and south Test Cell Research Facilities and Post-BMP and Post-STA sampling locations within STA-1W.

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 pulsed mode as well as in a treatment train layout with cattail and periphyton vegetation. Continue field scale monitoring and research efforts. FIU began monitoring vegetation biomass and periphyton species in Cell 4.
Periphyton Stormawater 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 SAV in a pulsed mode as well as in a treatment train layout with cattail and periphyton vegetation. Begin 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.	No future research currently scheduled.

Table 4C-1. (Continued) Summary of Advanced Treatment Technologies reviewed by the District.

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.	Scheduled completion date is October 2001. 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 2001.
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. Short term project that ran for less than 6 months. 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 will be 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. Best performance to date for each Advanced Treatment Tecnology at each scale tested. TP means presented are geometric means.

ATT	Mean Inflow [TP] (µg/L)	Mean Outflow [TP] (µg/L)	Time Frame	Water Depth (cm)	HLR (cm/d)	HRT (d)	Other Descriptors
Treatment Trailer							
CTSS – Post-BMP	161	6	12/4/99 – 12/23/99	NA	NA	0.05	Ferric chloride coagulant, inflow rate range of 0.4 to 0.8 L/s. Coagulant dose = 40 mg/L as iron
CTSS – Post-STA	20	6	12/4/99 – 12/23/99	NA	NA	0.05	Aluminum sulfate coagulant, inflow rate range of 0.4 to 0.8 L/s. Coagulant dose = 20 mg/L as aluminum
CTSS – Wellington Basin	224	6	09/2000	NA	NA	0.05	Aluminum chloride coagulant, inflow rate range of 0.4 to 0.8 L/s. Single 24 hour run, TP concentration is a single value
CTSS- C-11 Basin	On going study						
Mesocosm Research Platform							
SAV	99	13	11/98 – 3/99	40	10	4	Peat substrate with limerock treatment at outflow
PSTA	22	11	6/00 – 10/00	30	6	5	Substrate was sand prewashed with HCL
Test Cell Research Platform							
SAV	66	19	9/99 – 8/01	61	7.7	7.4	Peat substrate with limerock treatment at outflow
PSTA	21	11	4/00 – 4/01	60	6	6	30 cm shellrock over peat substrate
MWTS	99.6	32	2/00 – 12/00	33	10.4	3	North site, Post-BMP water. Coagulant used was aluminum chloride. TP outflow concentration from wetland
LICD	47	17	10/00 – 04/00	60	2.63	22	Aluminum chloride
Field Scale							
SAV	36	13	May/98 – May/99	63	11.8	5.3	STA-1W, Cell 4. No limerock at outflow

SUBMERGED AQUATIC VEGETATION (SAV)

The original SAV/Limerock (LR) technology used indigenous submerged plants to remove P from the water column, along with an LR filter positioned at the end of the system (DBEL, 1999; Gu et al., 2000) (**Figure 4C-2**). Removal of P is believed to be accomplished by plant uptake, as well as by adsorption to (or coprecipitation with) calcium carbonate ($CaCO_3$) that precipitates from the water column due to photosynthesis-related pH elevations. The LR further removed a small amount of PP and DOP. The original SAV/LR concept 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 dominant vegetation type present, recognizing that an SAV system will contain various assemblages of periphyton in addition to the dominant submerged macrophytes.

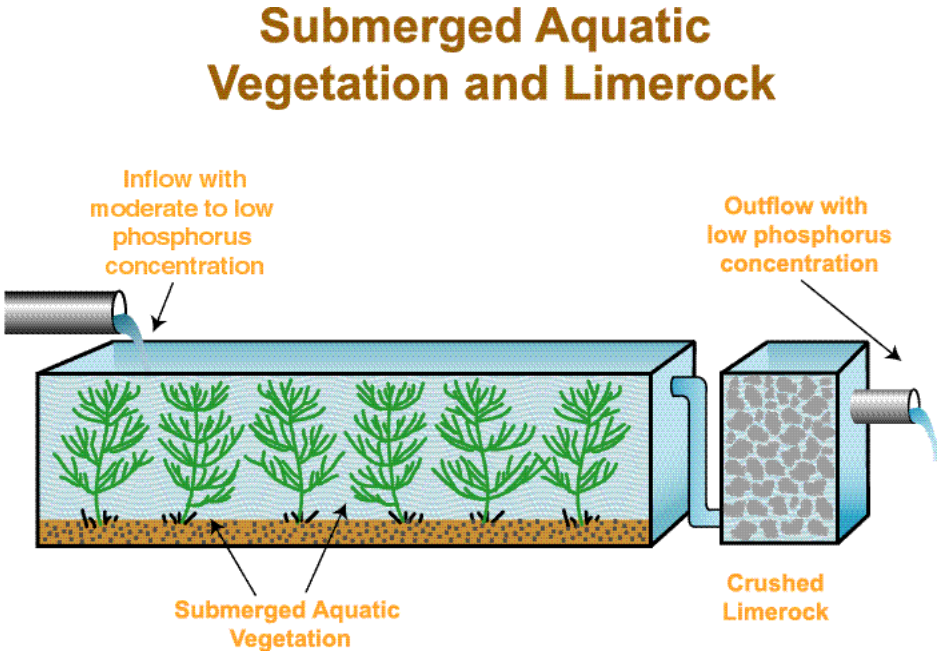

Figure 4C-2. Schematic representation of the submerged aquatic vegetation followed by a crushed limerock filter advanced treatment technology tested at STA-1W.

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, (Gu et al., 2000) and continued some of the experiments from Phase I (**Table 4C-3**). For a detailed description of the SAV project, please refer to Chapter 8 of the 2000 and 2001 ECRs (Gray and Coffelt, 2000; Coffelt et al., 2001). Additionally, **Appendix 4C-1** summarizes the data from the SAV mesocosm research conducted in Phase II, the Follow-on Study. United States Environmental Protection Agency (USEPA) Section 319(h) funding has been received for this project.

MESOCOSM RESEARCH

Effects of Variable Water Depth

The fluctuating water depth experiment at the north ATT research site was initiated May 1, 2000, with a reduction of the water depth to 0.8 m in duplicate deep (1.2 m) mesocosms. Additionally, the water depth in two shallow (0.4 m) mesocosms was increased to 0.8 m. These depths were maintained for five weeks, after which the shallow and deep mesocosms were returned to their original depths. Over the next four months the depth fluctuations were imposed every five weeks, providing varying water depths between 0.4 and 0.8 m for the shallow mesocosms, and between 0.8 and 1.2 m for the deep mesocosms. The process of raising and lowering water depths was performed gradually over a four-day period. Beginning at the end of September 2000, we lowered the water level in the shallow- and deep-depth mesocosms to 0.15 and 0.40 m, respectively. After five weeks at these lower-than-normal operating depths, the water level in each of the four mesocosms was returned to its previous stage of either 0.4 or 1.2 m for the final three weeks. During the entire study, one of each of the shallow and deep mesocosms, and all of the three moderate-depth (0.8 m) mesocosms from previous static depth experiments, were held at a constant depth to serve as "controls" (i.e., nonfluctuating depth). Weekly grab samples were analyzed for TP and SRP in these nine mesocosms (DBEL, 2001a).

Table 4C-3. An overview of research activities for the Phase II SAV/LR advanced treatment technology.

Topics	Platform	Experiments
Process Issues	Laboratory, Mesocosms, Test Cells, Cell 4	Characterization of DOP and PP
		SRP Co-precipitation
		Effects of calcium concentrations, pH and alkalinity
		Sediment Characterization
		Phosphorus Mass Balances
		Diurnal phosphorus cycle
Operation Issues	Cell 5, Mesocosms	SAV Inoculation Studies
		Lime Additions
		Vegetation Harvest
		Drydown Impacts
Management Issues	Mesocosms, Test Cells, Cell 4	Effects of Pulse-loading
		Effects of water depth
		Hydraulic Optimization
		Velocity Effects
		Substrate Effects
		Evaluation of Filtration Materials

No substantial differences in the outflow TP concentrations were observed between either variable-depth treatments or static and variable-depth mesocosms during the first 16 weeks of operation (**Figure 4C-3**). However, in August 2000 TP outflow concentrations from the variable shallow-depth mesocosms increased relative to the static depth mesocosms. The outflow water quality from the variable depth mesocosms at this time did not appear to be impaired by a further depth reduction to 0.15 (DBEL, 2001a), even though some desiccation of the top portion of the SAV (*Chara*) standing crop was observed.

When lowered to a depth of 0.4 m, the deep mesocosms did not exhibit elevated outflow TP concentrations when compared to when the water depth cycles were varied, or to the 1.2-m static "control" mesocosm. However, an increase in their outflow TP concentrations relative to the static "control" mesocosms was observed for the subsequent three-week period when water depth was returned to 1.2 m. The most obvious explanation for the export of TP from the variable depth mesocosms after the depth increase from 0.4 to 1.2 m is that inflow water was routed over the top of the "shortened" SAV canopy (DBEL, 2001a).

Effects of Pulse Loading

During the 40-week experimental period that began February 20, 2000, six mesocosms were operated under variable hydraulic loading rates based on a simulated 10-year period-of-flow record for STA-2 developed for the Supplemental Technology Standard of Comparison (STSOC). (This Report's time frame, only two ATTs [Chemical Treatment with Solid Separation, and Microfiltration] have completed the STSOC study. The STSOC study for the SAV project is currently ongoing, and results will be reported in next year's Report.) The HLRs in duplicate mesocosms were scaled to correspond with 11, 23 and 53 cm/d HLRs used in the residency time study (DBEL, 2001a,b). The investigation concluded on November 24, 2000, and culminated with two weeks of zero flow, the seventh such no-flow period during the study.

Outflow water quality was monitored throughout these quiescent periods. Generally, outflow TP concentrations were less than average in the low-load mesocosms, about average in the moderate-load mesocosms and higher than average in the high-load mesocosms (**Table 4C-4**). As previously reported (DBEL, 2000c), this phenomenon was attributed to phytoplankton growth in the stagnant, high-loaded water column, which would have received a higher internal loading during the quiescent period than the low-load mesocosms. Once flows were resumed, SAV outflow TP concentrations rapidly returned to levels observed prior to the no-flow period. Phytoplankton washout and removal of P diffusion gradient limitations on macrophyte P uptake might be possible reasons for the transient nature of the elevated TP concentrations observed during periods of zero flow (DBEL, 2000d).

TP concentration reductions in high-flow mesocosms (mean HLR of 53 cm/d) (mean HRT of 1.5 d) were greater in the control mesocosms than in the pulsed systems (52 versus 37 percent), indicating pulsing had a negative effect on P removal efficiency. However, this pulsing effect decreased with reduced loading (**Figure 4C-4**). Because the HLRs tested during this study (0 to 220 cm/d) are as much as two orders of magnitude greater than the "design" HLR for an STA (mean HLR for STA-1W is about 2.3 cm/d), the reduced performance observed under "high" pulsed flows is not likely to occur in a full-scale system. These trends suggest pulsed loading may affect performance in the inflow region of a full-scale treatment cell, but little or no effect would be detected at the outflow region under current design conditions of 2.3 cm/d (HRT of about 21 d) (DBEL, 2001a,b).

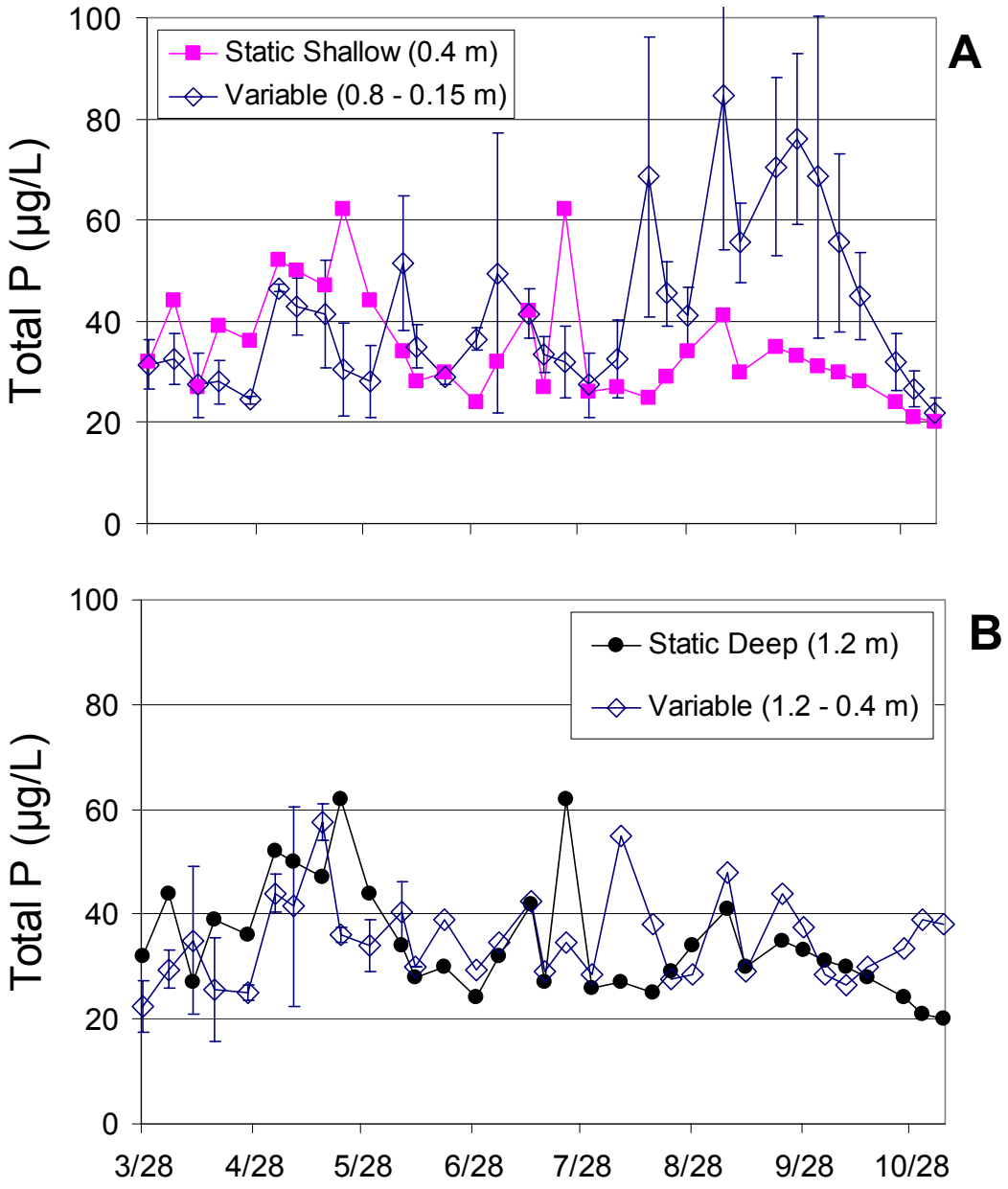

Figure 4C-3. Total P outflow concentration for (A) static and variable depth shallow mesocosms (B) and static and variable depth deep mesocosms located at the Post-BMP and Post-STA research sites. Mesocosm experiments extended from March 2000 through November 2000.

Table 4C-4. Average total phosphorus concentrations in the water column (outflow region) of north ATT site SAV pulse loaded mesocosms, during quiescent (7 two-week periods) and flowing (13 two-week periods) conditions.

	Low Load	Medium Load	High Load
Quiescent Average TP (µg L^{-1})	28	45	93
Flowing Average TP (µg L^{-1})	32	45	67

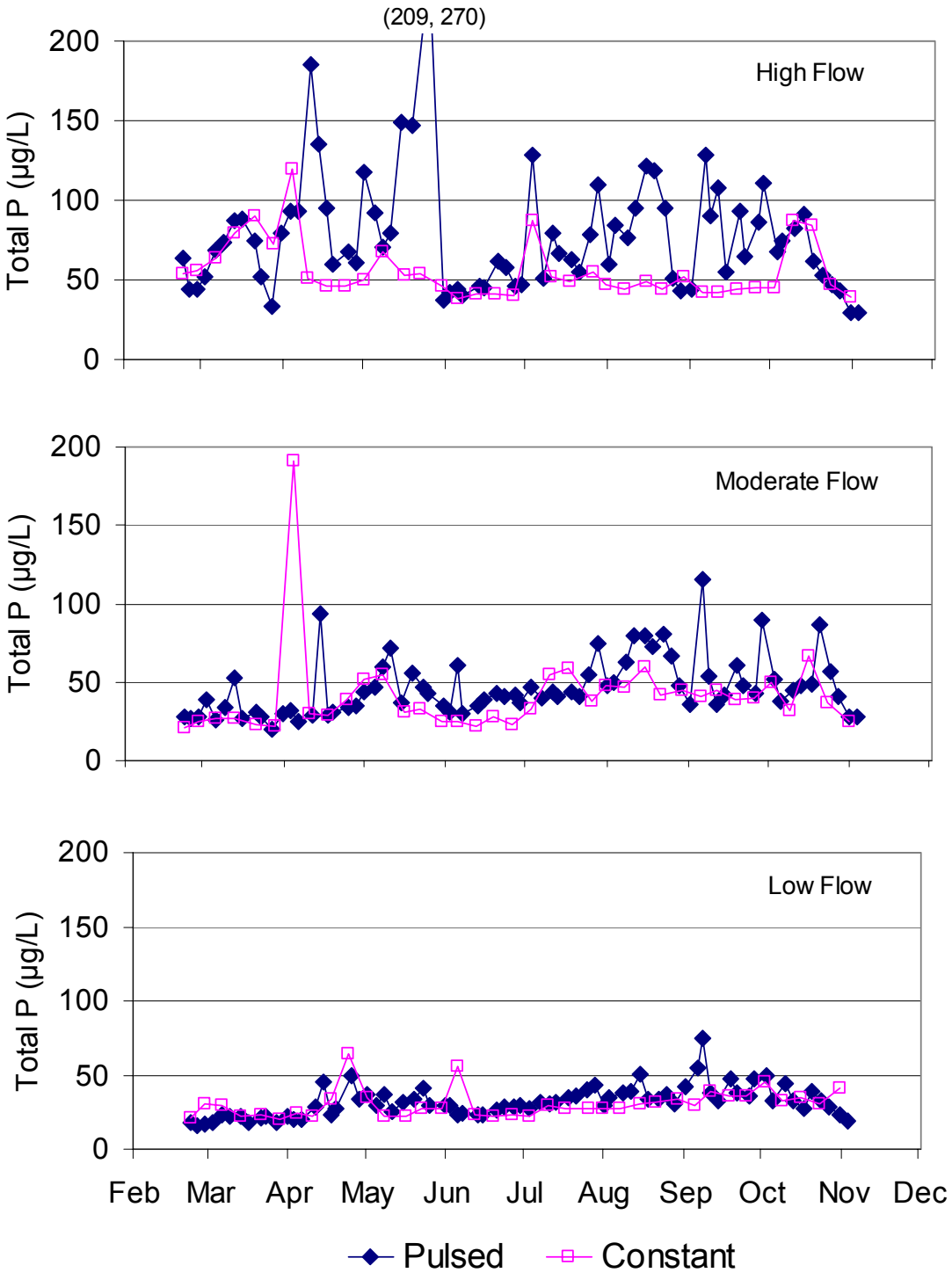

Figure 4C-4. Mean outflow TP concentrations from mesocosms that received high (55 cm/d), moderate (22 cm/d) and low hydraulic loading rates (11cm/d) of Post-BMP waters under pulsed and constant-flow regimes. Mesocosm experiment extended from February 2000 through December 2000.

