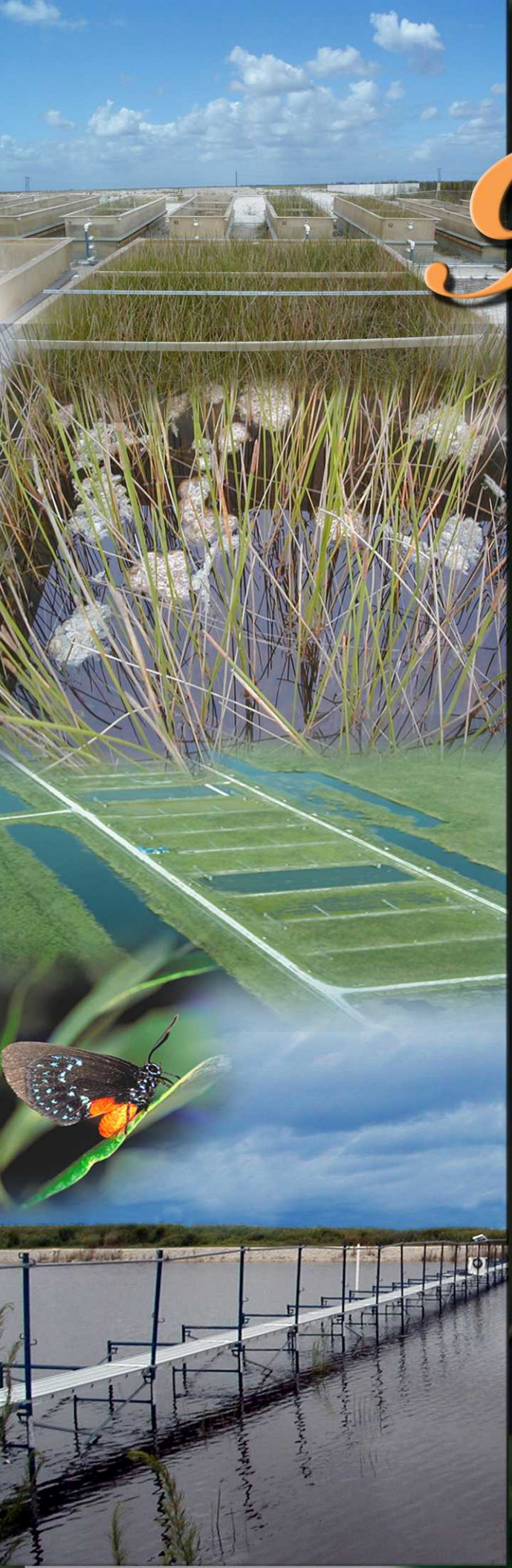

February 1999 to April 2001

STA Research and Demonstration Project Phase 1 and 2 Summary Report

Prepared for

South Florida Water Management District

Prepared by

CH2MHILL

October 2001

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Abbreviations and Acronyms

AM	Aquamat
AFDW	ash-free dry weight
AS	Aquashade
ATT	Advanced Treatment Technologies
BMP	Best Management Practices
^{o}C	degrees Celsius
ca	calcium
cf/d	cubic feet per day
cm	centimeter
CM	community metabolism
cm/d	centimeters per day
cm/s	centimeters per second
CompQAP	Comprehensive Quality Assurance Plan
CR	community respiration
CSTR	continuously stirred tank reactor
CU	color unit
DBEL	DB Environmental Laboratories
DMSTA	Dynamic Model for Stormwater Treatment Areas
DO	dissolved oxygen
DOP	dissolved organic phosphorus
DRP	dissolved reactive phosphorus
DW	dry weight
EAA	Everglades Agricultural Area
ECP	Everglades Conservation Project
EFA	Everglades Forever Act
ENCO	Environmental Conservation Laboratories
ENR	Everglades Nutrient Removal
ET	evapotranspiration
FDEP	Florida Department of Environmental Protection
FEB	flow equalization basin
FSC	field-scale cell
ft	feet
ft^2	square feet
GPP	gross primary productivity
ha	hectare
HCI	hydrochloric acid
HLR	hydraulic loading rate
HRT	hydraulic residence time
IFAS	Institute of Food and Agricultural Sciences

in	inch
L	liter
LR	limerock
m	meter
m/d	meters per day
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MJ	megajoule
m^2	square meter
mt/ha	metric tonne per hectare
µg/cm	micrograms per centimeter
µg/L	micrograms per liter
µm	micrometer
NA	not available
NPP	net primary productivity
NTU	Nephelometric Turbidity Unit
O&M	operation and maintenance
OPP	Optimal Performance Period
P	phosphorus
PAR	photosynthetically active radiation
PE	peat
POR	period of record
pp	porta-PSTA
ppb	parts per billion
PPB	PPB Environmental Laboratory
PSTAs	Periphyton-based Stormwater Treatment Areas
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
SA	sand
SAV/LR	submerged aquatic vegetation/limerock
SFWMD	South Florida Water Management District
SR	shellrock
STA	stormwater treatment area
STC	South Test Cell
STRC	Supplemental Technology Research Compound
STSOC	Supplemental Technology Standards of Comparison
TDP	total dissolved phosphorus
TDS	total dissolved solids
TIP	total inorganic phosphorus
TIS	tank-in-series
TKN	total Kjeldahl nitrogen
TOC	total organic carbon

TOP	total organic phosphorus
TP	total phosphorus
TPP	total particulate phosphorus
TSS	total suspended solids
VPP	Verification Performance Period
WCA	Water Conservation