Effects of Filter Media Size and Type on P Removal Performance

This experiment was designed to test the capacity of several filter media to remove particulate P. Three media were selected (limerock, Pro-Sil Plus™ and Fe-coated sand), while quartz sand was used as control. Pro-Sil Plus™ is a commercially available soil-liming material processed from Ca and Mg silicates. It is reported by the distributor to have a high P-adsorption capacity. Iron-coated sand was collected from a construction site in Central Florida. Limerock was obtained from the West Palm Beach Aggregates quarry. Sampling of the 16 filter column inflows and outflows was performed from August 18 to November 17, 2000. Total P, SRP and TDP concentrations were analyzed as twice-weekly grab samples, while specific conductance, Ca and alkalinity samples were composited each week (DBEL, 2000d).

Mean inflow and outflow concentrations of TP, SRP, Ca and alkalinity are presented in **Table 4C-5**. Outflow TP concentrations were slightly lower for the limerock and Pro-Sil Plus™ (13 to 14 µg/L) than for the quartz treatments (14 to 17 µg/L). There were no differences between coarse and medium-size filter media in TP removal. The TP concentrations in the twice-weekly grabs varied less toward the end of the sampling period across all three substrates within each size fraction (DBEL, 2001b).

The Pro-Sil Plus™ media reduced Ca and alkalinity concentrations by about five percent, whereas for other media types these constituents increased or remained unchanged (**Table 4C-5**). The Fe-coated sand columns released large quantities of SRP once flow was initiated. Although the release rate decreased following startup, export continued through the last week of the study (DBEL, 2001b).

Effects of Calcium/Alkalinity and Soluble Reactive Phosphorus Concentrations on Phosphorus Coprecipitation

Findings from the Phase I research using post-BMP waters suggest that P removal in an SAV system is controlled in part by water-column hardness and alkalinity (DBEL, 1999). SAV performance was tested at high and low Ca (80 to 100 versus ~20 to 30 mg/L) and alkalinity (325 to 375 versus ~75 to 150 mg $CaCO_3$ L^{-1}) concentrations, as well as high (125 to 160 µg/L) and low (20 to 40 µg/L) SRP concentrations. Eight microcosms containing *Najas guadalupensis* were receiving the various Ca/alkalinity and SRP media at a hydraulic loading rate of 9.6 cm/d (3.5-day HRT). To date, SAV cultured under the high Ca/alkalinity regimes has provided lower outflow TP concentrations than under the low Ca/alkalinity concentrations. For the "low-SRP" microcosms, outflow TP concentrations have averaged 12 and 17 µg/L under high and low Ca/alkalinity conditions, respectively. While under "high-SRP" conditions, outflow TP concentrations have averaged 26 µg L^{-1} (high Ca/alkalinity) and 64 µg/L (low Ca/alkalinity) (DBEL, 2001 a,b).

Considering that both SRP and dissolved organic carbon (DOP) can co-precipitate with $CaCO_3$ (Seuss, 1970; Murphy et al., 1983; Danen-Louwerse, et al., 1995), total soluble P (TSP) component of the analytical data was examined for the relevance of the P co-precipitation process. For these first three months of the experiment, TSP was reduced to a greater extent in the high-Ca/alkalinity, high-SRP treatment than in the low-Ca/alkalinity, high-SRP (**Table 4C-6**).

Table 4C-5. Mean (± 1 s.d.) TP, SRP, calcium and alkalinity concentrations in the inflow and outflows of filter media columns tested in the SAV/LR study during the August 18-November 17, 2000 period of record.

		Quartz			Limerock		Pro-Sil Plus™		Iron-coated Sand
	In-flow	**Coarse**	**Med.**	**Fine**	**Coarse**	**Med.**	**Coarse**	**Med.**	**Fine**
Total P (µg/L)	17 ±4	15 ±5	14 ±4	17 ±5	14 ±4	13 ±6	13 ±4	13 ±3	122 ±74
SRP (µg/L)	3 ±1	4 ±2	4 ±2	7 ±3	3 ±2	3 ±1	3 ±1	2 ±1	87 ±66
Calcium (mg/L)	74 ±5	77 ±6	76 ±6	77 ±5	77 ±5	77 ±5	71 ±12	72 ±12	73 ±7
Alkalinity ($mgCaCO_3/L$)	253 ±12	261 ±14	261 ±12	260 ±17	260 ±14	263 ±12	248 ±46	246 ±50	263 ±16

Table 4C-6. Mean (± 1 s.d.) TP, SRP, dissolved Ca and alkalinity concentrations in the inflows and outflows from duplicate aquaria operated under four treatments during the November 2000 – January 2001 quarter in the SAV/LR project.

	Treatment #1 Low Ca/alk Low P	**Treatment #2 Low Ca/alk High P**	**Treatment #3 High Ca/alk Low P**	**Treatment #4 High Ca/alk High P**
TP (µg/L)				
Inflow	38	166	34	171
Outflow	17 ± 3	64 ± 7	12 ± 2	26 ± 3
TP Removal	21	102	22	145
TSP (µg/L)				
Inflow	27	157	26	163
Outflow	9 ± 1	51 ± 6	7 ± 2	17 ± 3
TSP Removal	18	106	19	146
SRP (µg/L)				
Inflow	17	142	13	113
Outflow	2 ± 0	36 ± 7	2 ± 1	7 ± 2
SRP Removal	15	106	11	106
Alkalinity (mg $CaCO_3$/L)				
Inflow	63	62	340	339
Outflow	69 ±3	72 ± 2	270 ± 10	266 ± 7
Alkalinity Removal	-6	-10	70	73
Diss. Calcium (mg/L)				
Inflow	26	26	85	84
Outflow	28 ± 1	29 ± 1	57 ± 3	56 ± 2
Calcium Removal	-2	-3	28	28

Characterization of Particulate Materials

Particulate materials contain P, which is often not removed by the SAV community. It is important to understand the composition and characteristics of these particulate materials for the design of treatment systems. Particles from inflow and outflow waters of Cell 4 and two test cells (one SAV, one cattail) were isolated and characterized in this study. Different size fractions of particles were concentrated into slurries with a tangential flow filtration device. The isolated particles were characterized with respect to size, surface charge and mineralogical and chemical analyses. While data analyses are still underway, initial characterization demonstrates that particles from the inflow and outflow of all systems consist of calcite, silicate and organic matter. Calcite levels were found to be higher in the outflow waters from Cell 4 when compared to the test cells (DBEL, 2001b).

TEST CELL RESEARCH

The 0.2-ha test cells located at the north site were operated with an HLR of 11 cm/d, water depth of 0.6 m, and an HRT of 5 d, while the south-site test cells were operated with an HLR of 5 cm/d, water depth of 0.35 m and HRT of 6 d. In April of 2000 one test cell each at the north and south sites (NTC- 15 and STC-9) was retrofitted by adding a limerock berm across each outflow. The objective was to test the hypothesis that the limerock berm would provide attachment sites for bacteria that would mineralize the dissolved organic phosphorus (DOP) into SRP, a readily plant available form of P, thereby increasing the net P removal from the system. The north test cell inflow TP concentrations varied from 25 to 97 µg/L, with a mean of 57 µg/L. Both NTC-1 and NTC-15 reduced TP concentrations relative to inflow, with mean outflow TP concentrations of 17.2 and 21.4 µg/L, respectively (**Figure 4C-5**). The inflow TP concentrations in the two south test cells were lower than at the north site, with a mean of 20 µg/L. The mean outflow TP concentration from STC-4 was 21.3 µg/L, which was slightly elevated relative to the inflow, while STC-9 slightly reduced TP outflow concentrations to a mean of 16.5 µg/L. Reduced TP removal at the south test cells was also observed in the STA optimization cattail- dominated systems (Nungesser et al., 2001) and is most likely due to the low concentration of SRP in the south test cell inflow water. Additionally, preliminary evidence indicates the limerock berms provided no extra TP reduction at the north site and minimal TP reduction at the south site.

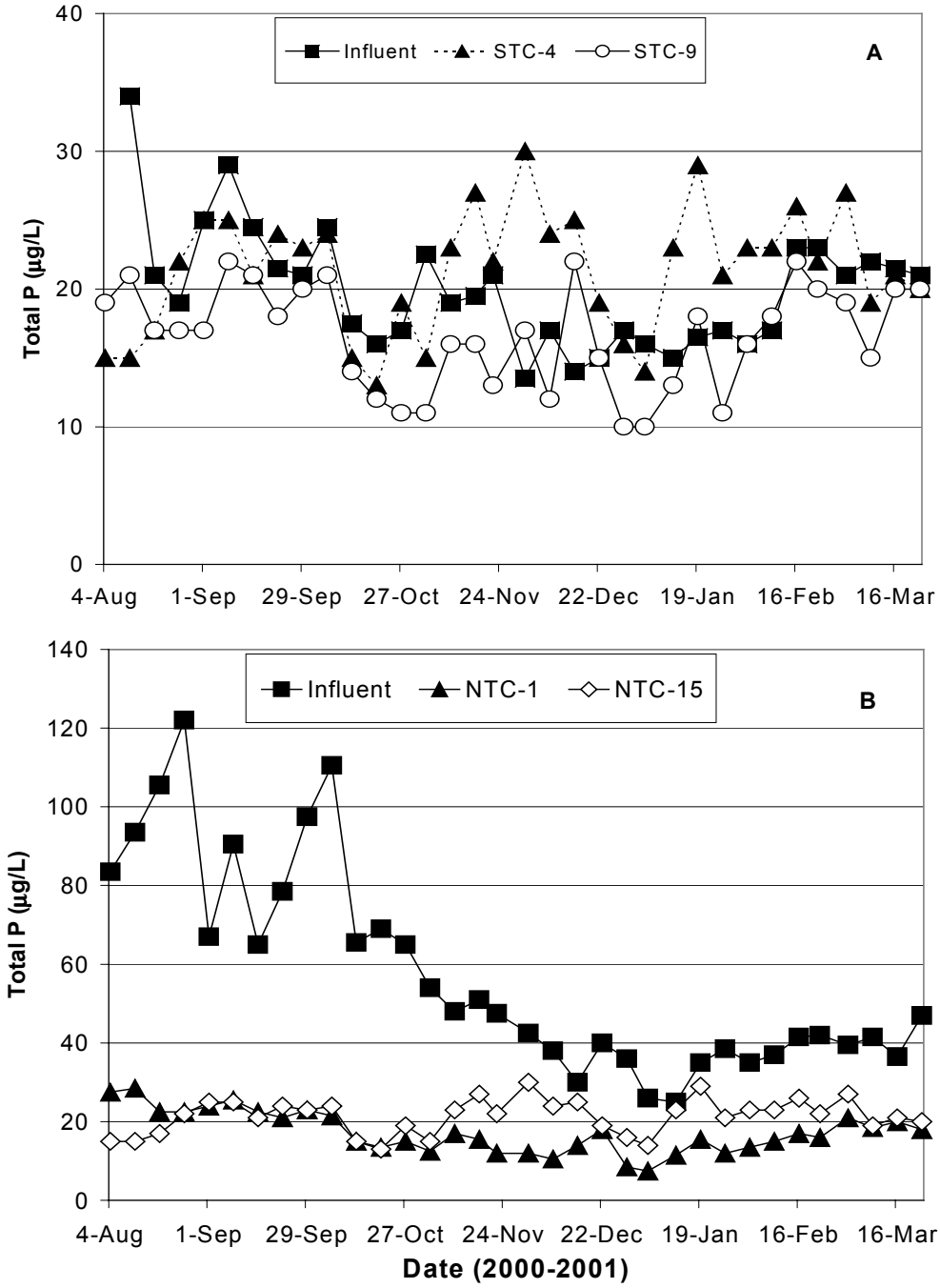

Figure 4C-5. Weekly inflow and outflow TP from SAV research project at the STA-1W Test Cell Research Facilities from August 2000 through March 2001. Inflow values represent the mean ± 1 standard deviation (n=2). **Panel A**.SAV test cells STC-4 and STC-9 located at the south test cell facility. **Panel B**. SAV tet cells NTC-1 and NTC-15 at the north test cells facility. STC-4 and STC-9. Outflow regions of STC-9 and NTC-15 are equipped with a limerock berms.

FIELD SCALE RESEARCH, STA-1 WEST

Cell 4 Hydraulic Optimization

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. Analysis of the tracer movement revealed that about 51 percent of the inflow water bypassed the SAV beds and moved rapidly down deep existing borrow canal areas (DBEL, 2000a). Actions to improve the hydrology 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. They were installed during 2000 (DBEL, 2001b). A second tracer study to verify the extent of hydraulic improvement has been delayed due to the regional drought, but is expected to be conducted in the second half of 2001 when sufficient flow is available.

STA-1W, Cell 5

A survey of SAV colonization at the 120 monitoring stations established in STA-1W, Cell 5, was conducted quarterly. SAV, in particular *Najas* and *Ceratophyllum*, were the most prevalent species observed throughout the cell. Increasing SAV presence in the sampling stations was observed over the sampling period (**Figures 4C-6** and **4C-7**).

Although we observed wide variability in the SAV standing crop among stations, lowest water column SRP concentrations were generally found at the sites with greatest standing crop biomass (DBEL, 2001b). Apparent color and TP concentrations showed a general trend of decreasing after SAV was introduced to Cell 5. SAV has continued to colonize throughout the wetland, a factor that likely is contributing to the improved water quality (DBEL, 2001b).

FORECAST MODEL DEVELOPMENT

A mechanistic model for the SAV/LR treatment system is currently under development. The model development provides a means for integrating data and concepts generated in the many multi-scale experiments in the project. The calibrated model will be used to address three research objectives: (1) to define the ultimate P removal potential in SAV systems, (2) to predict system response to disturbance, and (3) to predict long-term sustainability of SAV performance (DBEL, 2000b). Three quarterly sampling and analyses from STA-1W, Cell 4 were conducted to provide information on P mass balance, fluxes and release rates from sediments for model calibration. This model may be used as a module component in the Dynamic Model for Stormwater Treatment Areas (DMSTA) model currently under development by the United States Department of the Interior (DOI).

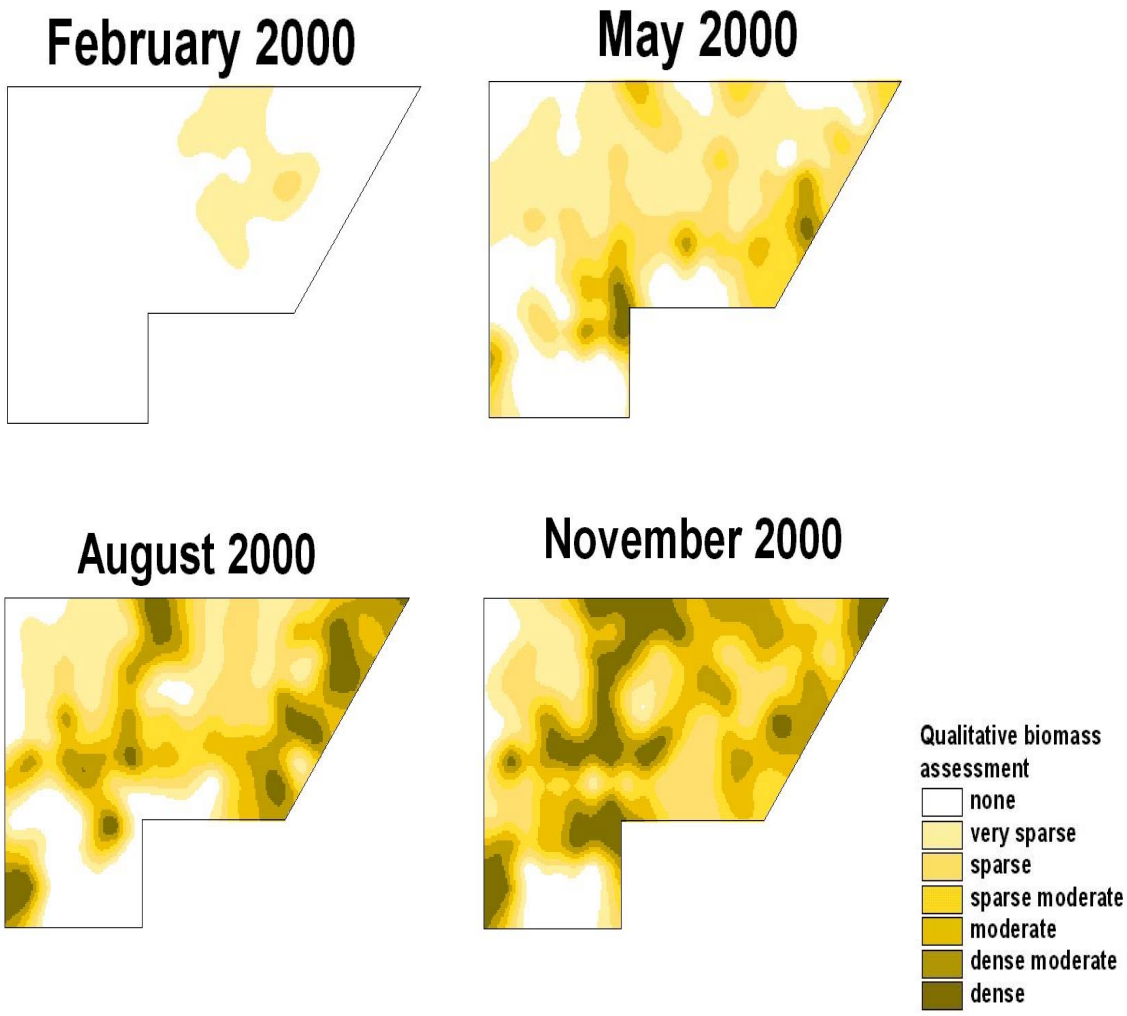

Figure 4C-6. STA-1W, Cell 5 SAV Colonization: Presence and distribution of *Najas guadalupensis* beds during four 120-station visual surveys during 2000.

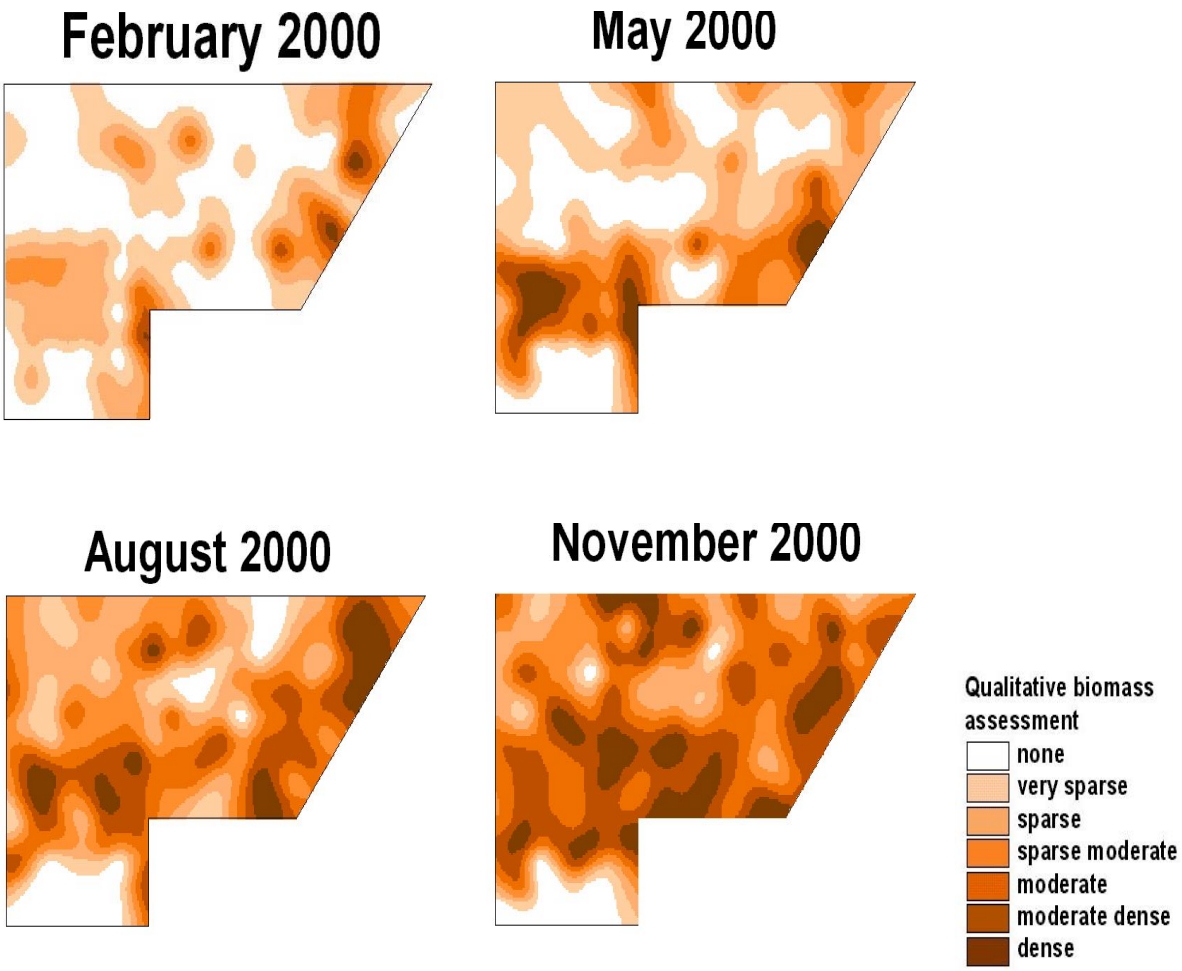

Figure 4C-7. STA-1W, Cell 5 SAV Colonization: Presence and distribution of *Ceratophyllum spp.* during four 120-station visual surveys during 2000.

FUTURE RESEARCH

Research on water quality data analysis for aquatic systems naturally dominated by SAV, and analysis of P accretion rates based on sediment records from Lake Pannasoffkee, a system in Central Florida with a long history of SAV colonization, are currently under way. The District is planning to conduct a literature review on SAV ecology, nutrient uptake associated with P removal, sedimentation and environmental effects on SAV growth, and P removal to gain more information for better evaluation of this ATT (Gu et al., 2000).

SUMMARY

Research over the last 12 months has focused on several key mesocosm and test cell experiments, while also monitoring the TP removal at field scales (STA-1W, Cells 4 and 5). Changes in water depth within the experimental range had no significant effects on TP removal performance. Findings from the pulse-loading experiments indicated that high pulse loading might have a negative effect on P removal efficiency in the inflow region of a full scale STA, but little or no effect would be expected at the outflow region under current design conditions of 2.3 cm/d.

Microcosm experiments indicated that high Ca and alkalinity treatment was more effective in SRP removal than low Ca and alkalinity treatment. In test cell and filter-media experiments, limerock or limerock berms provided better TP removal rates than systems without limerock components. Intensive field sampling and laboratory analysis for STA-1W, Cell 4 have provided sufficient data to be used in the calibration of the performance-forecast model. A survey of SAV growth in STA-1W, Cell 5 indicated that SAV has expanded vigorously since the inoculation took place over a year ago, suggesting that limited SAV inoculation can produce substantial increases in system colonization.

Preliminary results from the SAV test cell research are similar to those findings for cattail dominated systems, in that further TP removal from the southern test cells is extremely difficult with outflow TP concentrations often greater than or equal to inflow concentrations. Additionally, these combined findings may indicate that outflow TP concentrations at the south test cells (lower inflow TP concentrations) may be driven by autogenic biogeochemical nutrient cycling.

PERIPHYTON-BASED STORMWATER TREATMENT AREAS (PSTAS)

In a PSTA, post-STA water flows over substrate colonized primarily with calcareous periphyton (attached algae) and sparse macrophytes, the latter primarily functioning as additional substrate and a stabilizing mechanism for algal mats **(Figure 4C-8)**. Phosphorus is removed from the water column through biological uptake, through chemical adsorption with carbonate diatom shells associated with the algae and through coprecipitation 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 remained focused on using PSTA as a polishing cell within or in addition to an STA.

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 (SFWMD, 2000a). 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. This section summarizes the results from the final year of mesocosm and test-cell research, and then describes the final design of the 20-acre demonstration project currently under startup. **Table 4C-1** presents a brief description and status summary of the PSTA research, while **Table 4C-2** provides a summary of the best performing experimental period for PSTA experiments at each scale tested. Refer to Chapter 8 of the 2001 ECR (Coffelt et al., 2001) for a complete description of the PSTA concept and details of the Phase 1 mesocosm and test cell research.

CURRENT STATUS OF PSTA RESEARCH

Phase 2 of the PSTA project began in March 2000 and is ongoing. Phase 2 includes three of the south STA-1W test cells (PSTA test cells), 24 portable PSTA mesocosms (Porta-PSTAs) and startup of the 20-acre field scale project. Routine monitoring of the Porta-PSTAs was completed in early October 2000, while monitoring of the three test cells continued through March 2001. With the support of the Department, all major nutrient storage compartments of 10 Porta-PSTAs were intensively sampled in February 2001 to provide a detailed analysis of P storage sites, while the Stormwater Treatment Standard of Comparison (STSOC) testing was completed in two of the three PSTA test cells in April 2001. With the support of the Everglades National Park, construction of the 20-acre field site was completed in June 2001.

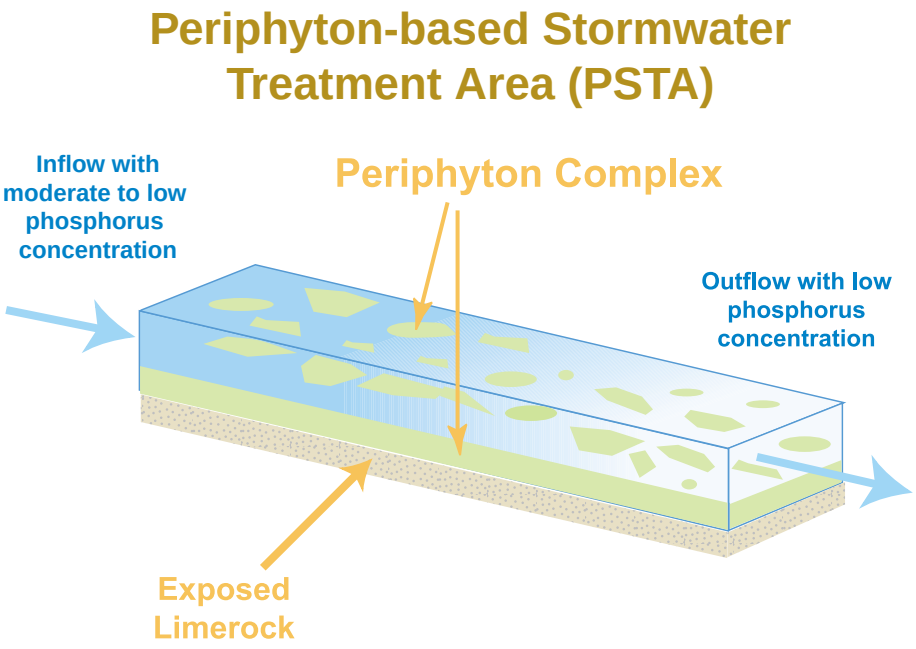

Figure 4C-8 Schematic representation of the periphyton vegetation advanced treatment technology tested at STA-1W.

PSTA Mesocosms

Twenty-two of the mesocosms measure 6 m L x 1 m W x 1 m D. The remaining two mesocosms are three meters wide to allow for assessment of side effects in mesocosm studies. Phase 2 experiments studied the effects of antecedent soil type, water depth, water regime, plant communities, flow velocities, soil amendments and mesocosm size on P removal performance. The peat and shellrock mesocosm systems were replicated three times, while other treatments were not. This Report will highlight the results of the replicated mesocosms. Refer to the July 2001 Phase 2 Interim Report (CH2M Hill, 2001a) for a more detailed description of the experimental design. **Appendix 4C-2** provides performance summaries, HLR and HRT values for these experiments. However, a complete statistical analysis of the data has not yet been completed; therefore, standard deviations or statements regarding the significance of differences has not been included.

Phosphorus inputs into the mesocosms during Phases 1 and 2 were highly variable and are demarcated on the graph (**Figure 4C-9**). The average TP inflow concentration during Phase 2 was about 29 µg/L. Total dissolved P made up 55 percent of the inflow, while SRP represented about 24 percent of the inflow, with means of about 16 and 8 µg/L, respectively (**Table 4C-7**).

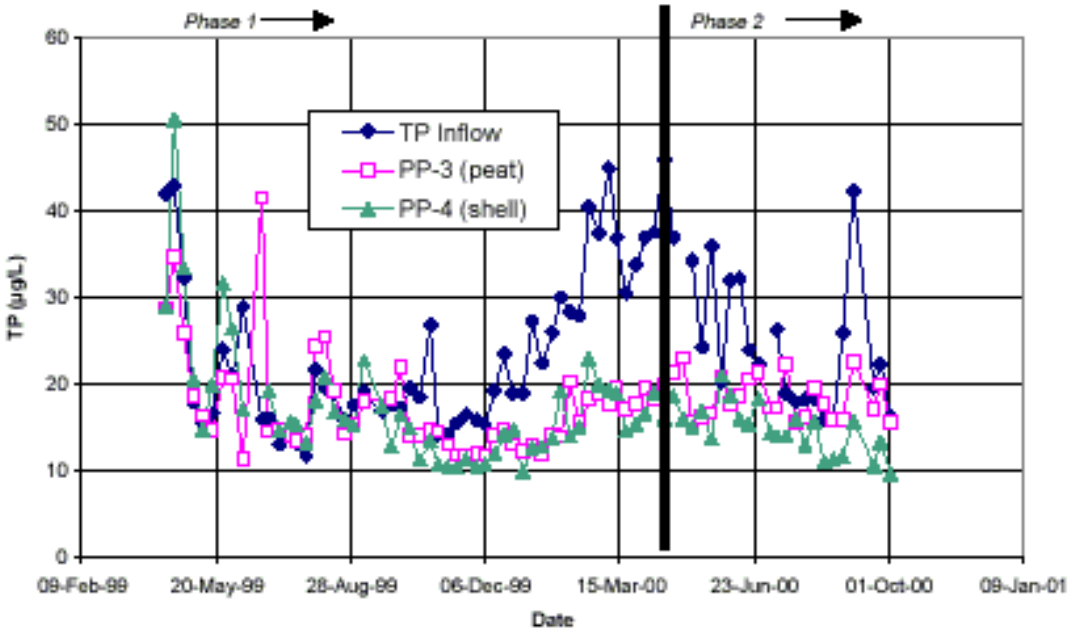

Figure 4C-9. Total phosphorus in selected Porta-PSTA Mesocosms for the entire Period of Record. The inflow is indicated by the blue line. The outflow from the shellrock and peat systems are in green and pink respectively.

Table 4C-7. Mean inflow and outflow concentrations from the PSTA mesocosms located at the South Supplemental Technology Treatment Site, STA-1W from April 2000 through October 2000 (Phase 2). Mesocosm treatment numbers 3 and 4 are summarized because they represent the longest running mesocosm system at one operating depth (30 cm) and HLR (6 cm/d).

Treatment	TP	SRP	TDP	TPP	DOP
Peat Inflow (μg L^{-1})	29.0	7.0	16.0	14.0	8.0
Peat Outflow (μg L^{-1})	19.0	2.0	10.0	9.0	5.0
% Reduction	36%	71%	37%	36%	37%
Shellrock Inflow (μg L^{-1})	29.0	6.0	15.0	14.0	9.0
Shellrock Outflow (μg L^{-1})	15.0	2.0	8.0	6.0	5.0
% Reduction	49%	77%	47%	57%	45%

Mean TP outflow concentrations were slightly higher from the peat mesocosms than from the shellrock mesocosms during Phase 2 (**Figure 4C-9**), with the mesocosm outflow concentrations diverging during Phase 2. Average outflow TP concentrations during Phase 2 were about 19 μg/L for the peat replicates and 15 μg/L for the shellrock replicates. However, the best of the three replicates in each of these treatments had identical average Phase-2 outflow TP concentrations. Additionally, both the peat and shellrock systems reduced the SRP to about 2 μg/L, with 92 percent of the values reported as less than or equal to the method detection limit (MDL) of 2 μg/L. As reported last year (Coffelt et al., 2001), shallow water depths had significantly elevated P uptake rate (k_1 values), and therefore water depths in all Phase 2 PSTA studies were dropped to 30 cm.

Ten Porta-PSTAs were intensively sampled in February 2001 to provide a detailed analysis of phosphorus storage sites. This information was used to augment the TP mass-retention values calculated for these mesocosms. In the sand, peat and shellrock system, the sediment accounted for the largest store of P, with values of 5,675; 9,460; and 270,701 mg/m^2, respectively, dwarfing the other P storage P compartments (**Table 4C-8**). However, these sediment values have not yet been adjusted for the initial mass of P, and P net losses or gains to the sediment are yet to be determined. Therefore, the sediment values will not be included for this comparison. The periphyton accounted for 96, 95, 76, 62 and 22 percent of the TP in the tanks with synthetic substrate, no substrate, sand, shellrock and peat, respectively. However, the mass of P contained in the sand substrate tank was greater than that contained in the other tanks sampled. The peat and no substrate tanks were the least efficient at reducing TP concentration, while the sand, synthetic sub-

strate and shellrock substrate tanks were the most efficient, with percent reductions of 34, 41, 46, 46, and 48 percent, respectively.

Table 4C-8. Mean phosphorus content (mg/m^2) of the major storage compartments in selected PSTA mesocosms at the time of the destructive sampling.

Treatment	Water Column	Periphyton	Mcacrophytes	Consumers	Sediment	Total
Peat	6.05	95.0	319.7	5.33	9,460.0	9,886.08
Shellrock	4.10	391.5	230.5	0.15	270,701.0	271,327.25
Sand	4.03	626.5	194.7	2.47	5,625	6,452.7
No Subtrate	3.44	183.7	0.0	5.69	0.0	192.83
Synthetic Substrate	3.59	272.6	0.0	9.07	0.0	285.26

South STA-1W Test Cells

Three test cells located at the south STA-1W test-cell site were assigned to the PSTA Research and Demonstration Project. During final construction, the substrate of two of the test cells was modified by placing the following layers over the liner:

- Test cell 13: 2.5 feet of sand surcharge, plus 1 foot of locally mined shellrock, plus 1 foot of peat taken from STA-1W, Cell 5 prior to flooding and amended with Ca during Phase 2
- Test cells 8 and 3: 3.5 feet of sand surcharge plus 1.0 foot of locally mined shellrock.

During the Phase 2 studies, the operating depth in these wetlands was lowered from 60 to 30 cm, while maintaining the HLR at about 6 cm/d, thereby reducing the HRT to about five days.

Phosphorus inflows to the south test cells were also highly variable, with mean inflow concentrations during Phase 2 of about 22 µg/L (**Figure 4C-10**). TDP was the dominant species of P entering the test cells, comprising about 60 percent of the inflow, while SRP represented about 30 percent of the inflow, with mean concentrations of about 13 and 7 µg/L, respectively (**Table 4C-9**).

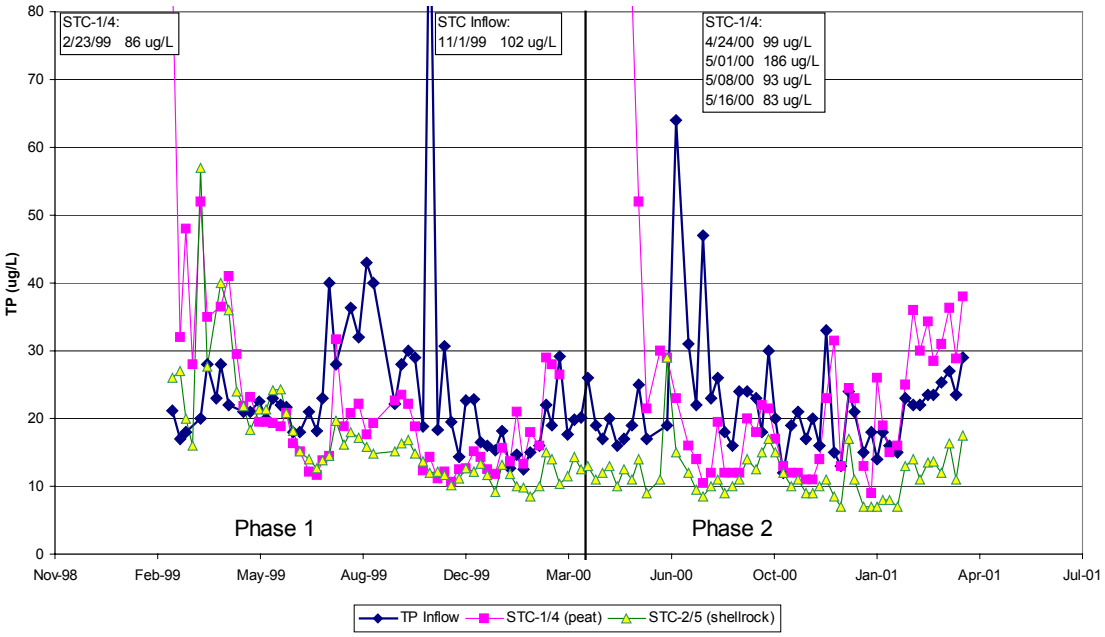

Figure 4C-10. Total phosphorus in the PSTA Test Cells for the entire Period of Record. The inflow is indicated by the blue line. The outflow from the shellrock and peat systems are in green and pink respectively.

Table 4C-9. Mean inflow and outflow concentrations from the PSTA Test Cells located at the South Test Cell Site, STA-1W from March 2000 through March 2001.

Treatment	TP	SRP	TDP	TPP	DOP
Peat Inflow (µg/L)	23.0	6.0	13.0	10.0	8.0
Peat Outflow (µg/L)	32.0	2.0	17.0	15.0	12.0
% Reduction	**-42%**	**67%**	**-27%**	**-49%**	**-53%**
Shellrock Inflow (µg/L)	23.0	6.0	13.0	10.0	8.0
Shellrock Outflow (µg/L)	12.0	2.0	7.0	4.0	5.0
% Reduction	**49%**	**68%**	**45%**	**58%**	**36%**

In preparation for Phase 2, the entire peat-based test cell was drained and limed and therefore experienced another startup phase. Outflow TP concentrations from the peat test cell exceeded inflow TP concentrations during Phase 2, with mean outflow concentrations of 32 µg/L. However, TP outflow concentrations from the shellrock lined test cell were reduced by about 47 percent, with outflow concentrations of about 12 µg/L. Both peat and shellrock systems reduced SRP to about 2 µg/L, with about 96 percent of the samples in each system reduced to less than or equal to the MDL. However, the shellrock test cell reduced TDP inflow concentrations by about 38 percent, while the peat test cell increased TDP mean outflow concentrations from about 13 to 17 µg/L (**Table 4C-9**).

The STSOC requires a standard format of testing procedures that will be applied to all the ATTs in order to ensure a standard format for comparison. The STSOC testing was performed on the half-acre peat and constant depth shellrock PSTA test cells for a five-week period beginning February 27, 2001 and ending April 3, 2001. The results of this study will be available on the ET Website by December 2001 and will be reported in next year's ECR. Please refer to Chapter 8 of the 2000 and 2001 ECRs for a more detailed description of the STSOC methodology (Gray and Coffelt, 2000; Coffelt et al., 2001).

PSTA Phase 2 Tracer Studies

Hydraulic tracer studies were conducted at three PSTA test cells and at one PSTA mesocosm tank (shellrock at 30 cm depth) between January 30, 2001 and February 27, 2001. The full report is located at Website http//www.sfwmd.gov/org/erd/ect/etweb/main_template/report.html. The objective of the tracer study was to document the nominal HRT during Phase 2 and describe the hydraulics of the wetland.

The nominal HRT (τ_n) represents the ratio between the volume of water in the wetland divided by the volumetric flow rate into the wetland, whereas the residence time distribution (RTD) characterizes the actual detention time of the stream of tracer particles leaving the wetland and is used to calculate a mean residence time (τ_m) that represents the actual HRT (Fogler, 1999; Levenspiel, 1999). In addition to verifying the HRT, tracer studies are useful tools used to characterize the flow patterns through a system. In general, wetland treatment systems are sized assuming steady-state, plug-flow hydraulics (Kadlec and Knight, 1996). Plug-flow hydraulics states that no diffusion or mixing occurs along the flow path and is the most efficient, requiring the smallest vessel size (Levenspiel, 1999). However, dye tracer studies of various treatment wetland systems have indicated that these systems are not likely to exhibit plug-flow hydraulics and that the mean residence time (τ_m) is generally over-estimated by the nominal HRT (τ_n) (Kadlec and Knight, 1996). Levenspiel (1999) described two other steady-state, one-parameter models – dispersion and tank-in-series – that can be used to characterize small deviations from plug-flow or non-ideal hydraulics. Plug-flow reactor volumes can be successfully modeled by conceptually combining an infinite number of continuous-stirred tank reactors in a series, and as the number of tanks-in-series (N) increases, the behavior of the wetland approaches plug-flow (Levenspiel, 1999). Levenspiel (1999) has shown that the five continuous-stirred tanks-in-series will have the same conversion rate as one plug-flow reactor of equal volume. Therefore, systems with five tanks-in-series or more can be thought of as operating as a plug-flow reactor.

Tracer spikes were prepared using LiCl brine solution, with approximately 78,460 mg/L as Li ion to yield average, well-mixed concentrations of about 350 µg/L as Li. The tracer solution was applied to each cell over a period of about two minutes by pouring the contents into the inlet distribution system. Automated ISCO samplers (Model 3700) were deployed at the outlets of each cell and were programmed to collect 125 ml samples at varying intervals, beginning at the time of

initial tracer application. Grab samples were also collected at the STA-1W outflow pump station during the course of the experiment to verify that the discharge from the study would not raise the background concentrations of Li in STA-1W. Samples were chilled with ice and sent for analysis. Daily test cell outflow rates were calculated as the net result of measured inflow rates, rainfall and evapotranspiration.

The tracer-study data were interpreted by following the gamma-distribution method suggested by Levenspiel (1999). The results indicate that the test cells have similar hydraulic properties with the number of tanks-in-series ranging from 3.8 to 4.1, while the mesocosm more closely resembles a completely stirred tank reactor with an estimated 1.1 tanks-in-series value (**Table 4C-10**). When the RTD curves are plotted in a dimensionless form to allow for comparison, the curves of the three test cells are nearly identical, while the mesocosm tank curve indicates different hydraulics (**Figure 4C-11**).

Table 4C-10. Summary of lithium tracer studies performed at the PSTA mesocosm and Test Cells located with the southern portion of STA-1W. Tracer tests began 30 January 2001.

	Half-acre Test Cells			Mesocosm
Parameter	**Shellrock 1**	**Shellrock 2**	**Peat**	**Shellrock**
Average volume (m^3)	698	716	729	1.8
Average flow (m^3/d)	60	116	115	0.23
Nominal HRT (d)	11.7	6.2	6.4	7.8
Mean HRT, τ (d)	14.1	5.6	4.7	6.7
Number of tanks (N)	4.1	4.0	3.8	1.1
Volumetric efficiency (%)	120	91	73	86
Mass recovery (%)	70	81	95	62

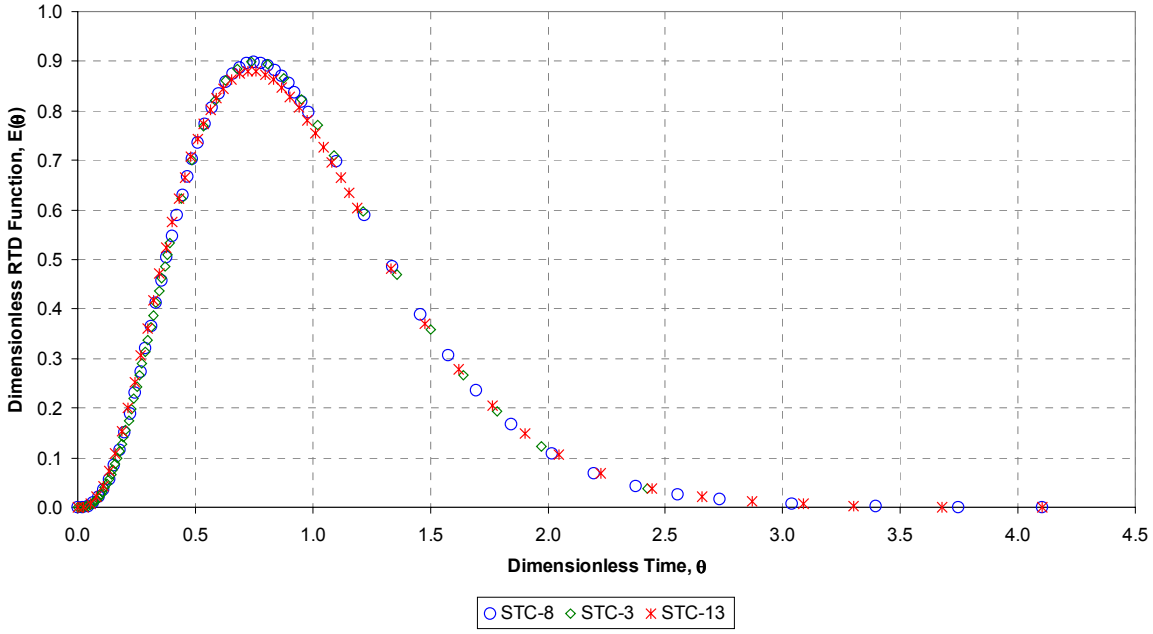

Figure 4C-11. Comparison of residence time distributions calculated using the Gamma distribution method for the periphyton test cells located at the STA-1W South Test Cell Research Facility. STC-3, STC-8 have shellrock substrates, while STC-13 has a peat substrate.

Table 4C-11 compares the recent test cell tracer results with results from a similarly conducted August 1999 Phase 1 tracer test in the same half-acre wetland systems. Water depths in all three systems were half the operating depths of those in 1999, while HLRs were maintained at about 6 cm/d. However, the vegetation percent cover in the shellrock wetlands increased from the Phase 1 tracer sampling period to the Phase 2 tracer period, while in the peat systems the percent cover increased only slightly. These results suggest that the hydraulics within all three test cells improved with time, with the shellrock systems undergoing the greatest improvement in estimated number of tanks-in-series. This improvement may be a result of the increased vegetation density that occurred between the two sampling times.

Table 4C-11. Comparison of number of tanks in series (N) determined from the August 1999 lithium tracer study and the February 2001 tracer study performed at the PSTA Test Cell, South Site STA-1W.

Test Cell	Phase 1 (N)	Phase 2 (N)
	(calculated with Gamma distribution technique)	
Shellrock 1	1.8	4.1
Shellrock 2	1.8	4.0
Peat	3.1	3.8

PSTA Field Scale

The PSTA field scale site design includes four 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. Based on encouraging preliminary test-cell data, the site design was revised to include a fourth peat-based cell to provide construction cost estimates and long-term viability of a field-scale, peat-based PSTA system. Additionally, the cells filled with limerock will be operated at the same depths and hydraulic loading rates, but the nominal velocity and aspect ratio are different due to internal sinusoidal levees placed within one of the cells (**Figure 4C-12**). The objective of this design is to discern if velocity is an influencing factor in P removal performance in PSTA systems. Construction has been completed and startup is underway. Performance results will be updated in next year's ECR.

SUMMARY

The destructive sampling of the mesocosms yielded valuable information about the various P storage compartments within a PSTA system. Preliminary analysis suggests that for this short-term mesocosm study, the vegetation (macrophytes and periphyton) was the major P storage compartment and a sand substrate was most effective in encouraging periphyton growth, providing TP reduction values comparable to systems with a shellrock substrate.

The preliminary findings from the test-cell research indicate that a peat-based periphyton system, even amended with Ca, is not as efficient at reducing P as the shellrock PSTA system, with outflow TP concentrations often exceeding inflow concentrations. However, the mesocom research was less conclusive, and given the short-term operation of the test cell PSTA research, the District, with concurrence by the Department and DOI, will continue to research the efficacy of substrate and substrate additions in TP removal from PSTA systems. Additionally, preliminary findings from the tracer studies indicated that both shellrock and peat-based PSTA systems will achieve similar hydraulic efficiencies over time, indicating that substrate type may be a more important factor than hydraulics in attaining the best P removal performance.

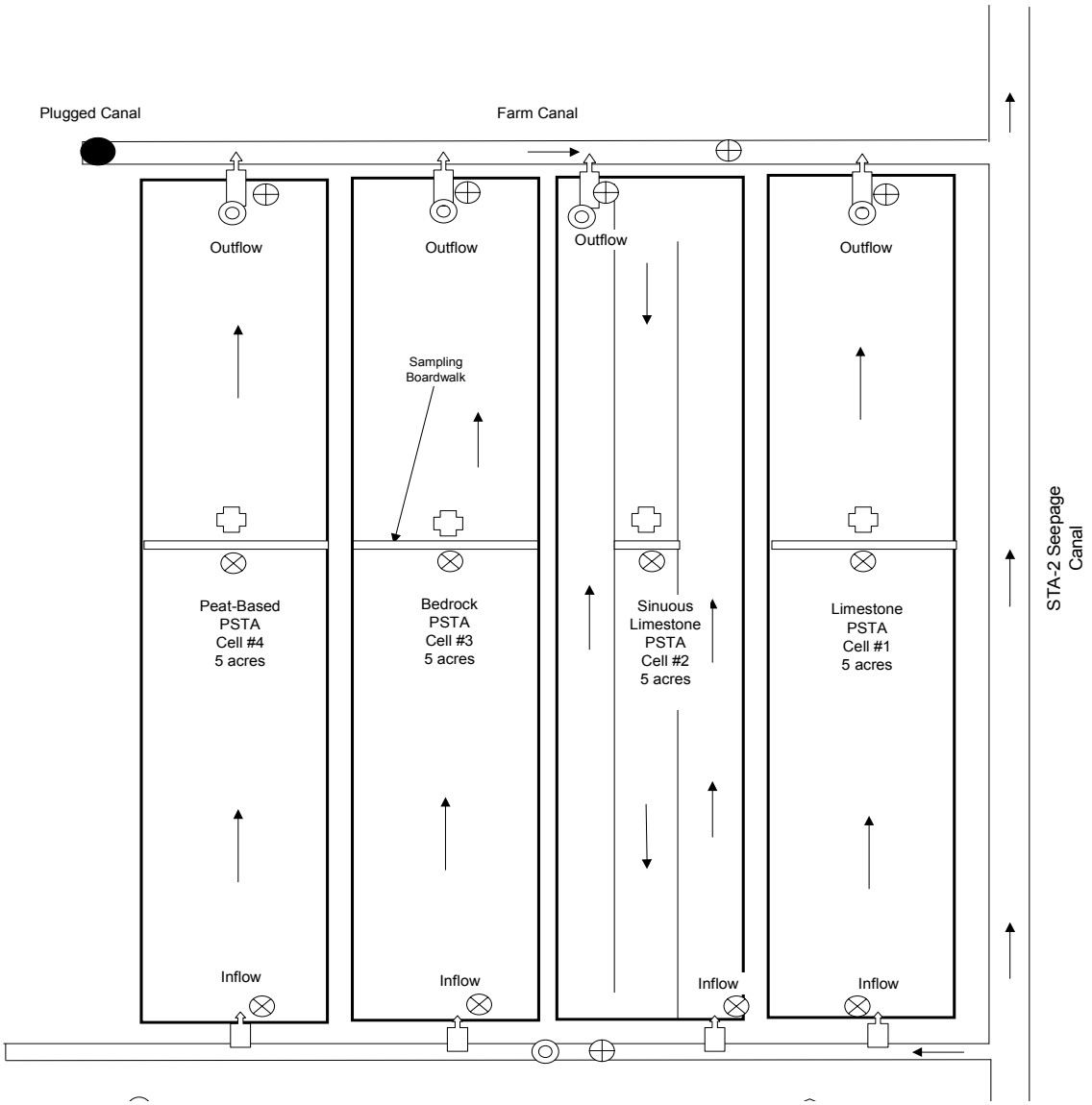

Figure 4C-12. Peripyton Stormwater Treatment Area 20-acre field site schematic. The site is located along the western edge of STA-2.

MANAGED WETLAND TREATMENT SYSTEMS

In the Managed Wetland Treatment System (MWTS) concept, stormwater is mixed with chemicals to initiate flocculation, and is then discharged into a treatment wetland dominated by cattails prior to eventual discharge to the Everglades Protection Area (EPA). The original concept, as proposed in the 1996 Desktop Study (Peer Consultants P.C./Brown and Caldwell, 1996), envisioned chemical treatment occurring upstream of the STA, thereby removing a percentage of the phosphorus prior to release into the STA (**Figure 4C-13**). The primary function of the STA would be to buffer the chemical changes affected by the treatment plant and produce water with an ionic signature compatible to the EPA.

The general purpose of this project was to test the ability of an MWTS to achieve Everglades Forever Act (EFA) goals of a discharge with a TP concentration not greater than the planning target of 10 µg/L. This was a research, demonstration and optimization project with four general research objectives:

- Achieve TP concentration of 10 µg/L or less by chemical treatment
- Determine the effective range of treatment overflow rates and solids-retention times (SRT) for chemically treated EAA runoff
- Use a paired-watershed analysis and other statistical techniques to evaluate if outflow from an MWTS that receives chemically treated water differs qualitatively from outflow of treatment wetlands that receive only EAA runoff water
- Identify whether the outflow from an MWTS is marsh-ready, as defined by Department procedures.

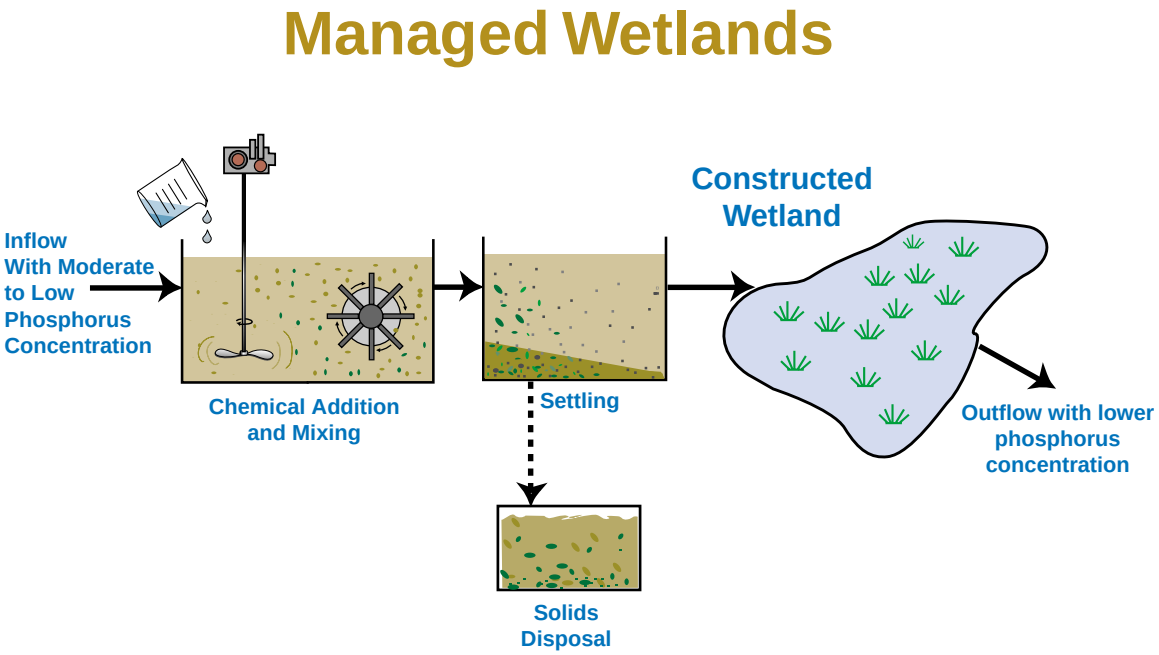

Figure 4C-13. Schematic representation of the managed wetland advanced treatment technology tested at the north and south STA-1W Test Cell Research Facilities.

This section is a synopsis of the information described in the final report of the MWTS Project (CH2M Hill, 2001b) as well as reports presented in previous ECRs. For more information on trends summarized, the full report is available at Website http://www.sfwmd.gov/org/erd/ecp/etweb/main_template/report.html. **Table 4C-1** presents a brief description and status summary for the MWTS project, while **Table 4C-2** provides a summary of the best performing experimental period for the MWTS project. In addition, for a more detailed explanation of the MWTS research, see Chapter 8 of the 2000 and 2001 ECRs (Gray and Coffelt, 2000, Coffelt et al., 2001).

CURRENT STATUS OF MANAGED WETLANDS

MWTS was to proceed in two phases. Phase 1 was conducted and completed at the STA-1W test cells to determine the efficacy of this technology in cattail systems. Phase 2 was to be conducted with the cooperation and participation of the Seminole Tribe of Florida at the Big Cypress Reservation to determine the performance of this technology when coupled to a forested (cypress) wetland. However, after preliminary soil testing and design work had been initiated, the Seminole Tribe of Florida decided not to pursue MWTS as a water quality treatment option for the reservation. As a consequence, the District cancelled Phase 2 of the project. Additionally, under the advisement of the MWTS scientific review panel, the District did not proceed with scale-up cost estimates for this technology and has discontinued research on MWTS using an emergent wetland as an ATT option.

STA-1 WEST TEST CELL RESEARCH

Six half-acre wetlands at the STA-1W north test cell (NTC) and south test cell (STC) treatment site were dedicated to MWTS, three each at the north and south sites. However, only two wetlands at the south site were utilized. Each wetland was operated to achieve a target hydraulic loading rate of 10 cm/d with a depth of 30 cm, which resulted in nominal mean HRT of 2.6 days. This experimental HLR was higher than the STA design HLR of 2.6 cm/d because the MWTS would achieve the TP reduction through chemical treatment and not through biological uptake/sedimentation, as in an STA. However, the control wetlands, which received no chemical treatment, were also operated with a target HLR of 10 cm/d, 30 cm depth and nominal HRT of 2.6 days. By design, the mean nutrient inflow concentrations are higher at the NTC than at the STC. Testing in this phase used a paired-watershed design (USEPA, 1993).

The baseline calibration period at the NTC and STC treatment sites ran from July 1999 through the end of January and February 2000, respectively. During the calibration period, all water flowed from a single upstream storage pond directly into each cell. During the experimental period, the inflow water at the NTC and to the STC wetlands was routed to a splitter box, where an equal amount of water was then sent to each of the wetlands (three in the NTC and three in the STC).

Chemical treatment began at the NTC site in February 2000 using two different chemical coagulants: ferric chloride ($FeCl_3$) and poly-aluminum chloride (PACL). In the STC, site operation of the chemical treatment plant began in March 2000 and used PACL as the coagulant. The chemical treatment plants at both sites continued operations through December 2000. Originally, three wetlands were to serve as control systems (one wetland at the north site and two at the south site, NTC-control and STC-control, respectively). However, for efficiency and experimental design purposes one of the two control wetlands at the south site was eliminated from sampling early in the experimental period.

For each chemical treatment plant, water flowed through two 75.7 liter (20-gallon) rapid-mix tanks, a flocculation tank, a settling-plate tank and a sludge-storage tank, in that order. Inflow water was introduced into the first rapid-mix tank. Coagulant and any pH adjustment chemical were also introduced into the first rapid-mix tank and the polymer into the second. After mixing, the water flowed into a flocculation tank, then passed through a multi-plate clarifier for settling. The clarified effluent flowed by gravity to the top of a sludge storage tank, entering through a diffuser near the water surface of the tank, and flowed out of the same tank through a pipe located just under the water surface of the sludge-storage tank opposite the diffuser. The sludge from the clarifier was piped into the bottom of the sludge-storage tank.

Water quality samples were regularly collected on a variety of schedules from the inflow and plant outflow stations at one-third and two-thirds the distance from the plant outflow station to the marsh outflow and the marsh outflow. The water quality sampling for field and laboratory parameters followed the schedule defined in the MWTS research plan and work plan (CH2M Hill, 2001). Data analyses included:

- Hydrologic balances
- Water quality trends throughout the experimental period
- Mass balances for P and N species
- Paired watershed analysis of TP, TDP, SRP, total Kjeldahl Nitrogen (TKN) and alkalinity, Al, Ca, Cl, Fe, Mg, SO_4, TDS and total organic carbon (TOC)
- Statistical and visual-display comparisons of a suite of mineral concentrations in the several wetlands used in the experiment. Single-species and multi-parameter comparisons were made.

Experimental Results

PHOSPHORUS

Throughout the treatment period, inflow TP concentration at the north site was greater than that from the respective test-cell outflows. This trend was often reversed for the south site, where weekly outflow TP concentrations from both treatment (PACL), and often the control test cells, exceed inflow concentrations. Additionally, at the north site, the inflow TP concentration steadily decreased from about June 2000 through the end of the study in December 2000, but this trend was not evident at the south site (**Figure 4C-14**). This decrease in inflow concentration was most likely a result of the long-term drought that occurred during this time, when lack of runoff resulted in decreased flow into the STAs. Though STA-1W remained hydrated throughout this period, there was little-to-no flow through this system, resulting in a stagnant water source for the north and south test cell sites.

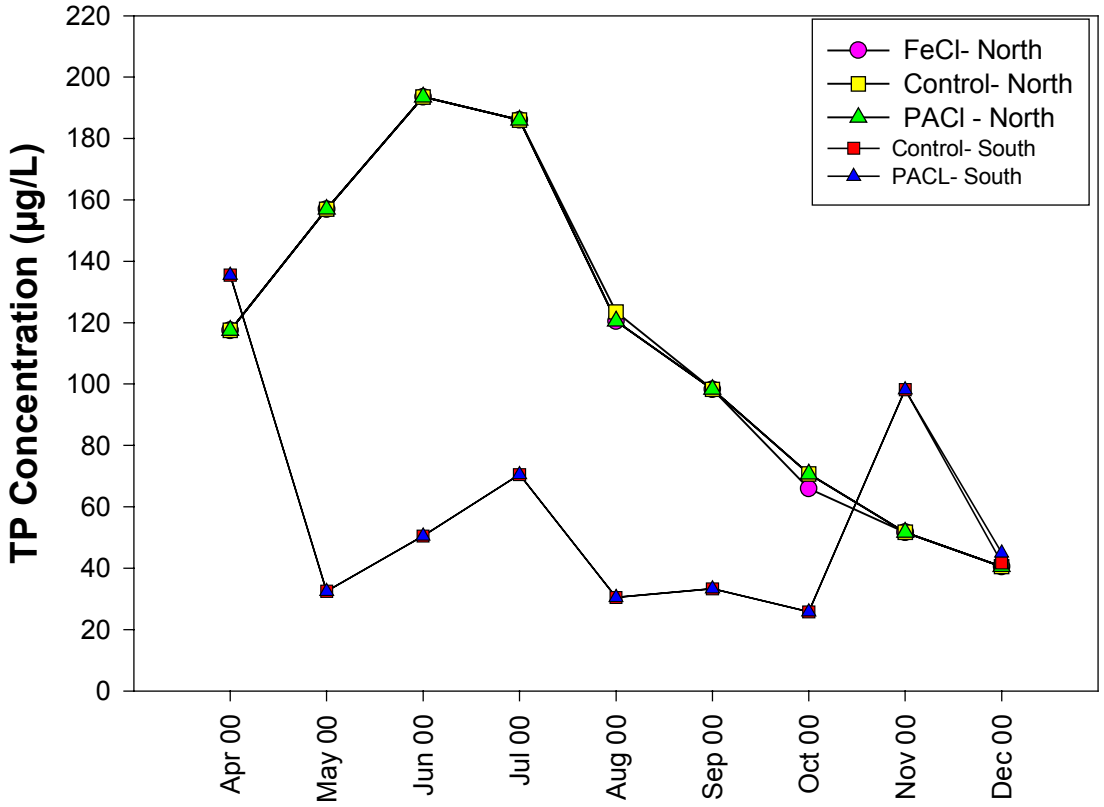

Figure 4C-14. Mean monthly TP concentrations at the STA-1W North and South Site Managed Wetlands research test cells from April 2000 through December 2000. Inflow represents mean TP concentration of all water before entering the chemical treatment plant and outflows represent TP concentrations exiting the wetland.

Inflow P concentrations ranged from 40 to 193 µg/L at the north site and 26 to 136 µg/L at the south site, with mean TP inflow concentrations of 112 and 55 µg/L, respectively (**Table 4C-12**). The inflow P concentration was relatively evenly split between particulate and dissolved fractions at both the north and south sites, with particulate comprising about 47 percent of the P concentration.

Table 4C-12. Mean concentrations of selected parameters sampled at the MWTS research sites located at the Sta-1W North and South Test Cell (TC) Research Facility. Means calculated for the sampling period from February 2000 through December 2000 for the North Test Cells and March 2000 through December 2000 for the South Test Cells.

Site	Parameter Concentration										
	TP	SRP	TDP	TN	SO_4	Color	TOC	Alk	TFe	TAl	Cl
	µg/L	µg/L	µg/L	mg/L	mg/L	cpu	mg/L	mg/L	µg/L	µg/L	mg/L
North FeCl TC											
Plant Inflow	110.9	31.8	63.4	2.62	56.0	156.8	37.3	250.0	50.8	21.9	168.0
Plant Outflow	80.3	5.0	24.9	3.12	49.7	100.8	36.8	291.2	17612.1	25.0	277.6
Wetland Outflow	38.0	11.5	22.8	1.75	47.0	95.6	28.7	278.0	162.5	23.0	238.6
North Control TC											
Wetland Inflow	113.3	31.8	61.5	2.62	55.6	155.0	37.2	250.0	50.2	20.9	168.1
Plant Outflow	-	-	-	-	-	-	-	-	-	-	-
Wetland Outflow	64.3	10.5	39.6	2.28	54.5	138.6	38.1	267.2	28.8	22.0	151
North PACl TC											
Plant Inflow	111.7	31.6	62.4	2.62	55.5	155	37.5	250.6	49.3	20.8	168.1
Plant Outflow	110.4	5.1	23.4	2.70	50.8	47.5	41.6	196.6	207.1	27327.1	227.6
Wetland Outflow	27.4	5.0	21.0	1.43	47.9	56.8	28.5	249.3	8.5	46.2	166.8
South Control TC											
Wetland Inflow	54.7	6.2	28.5	2.34	52.8	147.3	23.0	263.3	4.9	12.2	167.3
Plant Outflow	-	-	-	-	-	-	-	-	-	-	-
Wetland Outflow	47.3	4.8	27.0	2.31	45.6	131.3	42.3	258.0	7.7	13.4	163.8
South PACl TC											
Plant Inflow	54.6	6.1	28.0	2.34	53.0	147.3	43.1	263.5	4.9	11.9	168.0
Plant Outflow	57.0	8.0	22.9	2.32	50.1	48.7	34.9	205.0	18.6	18833	252.7
Wetland Outflow	41.7	5.2	25.6	1.69	46.9	54	26.3	236.4	5.3	17.6	177.0

Mean TP outflow concentrations were 80, 110 and 57 µg/L from the north $FeCl_3$, north PACL and south PACL treatment plants, respectively (**Figure 4C-15**). While inflow TP concentration was relatively evenly split between particulate and dissolved fraction, PP comprised the majority of the plant effluent TP concentration, with percentages ranging from 61 percent at the south treatment plant to 73 percent at the north PACL treatment plant. The percentages of PP to TP from the test cell outflows were less, with values between 28 and 48 percent for all wetlands at both sites, indicating a settling of the particulate material in treatment and control test cells.

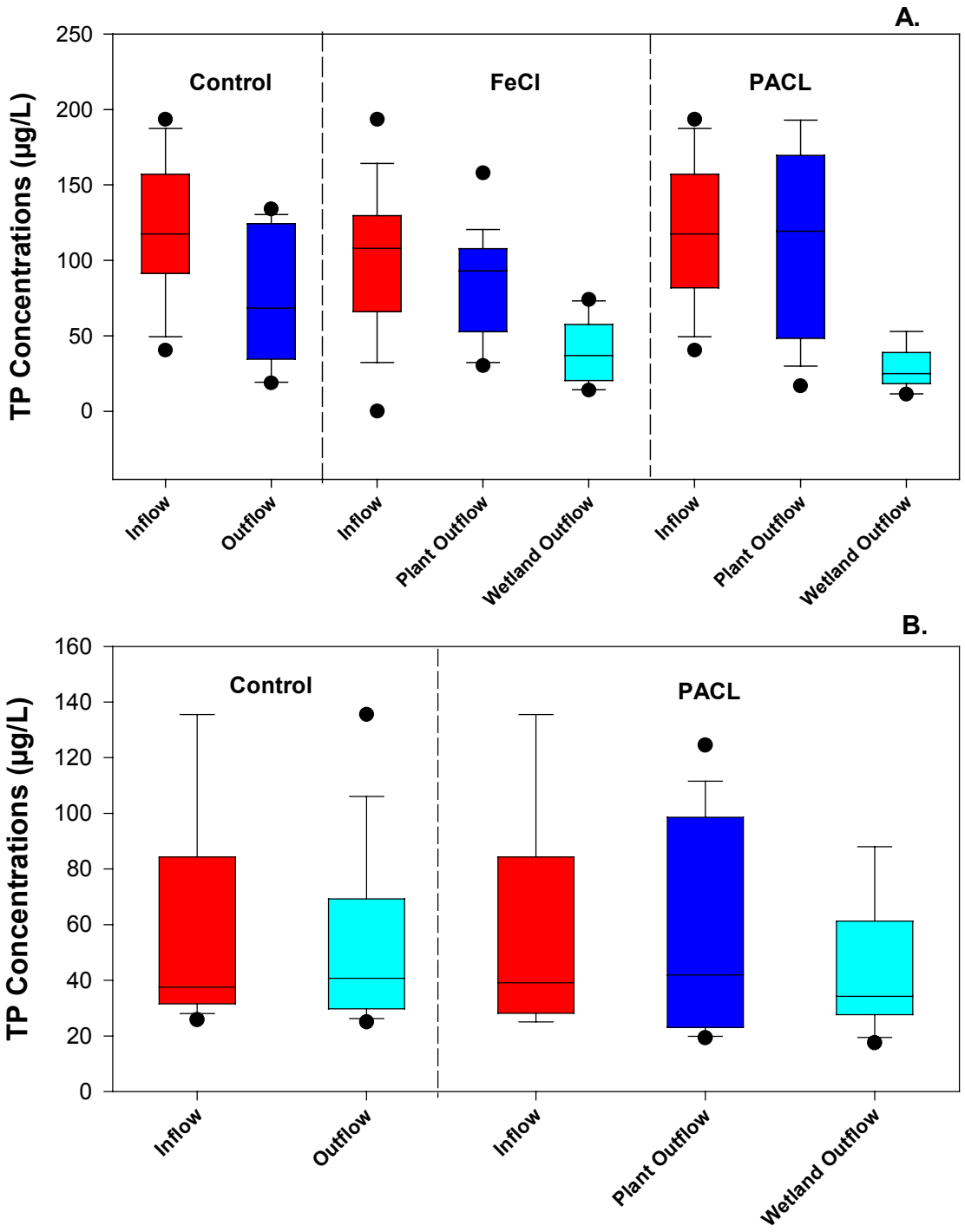

Figure 4C-15. Mean TP outflow concentrations from the Managed Wetlands research test cells from April 2000 through December 2000. Panel A sites were located at the STA-1W North Test Cell Research Facility and Panel B sites were located at the STA-1W South Test Cell Research Facility.

Although the test cell outflow TP concentrations never achieved the target 10 µg/L, the outflow concentrations from the treatment systems at the north site were lower compared to the control test-cell systems, averaging about 33, 18 and 16 µg/L for the last four months of operation from the control, $FeCl_3$ and PACL treatment systems, respectively.

Overall, the $FeCl_3$ treatment resulted in a 66 percent TP concentration reduction, while PACL yielded a 75-percent reduction at the north treatment plant, but a 23-percent increase at the south site. The control test cells resulted in only 43 and 13 percent TP concentration reduction at the north and south sites, respectively.

NITROGEN

From July 1999 through December 2000, the average TN inflow concentration at the north site was about 2.5 mg/L, which was slightly higher than the mean TN inflow concentration at the south site of about 2.2 mg/L. Organic N comprised about 92 percent of the TN inflow concentration at the south site, but only about 85 percent of the TN at the north site.

Chemical treatment increased the N removal from the wetlands at both the north and south sites compared to the control system, and overall TN removal was greater at the north site wetlands than at the south (**Table 4C-12**).

OTHER WATER QUALITY PARAMETERS

Inflow and wetland outflow concentrations were approximately equal in all cells for total suspended solids (TSS), Mg and Ca. Other water quality trends included:

- Sulfate: Mean percent reductions at all three north site wetland systems ranged from 2 to 16 percent, while at the south site the mean percent reductions ranged from 11.5 to 13 percent
- Color: Inflow color values were similar at both the north and south site systems. The chemical treatments at both the north and south sites reduced color relative to the control wetlands. At the north site, the PACL treatment reduced color by about 63 percent, while the $FeCl_3$ and control had mean percent reductions of about 40 and 10.5 percent, respectively. The south PACL treatment system reduced color by 67 percent, while the control had a mean percent reduction of 10.8 percent
- Total organic carbon: At both the north and south sites, the chemical treatment systems reduced TOC concentrations relative to controls, with mean percent reductions ranging from 24 to 38 percent for the treatment systems, and no reduction at the controls
- Alkalinity: At the north site, alkalinity increased relative to inflow concentrations, but decreased slightly at the south site
- Total iron: Mean total Fe (TFe) inflow concentrations at the north site were 50 µg L^{-1}, which was higher than mean inflow concentrations of 5 µg/L at the south site. At the south site, mean outflow TFe concentrations exceeded mean inflow concentrations in both control and treatment systems. At the north site, mean TFe outflow concentrations were nearly triple the inflow concentrations for the $FeCl_3$ treatment, and the mean outflow concentration from the $FeCl_3$ treatment plant

was 17,612 µg L^{-1}. At the north site, the PACL and Control treatment systems reduced wetland TFe outflow concentrations relative to inflow, with mean percent reductions of 83 and 43 percent, respectively;

- Aluminum: Mean TAl inflow concentrations at the north site were greater than mean inflow concentrations at the south site, with means of 22 and 12 µg/L, respectively. Mean TAl outflow concentrations from all wetland systems at both the north and south sites were greater than mean inflow concentrations. However, the mean outflow TAl concentrations from the north site PACL treatment system was 46.2 µg/L, a little more than double the inflow concentrations, but the mean outflow concentration from the PACL treatment plant to the wetland was 27,327 µg L^{-1}
- Chloride: Mean Cl inflow concentrations at the north and south sites were similar, and means ranged from 167.3 to 168.1 mg/L. All treatment systems elevated Cl concentrations from the treatment plant relative to inflow concentration, with means of 227.6, 252.7 and 277.6 mg/L for the north site PACL, south site PACL and $FeCl_3$, respectively.

Paired Watershed Experimental Design Analysis

Paired Watershed Analysis (PWA) is a statistical technique that tests chemical concentration changes in discharges from the cells as a result of chemical treatment and wetland conditioning. Linear regression and analysis of covariance (ANCOVA) were used to statistically model and compare water quality differences in control and treatment cells (USEPA, 1993). The analysis provided statistical evidence of change, or lack thereof, for the various constituents by comparing statistical predictions against observed data.

At the north site, the $FeCl_3$ and PACL treatments removed significantly more P and N relative to the north site control cell and allowed a quantification of the degree of the effects. The PACL treatment cell showed a larger reduction in TP (about 30 percent) than occurred in the $FeCl_3$ treatment cell (about 20 percent) compared to the calibration (prechange) period of operation. SRP results were less distinct, and TDP dynamics were not well modeled using either Ordinary Least Squares or Robust (nonparametric) regression techniques.

Evaluation of Toxicity

As part of the STSOC, all ATTs perform the 14-day Algal Growth Potential (AGP) test, 96-hour Chronic and seven-day Chronic Static Renewal Screen Toxicity Test, Toxicity Characteristic Leaching Procedure (TCLP) and soil tests.

- *Algal Growth Potential* – There was no significant growth potential found with the AGP test. All maximum standing crop values for all treatment and control treatment systems at both the north and south sites were significantly below those of the laboratory controls.
- *Toxicity Tests* – Toxicity testing was inconclusive, with both the control and treatment outflow water resulting in growth or survival reductions during some portion of the tests.
- *Toxicity Characteristic Leaching Procedure* – Sludge samples collected from the solids separator/storage tanks for each chemical treatment plant at both north and

south sites were tested for potential leaching. The leachate was well below federal statutory limits for all chemicals (there are no Florida statutory limits for TCLP).

Soil samples were collected at the beginning and end of both the calibration and treatment periods (March and December 2000). Tests for TAl, TFe and TP showed considerable initial variation between cells. Total Al soil burdens (µg/g dry soil) from the north and south site PACL treatment wetlands made during the treatment period were slightly lower than those during the calibration period. Iron burdens rose slightly in the north site $FeCl_3$ treatment wetland (27 µg/g dry soil). Phosphorus burdens were highest in the March 2000 samples, but varied enormously both in time and by cell. No clear conclusions could be drawn from the data.

SUMMARY

The MWTS testing program was designed to simulate the performance of a pond-based chemical treatment system, with in-pipe injection of flocculating chemicals, followed by discharge to a floc settling pond with a long retention time. A treatment wetland would receive the outflow from the pond for final water quality polishing and protection. The experimental system, as operated, included a chemical plant that injected and mixed chemicals with the inflow water and settling and storage components, with a release from the storage tank to the wetland.

The experimental design included a hydraulic loading rate that would result in full-scale design with a reasonable wetland space requirement. The chemical plant's clarifier and sludge-storage tanks did not completely capture the floc due to operational and design constraints. With the wetlands performing a solids-capture function, the experiment, as performed, provided results for a chemical treatment – settling pond – wetland system with periodic floc overflow. The solids-management problems encountered with the treatment units at the north and south sites can be overcome with a pond-based treatment system. The treatment-pond concept was to be tested in Phase 2 of the project; however, Phase 2 work was not completed.

A brief summary of operational results from Phase 1 is as follows:

- The MWTS treatment system can reduce P outflow concentrations better than an emergent wetland system alone. At the north site, the control, FeCl and PACL wetland treatment systems had mean TP percent concentration reduction values of 43, 66 and 76 percent, respectively.
- No re-dissolution of P from settled solids was detected, verifying that a pond-based treatment system sized for solids storage would provide effective P removal.
- Floc overflow (not unknown, even expected, as an occasional accidental event in the wastewater industry) occurred and was controlled by the treatment marsh, thus protecting receiving waters beyond the marsh outflow.
- PACL treatment almost doubled the Al concentrations in the wetland outflow of the north site system, but dramatically increased Al concentrations from the treatment plants at both the north and south sites.
- $FeCL_3$ treatment tripled the Fe concentrations in the treatment wetland outflow, as well as dramatically increased the Fe concentrations from the treatment plant.

- The residuals produced were found to be nonhazardous by standard testing procedures.
- There was no apparent biotoxicity associated with the outflow waters, although several tests were inconclusive.
- It is probable that the MWTS system had floc overflow far in excess of what a full-scale engineered system would produce, suggesting that the original equipment configuration should be redesigned and additional operational procedures needed.
- The District has discontinued research on MWTS using an emergent wetland as an ATT option.

LOW-INTENSITY CHEMICAL DOSING (LICD)

The LICD technology consists of the addition of small doses (less than 5 mg/L) of Fe or Al salts directly to the runoff from the EAA prior to its release into the STAs. The addition of the metal salt should enhance and accelerate the rate of P removal through precipitation of soluble P and coagulation of chemically formed and naturally occurring particulate P. No mechanical rapid mixing or flocculation process was envisioned in the LICD concept as presented in the 1996 Desktop Study (Peer Consultants P.C./Brown and Caldwell, 1996). In LICD, the rapid-mixing process is to occur as a byproduct of the turbulence generated by stormwater entering an STA, with the STA functioning as a filter and settling basin for the precipitated P, settling the floc to the bottom of the wetland (**Figure 4C-16**).

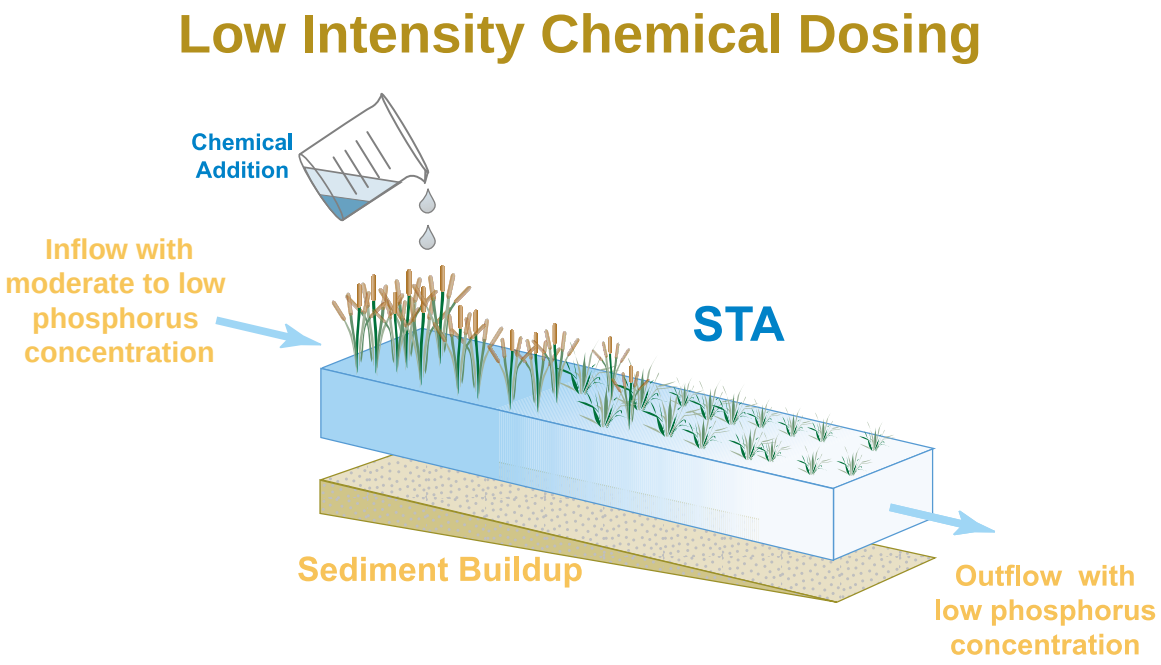

Figure 4C-16. Schematic representation of the low intensity chemical dosing advanced treatment technology tested at north STA-1W Test Cell Research Facility.

PREVIOUS WORK

An LICD project conducted in STA 1-W, Cell 2 by Duke University was completed in December 1999. This project was funded in part by a Section 319h Program grant from the USEPA through a contract with the Department. This previous study increased the body of knowledge regarding this treatment technology and its potential for TP removal. However, there was concern that due to mesocosm size and shape, this experimental method did not allow enough contact with the vegetation to promote filtration and settling of the fine precipitated solids. Additionally, the Duke study deviated from the original concept by using high dosage rates of coagulants and the addition of a polymer. (Refer to Chapter 8 of the 2001 ECR for a complete project description and summary of these project results [Coffelt et al., 2001]).

PROJECT DESCRIPTION

Upon recommendation by the Department of the Interior (DOI) and the Florida Department of Environmental Protection, the District conducted a small LICD demonstration project in three half-acre wetlands located within the north test cell facility of STA-1W (**Figure 4C-1**). The purpose of this study was to examine the effect of extremely low doses of coagulant (<5 mg/L Al) on P outflow concentrations in these systems. Polymers and enhanced mixing techniques were eliminated from the study design so that LICD could be evaluated in its original form. Aluminum ($AlCl_3$) was selected over $FeCl_3$ due to concerns that anaerobic conditions at the bottom of the wetland might cause release of P from Fe-based coagulant residuals. Additionally, alum was removed from consideration as a precautionary measure due to research indicating a possible correlation between increased SO_4 concentrations and increased methylation of Hg in aquatic systems.

Distribution manifolds were installed in each of the three half-acre cattail-dominated wetlands to ensure an even hydraulic distribution across the top of each cell. The wetlands were dosed at a rate of 5.0, 2.0 and 0.5 mg Al L^{-1} each. The wetlands were hydraulically loaded at about 2.6 cm/d, and the depth was maintained at 60 cm. For comparative purposes, operation of two cattail-dominated wetlands with the same depth and loading rate, but receiving no chemical addition, was continued. This loading rate and depth approximates the average design conditions for the STAs (Walker, 1991). Weekly grab and/or composite water samples were taken at the storage-cell outlet (representing inflow water) and at the outflow from each test cell. Water samples were collected around midday from the test cells and analyzed for 31 parameters (**Table 4C-13**) in accordance with the District's CompQAP (SFWMD, 1999). The MDL value was used in all calculations when the sample concentration was reported as values less than or equal to the MDL.

Baseline data were collected from June 16, 2000 until October 21, 2000, at which time low-level coagulant dosing began and continued through March 1, 2001.

Table 4C-13. Physical and chemical parameters monitored at inflow and outflow stations located at the ENR test cell STA Optimization research site.

Nutrients	Physical Parameters	Chemical Parameters
Total phosphorus	Dissolved oxygen	Total suspended solids
Total dissolved phosphorus	Temperature	Total dissolved solids
Soluble reactive phosphorus	pH	Total organic carbon
Total nitrogen	Specific conductance	Dissolved organic carbon
Total Kjeldahl nitrogen	Stage	Total inorganic carbon
Total Dissolved Kjeldahl nitrogen	Flow	Alkalinity
Ammonia nitrogen		
Nitrate-nitrite nitrogen	**Other Cations**	
Silica	Aluminum	Calcium
Other Anions	Iron	Potassium
Sulfate	Magnesium	Sodium
Chloride	Manganese	Zinc
	Molybdenum	

Project Results

A summary of the baseline data suggests that the experimental and control cells were performing similarly before chemical dosing began, with all cells reducing inflow TP concentrations and with median TP outflow concentrations ranging from about 39 to 62 µg/L (**Figure 4C-17**).

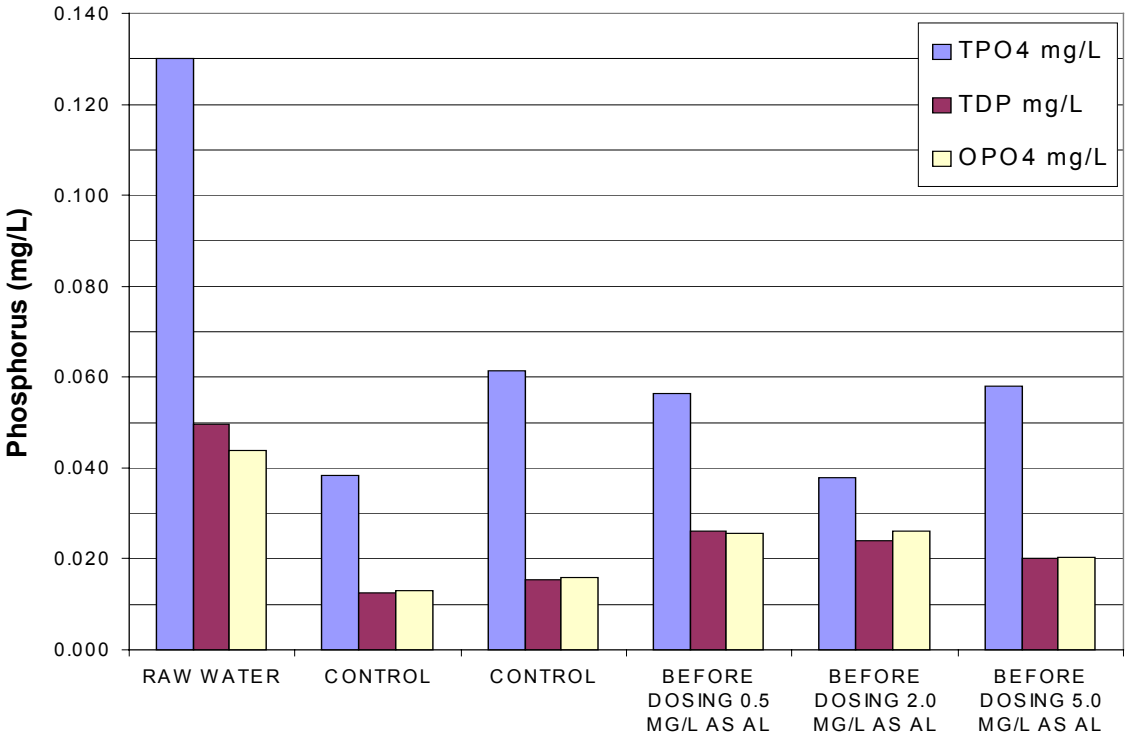

Figure 4C-17. Median phosphorus inflow concentrations for the Control and LICD treatment wetlands located at STA-1W, north Test Cell Research Facility for the period of 21 October 2000 to 1 March 2001.

Median TAl and Cl outflow concentrations were also very similar among all the wetland outflows, ranging from 11 to 17 µg L^{-1} and 160 to 190 mg/L, respectively. However, none of the wetlands effectively reduced either Al or Cl concentrations relative to the inflow.

Low-level chemical dosing extended from October 21, 2000 to March 1, 2001. Preliminary results indicated that all wetlands reduced TP concentrations relative to the inflow concentration. However, the treatment wetland median outflow TP concentrations were similar to the TP outflow concentrations of the controls. Additionally, concentration of SRP and TDP was similar among all systems, indicating that the chemical addition was also not affecting relative percentage of P species within the system (**Figure 4C-18**).

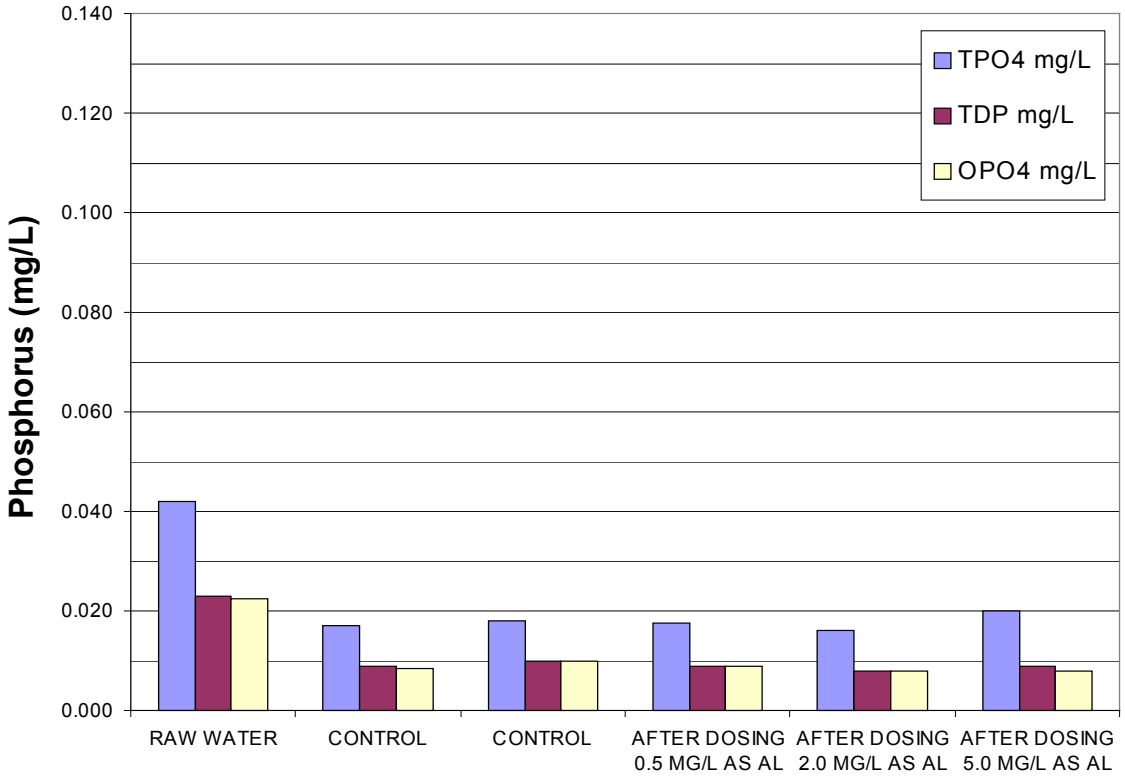

Figure 4C-18. Median phosphorus outflow concentrations for the Control and LICD treatment wetlands located at STA-1W, North Test Cell Research Facility for the period of 21 October 2000 to 1 March 2001.

Following the addition of $AlCl_3$, the median TAl outflow concentration in the dosed wetlands increased relative to inflow concentrations and the control wetland outflow concentrations. The median outflow TAl concentrations ranged from 25 to 46 in the experimental wetlands, while the control wetland outflow concentrations were about 9 µg/L (**Figure 4C-19**). Additionally, the outflow concentration of TAl in the wetlands receiving the 2- and 5-mg/L doses was almost double that of the lower 0.5-mg/L dosed wetland. Clearly, Al outflow concentrations were increased due to the addition of TAl in the form of liquid $AlCl_3$. However, the majority of the Al from these dosed systems was dissolved, indicating that either mixing was not adequate or that the pin floc generated as part of the coagulation process could pass through the 0.45-µm filter.

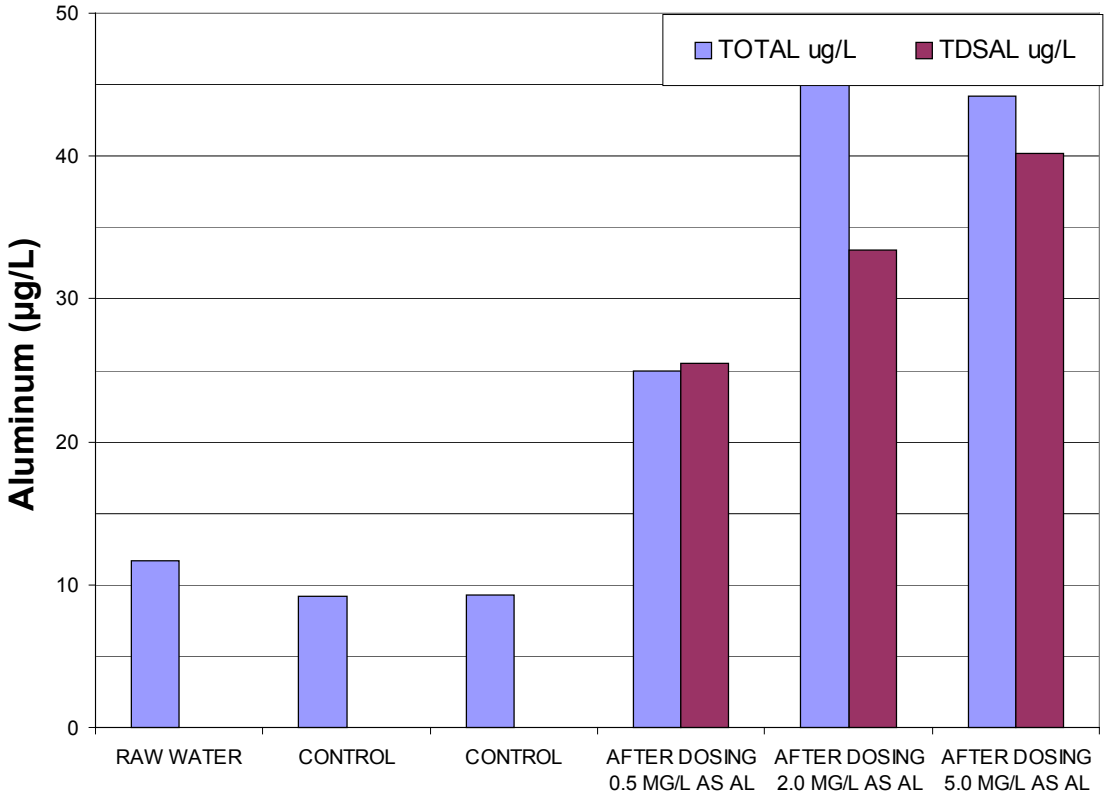

Figure 4C-19. Total and dissolved median outflow aluminum concentrations from the Control and LICD test cells located at the STA-1W North Test Cell Research Facility for the period of 13 June 2000 to 1 March 2001.

Following dosing, the median total Cl outflow concentrations were similar among all the wetlands, ranging from 130 to about 155 mg/L. Data from other chemical treatment experiments (CH2M Hill, 2001b; HSA, 2001) reported an increase of Cl ions exported from the treatment unit as a result of the metal-Cl complex addition. However, in this study the maximum concentration of Cl added to the system was about 0.2 mg/L, and therefore the increase would not be detected relative to the inflow concentration levels of about 175 mg/L (**Figure 4C-20**).

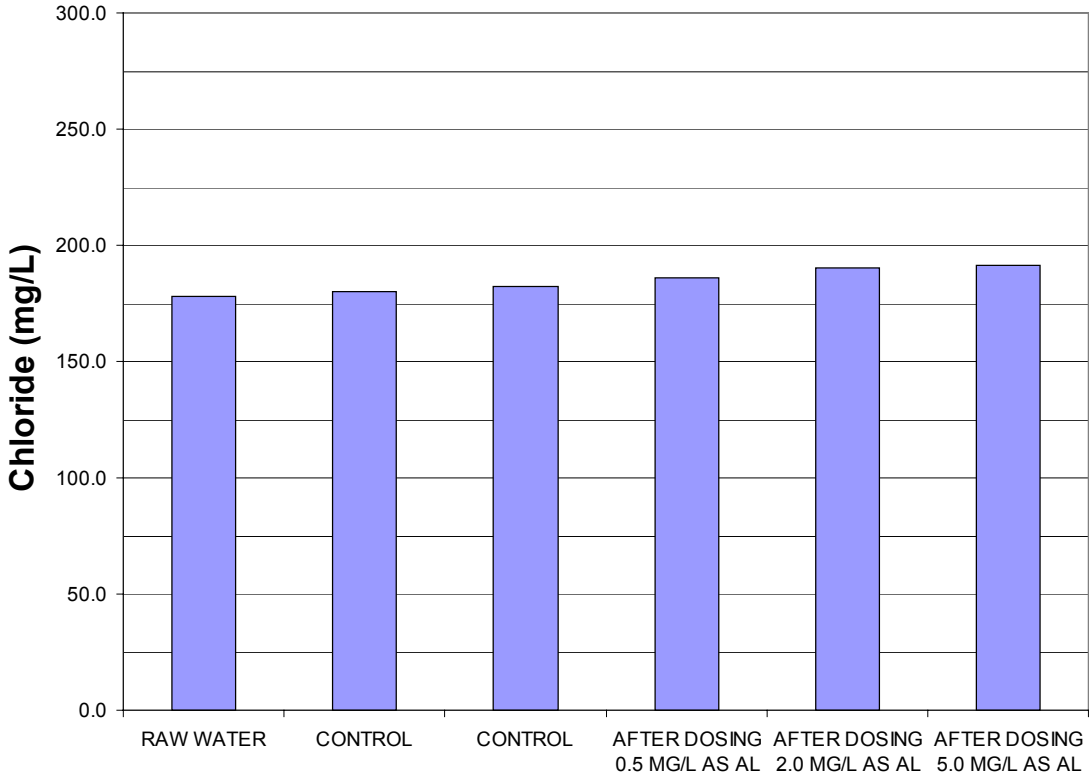

Figure 4C-20. Median total Chloride outflow concentrations for the Control and LICD test cells located at the STA-1W North Test Cell Research Facility for the period of 13 June 2000 to 21 October 2001.

Median values were summarized for the other tested parameters and are presented in **Appendix 4C-3**.

SUMMARY

Results from this study indicate that LICD, as described in the Peer Review Desktop Study (Peer Consultants P.C./Brown and Caldwell, 1996), was not able to improve TP concentration reductions relative to the performance of a passive cattail marsh wetland. Additionally, results from a study performed by Duke University (Bachand et al., 1999; Coffelt et al., 2001) showed that even at high coagulant doses of about 20 mg/L the LICD system had TP outflow concentrations of 20 to 30 $\mu g\ L^{-1}$ and was not able to reach the planning target of 10 µg/L. Based on these results, the District felt that completion of an STSOC for this technology was not warranted at this time.

CHEMICAL TREATMENT

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. Bioassay and Algal Growth Potential (AGP) studies also demonstrated no significant impact on receiving waters, and residual solids proved to be nonhazardous for disposal. Direct filtration and dissolved air flotation, also identified in the Desktop Study, did not achieve the 10 µg/L TP planning goal and are not being considered as viable technologies for future evaluation. 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).

Following the format identified in the STSOC guidelines (PEER Consultants/B&C, 1999), a total of 12 (six for post-STA and six for post-BMP) scenarios were developed to achieve flow-weighted average effluent TP concentrations of 0, 10 and 20 percent flow diversion for the 10-year POR for STA-2 from January 1, 1979 to September 30, 1988.

The standardized costing data for equipment, land, levees and other STA cost estimates to be used in developing full-scale treatment facilities for each technology was developed by PEER Consultants/B&C in 1999 and updated by the District in 2000. These data were used to determine the 50-year present-worth analysis and a 10-point evaluation methodology of capital and operational costs for post-BMP and post-STA applications. **Table 4C-1** presents a brief description and status summary of the CTSS projects, while **Table 4C-2** provides a summary of the best performing experimental period for the CTSS projects. For a complete description of the STSOC and the Chemical Treatment process and research, refer to Chapter 8 of the 2000 and 2001 ECRs (Gray and Coffelt, 2000; Coffelt et al., 2001).

CHEMICAL TREATMENT/SOLIDS SEPARATION

The CTSS project evaluated the feasibility of using chemical coagulation coupled with high rate solids-separation techniques to remove TP from post-BMP and post-STA treated stormwater runoff from the EAA. The chemical coagulation phase involved the use of metal (Fe or Al) salts, routinely used in municipal water treatment facilities, to precipitate P. These metal salts, combined with organic polymers, coagulate the precipitates and allow small particulates to be flocculated into larger, denser and more aggregates, which are more readily settled or filtered. Solids generated from the coagulation and flocculation process are then separated from the liquid through settling and/or filtration and disposed of by land application or by transportation offsite after other dewatering techniques (**Figure 4C-21**).

A relatively narrow range of pilot operating conditions provided an outflow TP concentration of less than 10 µg/L during optimization testing. Post-BMP and post-STA site demonstration trials were conducted using $FeCl_3$ and aluminum sulfate (alum) coagulant, respectively. Both sites consistently produced mean outflow TP concentrations at or below 10 µg/L. The performance on TP removals in jar and pilot tests of aluminum chloride ($AlCl_3$), alum, $FeCl_3$, and polyaluminum chloride (PACl) have proven to be equally effective. Recently, as a precautionary measure alum was removed from consideration due to research indicating a possible correlation between sulfate concentrations and increased methylation of Hg in aquatic systems. Additionally, $FeCl_3$ has been removed from consideration due to possible P feedback into the water column due to redox fluctuations in the wetland system. PACl is generally more expensive than $AlCl_3$; therefore $AlCl_3$ will be the coagulant used in any further chemical treatment testing. However, because the coagulants performed equally well in all tests, the past performance data and scale-up design scenarios generated using either alum or $FeCl_3$ will provide valid comparisons to continuing chemical treatment demonstration projects.

Conceptual Design

Small-scale demonstration chemical treatment plants operated by the District have consistently produced an outflow TP concentration of less than 10 µg/L when operated within a relatively narrow range of inflow rates. Operational problems caused by wide fluctuations in EAA stormwater flows are avoided by means of flow equalization. A flow equalization basin (FEB) is required in any full-scale treatment system to accommodate peak rainfall events, equalize the daily and seasonal input cycles and balance the extremes of the quality and quantity of water to provide a constant flow through the chemical treatment process.

Treatment plant sizes for each POR flow diversion scenario were determined considering the use of an FEB and CTSS to meet the desired effluent quality. **Table 4C-14** details the calculated flows for the resultant 12 full-scale treatment scenarios (HSA, 2000):

- The post-BMP conceptual design scenarios used 6,000 of the 6,430 acres within STA-2 for flow equalization, and the remaining 430 acres for the treatment plant works, residual-solids thickening and treated water conditioning using a buffer cell;
- The post-STA conceptual design scenarios assumed an average STA outflow concentration of 65 µg/L using 4,400 acres of STA-2 as a constructed wetland treatment system, a 1,500-acre basin as a flow-equalization basin and 530 acres for the treatment plant works and buffer cell.

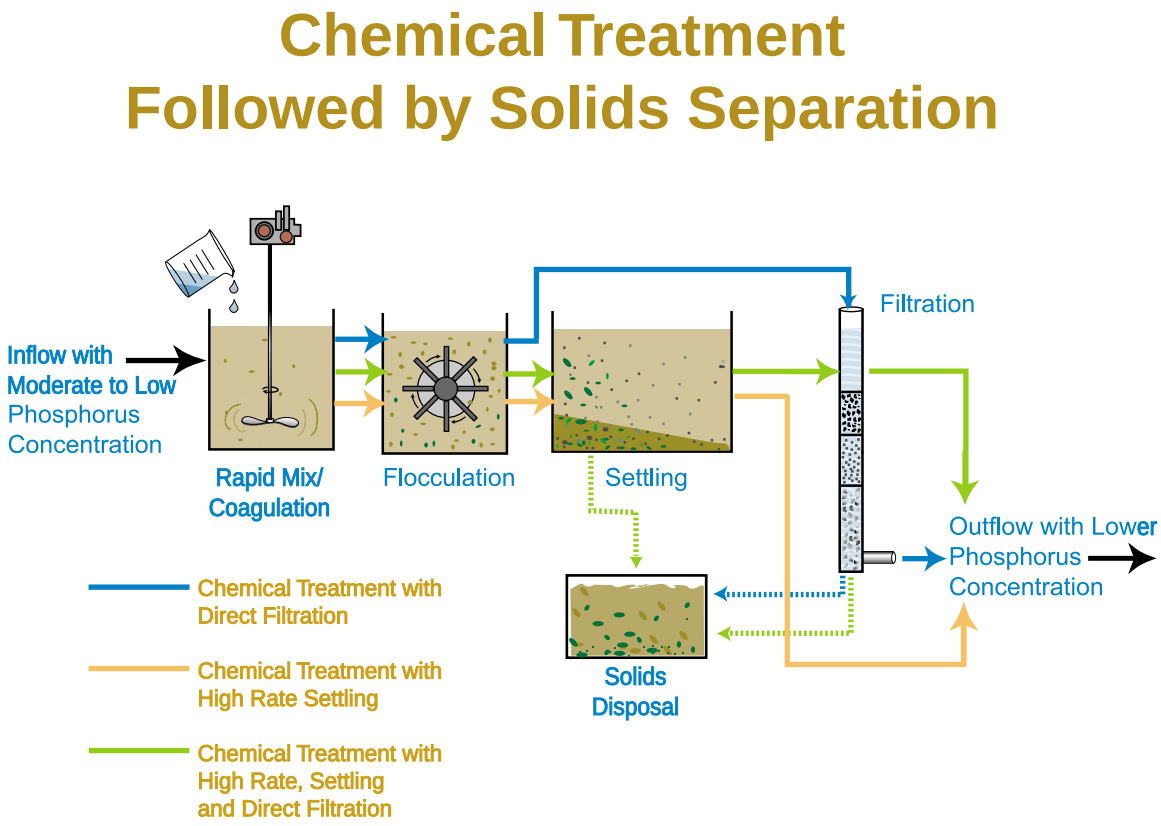

Figure 4C-21. Schematic representation of the chemical treatment followed by solid separation advanced treatment technology tested at STA-1W Post-BMP and Post-STA research sites.

Table 4C-14. STSOC full-scale treatment scenarios for the Chemical Treatment Solid Separations Project.

Location	Effluent TP	No Diversion (MGD)	10% Diversion (MGD)	20% Diversion (MGD)
Post-BMP	10 ppb	380	270	200
	20 ppb	220	150	190
Post-STA	10 ppb	390	260	100
	20 ppb	140	100	80

Residual solids would be discharged to an onsite storage lagoon for a period of three days. Supernatant overflow from the solids storage area would be returned to the FEB for treatment. Settled solids in the lagoon would be pumped to a dedicated land application facility. The estimated required area for this dedicated solids disposal area ranges from 1,150 to 1,680 acres and is based on an annual solids loading criterion of 28 tons of dry solids per acre per year. However, additional research is necessary to refine the accuracy of these disposal estimates.

Present-worth Costs

Once full-scale designs for the different scenarios were completed, a 50-year present-worth cost analysis for capital, operation and maintenance (O&M), replacement and salvage items cost estimate was prepared and peer reviewed for STA-2 (PB, Hazen and Sawyer, 2000). This present-worth cost analysis, with a net discount rate of four percent, was developed using equipment supplier quotes and prior engineering experience. **Table 4C-15** summarizes the capital, operating, demolition, salvage and lump-sum estimates of the 50-year present worth for the 12 full-scale treatment facilities for STA-2.

The 50-year present worth calculations were used to calculate the units' costs per cubic meter capacity of the treatment plant. These costs were also used to produce the relative treatment costs in terms of dollars per kilogram of P removed. **Figure 4C-22** clearly shows that capital costs (dollars per cubic meter capacity) are similar for post-STA and post-BMP chemical treatment sites. However, chemical treatment plants operated at the post-BMP (higher TP inflow concentrations) site are more cost effective than post-STA when comparing unit costs of dollars per kilogram of P removed from the water.

A breakdown of the capital and operating costs indicated that civil work (40 percent), equipment (24 percent) and land (24 percent) are the major cost items to consider for full-scale implementation. Chemical costs accounted for almost 70 percent of the operating costs, and further research efforts would focus on optimizing this process to reduce the chemical dosages needed. Energy consumption, residuals management, sampling and monitoring are other key operational costs.

Table 4C-15. 50-year Present Worth analysis for Post BMP and Post STA alternatives Chemical Treatment with Solids Separation ATT project.

POST- BMP						
Blended effluent Total P concentration (ppb)	10			20		
Diversion of 10-YR POR Flow Volume	0	10%	20%	0	10%	20%
Treatment plant design average daily flow (mgd)	380	270	200	220	150	120
50-YEAR PRESENT WORTH for POST-BMP ($)						
Capital Cost	204,274,983	178,657,379	164,194,073	167,671,112	152,422,821	145,181,019
Operating Cost	166,913,411	150,027,568	131,949,704	146,809,514	129,724,026	117,267,843
Demolition/Replacement Cost	60,646,664	53,831,389	50,436,937	50,799,811	47,127,564	45,292,166
Salvage Cost (subtracted from total cost)	(4,208,390)	(4,208,390)	(4,208,390)	(4,208,390)	(4,208,390)	(4,208,390)
Lump Sum Cost	600,000	600,000	600,000	600,000	600,000	600,000
TOTAL COST	428,226,667	378,907,946	342,972,325	361,672,048	325,666,021	304,132,638
POST- STA						
Blended effluent Total P concentration (ppb)		10				
Diversion of 10-YR POR Flow Volume	0	10%	20%	0	10%	20%
Treatment plant design average daily flow (mgd)	390	260	190	140	100	80
50-YEAR PRESENT WORTH for POST-STA ($)						
Capital Cost	187,673,759	164,363,313	154,984,595	145,269,684	137,638,137	133,258,251
Operating Cost	193,309,106	172,038,459	148,657,928	135,872,093	118,157,906	106,517,232
Demolition/Replacement Cost	56,261,028	49,944,912	47,877,486	45,183,597	43,119,738	41,956,072
Salvage Cost (subtracted from total cost)	(4,208,390)	(4,208,390)	(4,208,390)	(4,208,390)	(4,208,390)	(4,208,390)
Lump Sum Cost	600,000	600,000	600,000	600,000	600,000	600,000
TOTAL COST	433,635,503	382,738,295	347,911,619	322,716,984	295,307,391	278,123,165

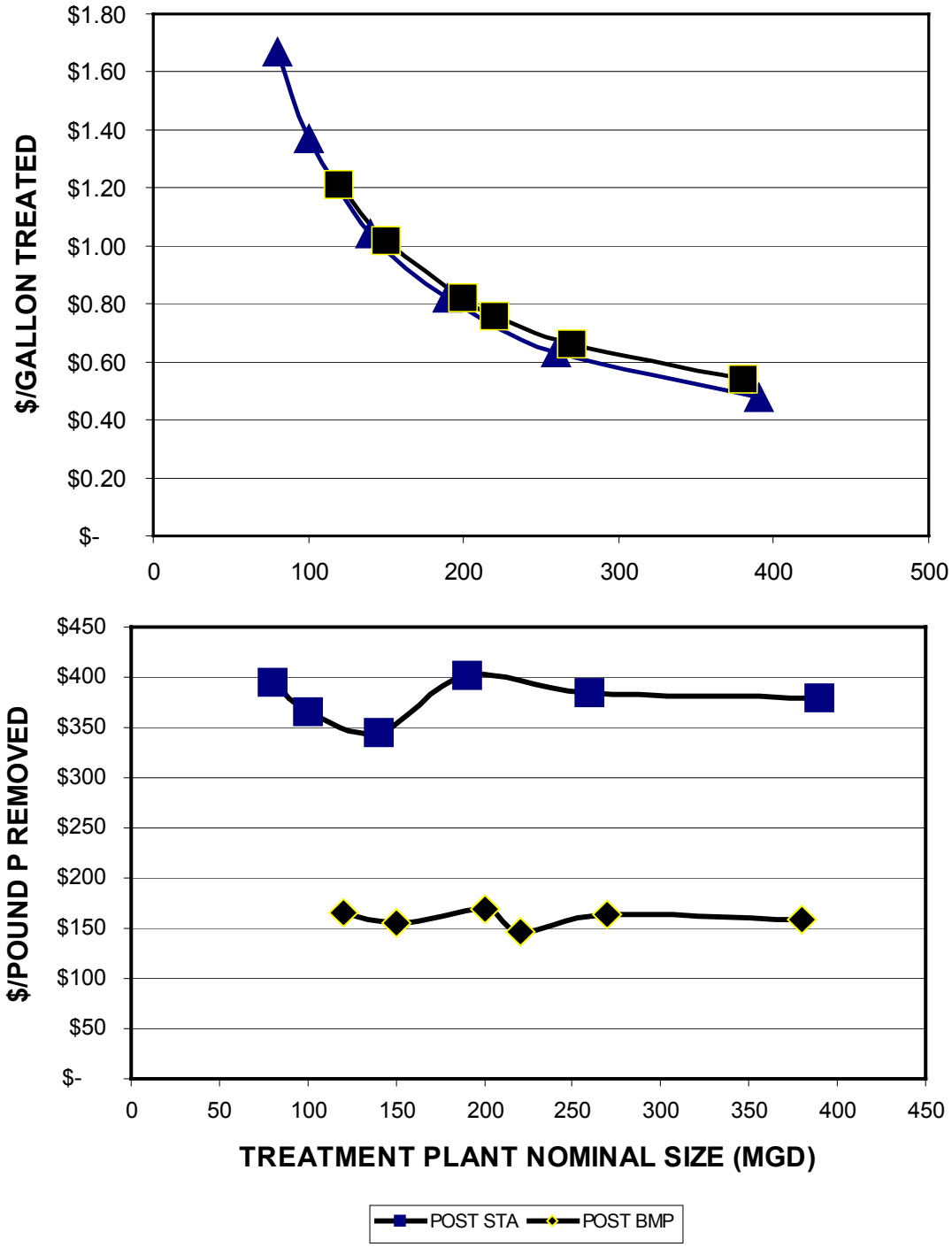

Figure 4C-22. Capital cost in dollars per gallon water treated (Panel A) and present worth cost in dollars per pound of phosphorus removed (Panel B) for the Chemical Treatment Solid Separation demonstration project.

Urban Basin Demonstrations

To assess the effectiveness of the chemical treatment processes on the urban runoff, the District conducted pilot studies (6 to 12 gpm) at the Wellington/Acme Improvement District pump station G-94D. Results of the pilot investigations conducted during six pumping events at the site indicated that TP concentrations in urban runoff could be reduced to 10 mg/L using chemical treatment process equipment. For this study, both coagulants AlCl and $FeCl_3$ were used.

Based on this demonstration project, preliminary cost estimates and land requirements to build a full-scale system (462,500 m^3/d) capable of treating the combined storm water flows from Wellington Pump Stations 1 and 2 were developed. It is estimated that initial construction costs for the chemical treatment plant would be about $46 million, and estimated annual operating costs for the full-scale treatment system would be slightly less than $2 million. It would require about 277 acres to build a full-scale treatment system, including the flow-equalization basin, settling basin and any residual solids management needs.

The District is currently conducting a similar pilot study at the S-9 pump station in the C-11 basin. This basin has fewer horse farms and smaller lot sizes than the Wellington Basin and, therefore, matrix characteristics of the runoff may be different, requiring different coagulant and polymer dosages. Due to the extended drought and reduction in runoff in the C-11 basin, this demonstration project will not be completed until December 2001.

Field-Scale Demonstration Project

To date, all CTSS research and demonstration projects have been conducted at a very small scale – less than 12 gpm. At this scale, optimization of chemical usage, or reliable estimates of residual production, have not been possible. The District is moving forward with a field-scale demonstration project to accurately assess the costs of the chemical treatment process and evaluate its ability to consistently reduce urban stormwater runoff TP concentrations to less than 10 µg/L. This project is currently slated to be located in the Village of Wellington and will consist of a CTSS facility capable of processing from 370 to 3,700 cubic meters/d (100,000 to 1,000,000 gallons per day), with operation and monitoring for a six-to-nine-month period. Data generated from this project will aid the District in accurately determining the size, design characteristics (retention time, loading rates) for a full-scale system. Additionally, more accurate data will be produced regarding the amount of residuals generated as well as the effectiveness of a settling basin in the treatment of occasional solids carry over from the clarification process. Lastly, this project will include an evaluation of several residual management alternatives, such as possible aluminum metal recovery, solids recycling and possible application to agricultural lands for use as BMPs.

Summary

- Given its potential major economic impact, additional research should be performed to determine viable methods of metal salt recovery.
- Capital and operational costs, residuals management and water quality compatibility are the major concerns for full-scale implementation of chemical treatment. Also chemical treatment facilities do not provide the ancillary benefits (e.g. wildlife and fisheries, recreation) that an STA offers.
- Chemical treatment is more cost effective with higher TP concentration inflow water: about $68/Kg ($150/lb) versus $172/Kg ($380/lb) of P removed.

- Civil works and land cost account for more than 80 percent of the capital costs.
- Chemical costs are a critical component of operating costs.
- Residuals management is a major component of the operating costs. Chemical treatment, coupled with an FEB, can effectively reduce TP concentrations in post-BMP water to less than 10 µg/L.
- Based on the 10-year POR flow data used for developing the facility conceptual design, CTSS, coupled with an FEB, can adequately attenuate peak hydraulic flows and consistently produce outflow TP concentrations of 10 µg/L.
- Based upon the pilot study at Village of Wellington Pump Station Number 2, CTSS can successfully reduce urban TP concentrations to less than 10 µg/L.

Chemical Treatment/Microfiltration

The microfiltration (MF) process is a membrane solids-separation technique that can be used to remove particles and suspended solids from a variety of source waters. In general, the lowest pore size for a commercially available (scaled-up for municipal use) MF membrane is approximately 0.2 µm absolute. The performance of two of these membranes, the US Filter-Memcor polypropylene and the Zenon MF-150 ZeeWeed® membranes, was tested from September 1996 to August 1997 at the ENRP for solids separation following chemical treatment. Funding for this research was primarily provided by the EPA-319 H Grant Program and the District. The Sugar Cane Growers Cooperative of Florida and CRA provided additional project funding. The Department served as the contracting agency for this study. For a complete description of the Microfiltration process, refer to the final report update of January 2001 (HSA, 2001).

The 1998 final report provided a full-scale conceptual design and cost estimates for constructing a 740,000 m^3/d (200-mgd) and 647,500 m^3/d (175-mgd) MF treatment system for post-BMP and post-STA sites, respectively (HSA, 1998). The report was completed prior to the District finalizing the STSOC procedures that were to be utilized for evaluating the ATT applications. Additionally, since the completion of the research and the publication of the final report in 1998, there has been steady advancement in configuration, membrane composition, membrane technology, market conditions and availability that changed capital and operational costs considerably. As a result of these advancements, the capital and operational costs developed in 1998 were updated in 2001 and this update was subjected to the same peer review process as the CTSS technology.

Technology Update

Due to the advancement in membrane design, the MF membranes pilot tested in 1996 and 1997 are no longer manufactured. The District originally tested a Zenon 0.2 µm pore-size membrane, which is no longer manufactured. However, Zenon recommended that the Model 500C ZeeWeed® membrane, now classified as an ultrafiltration (UF) membrane, with pore sizes ranging between 0.04 and 0.1 µ, be used instead. Additionally, the District also tested US Filter-Memcor hollow fiber polypropylene membrane (enclosed cartridge configuration). Technological improvements have resulted in a higher-grade, chlorine-resistant, polypropylene membrane (PVdf membrane material) available either in cartridge or submerged configuration and at a comparable cost to the filter tested.

Updated Cost Estimates for Full-scale Implementation

Using the format identified in the STSOC (PEER Consultants/Brown and Caldwell, 1999), the full-scale post-BMP and post-STA cost estimates provided in the 1998 MF final report were updated to reflect current costs. Unit prices and cost information specified in the STSOC were then used to prepare the cost update and were peer reviewed (Parsons Brinckerhoff and Milian, Swain and Associates, 2001). The membrane cost estimates were developed from equipment supplier quotes and prior engineering experience. The report indicated that even though Memcor CMF and Zenon MF pilot systems performed comparably with respect to P removal and flux restoration, capital and operational costs provided by Zenon were slightly lower than those provided by US Filter (Memcor). Therefore, to provide the lowest representative costs, the 12 full-scale facility estimates were based on the Zenon 500C UF membrane system.

Treatment plant sizes for each POR flow diversion scenario included an FEB and CTSS treatment unit to meet the desired effluent quality. **Table 4C-16** details the calculated flows for the resultant 12 full-scale treatment scenarios for STA-2 (HSA, 2000). The 50-year present-worth calculations were then used to calculate the unit cost per cubic meter capacity and per kilogram (pound) of P removed for STA-2 only ($/Kg [pound] of P removed) (**Figure 4C-23**).

Table 4C-16. STSOC full-scale treatment scenarios for the Chemical Treatment Microfiltration Project.

Location	Effluent Total P	No Diversion (mgd)	10% Diversion (mgd)	20% Diversion (mgd)
Post–BMP	10 ppb	450	315	230
	20 ppb	240	165	125
Post–STA	10 ppb	500	305	225
	20 ppb	160	110	85

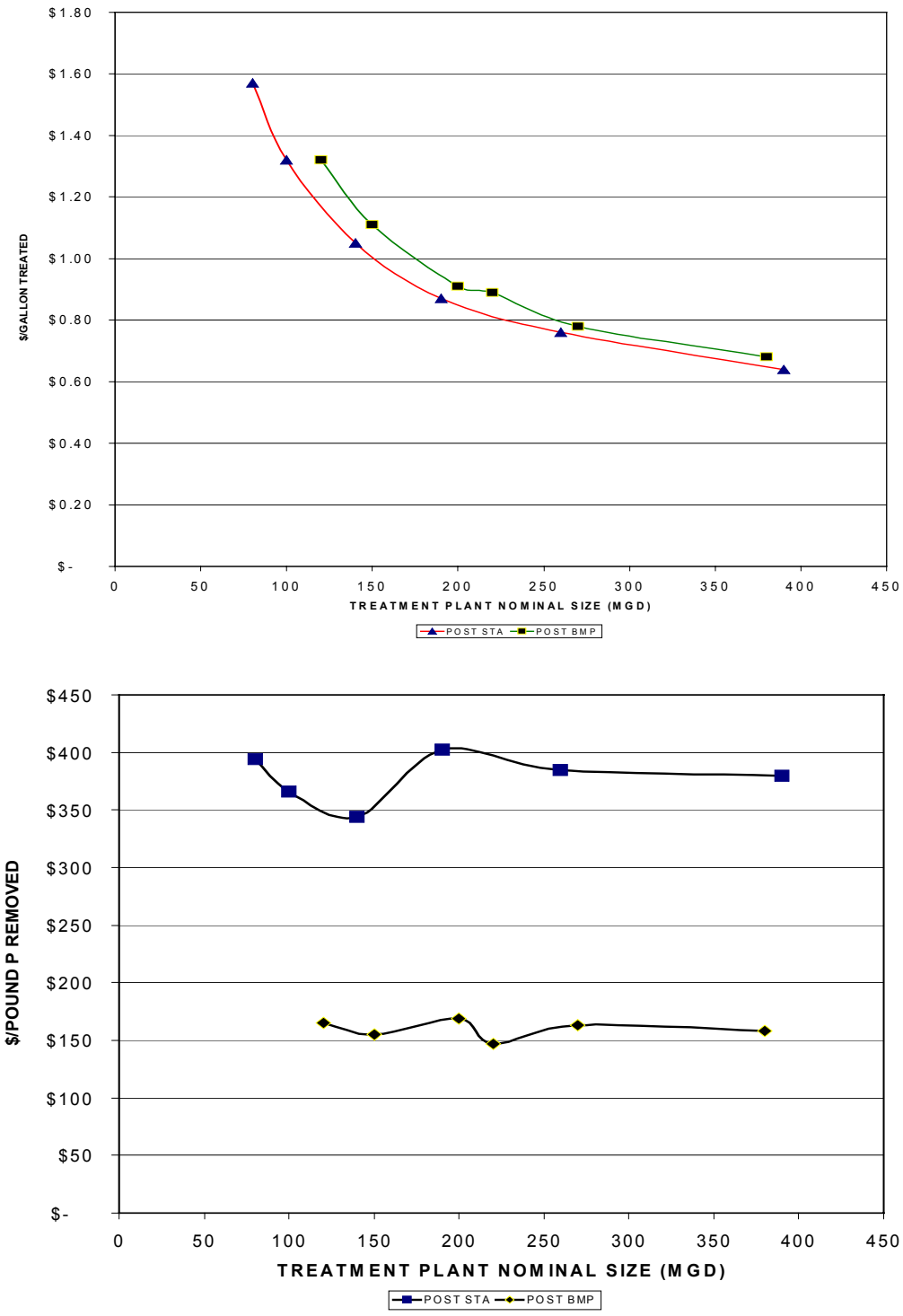

Figure 4C-23. The relative treatment costs in terms of dollars per gallon of water treated (Panel A) and dollars per pounds of phosphorus removed (Panel B) for a full-scale microfiltration treatment plant.

CHEMICAL TREATMENT/MICROFILTRATION SUMMARY

- Chemical treatment, combined with microfiltration for solids separation, has proven to be a viable technology consistently producing outflow TP concentrations of 10 µg/L.
- Treatment plants using membrane technologies benefit from producing a superior water requiring less operator attention, being aesthetically more pleasing and providing an edge against future, more stringent regulations. An evaluation of this technology indicates there has been a steady advancement in configuration, membrane composition, membrane technology, market conditions and availability that changed capital and operational costs considerably. As a result of these advancements, the capital and operational costs developed in 1998 were updated in 2001, showing that cost-averaged $85.4/Kg ($188/pound) of TP removed (post-BMP) versus $185/Kg ($408/pound) of TP removed (post-STA).
- Local land application of residual solids appears to be the most cost-effective disposal method for the MF Process. Because of the proprietary nature of membrane manufacturing, it is recommended that alternative delivery methods be investigated to assure long-term performance and membrane availability.

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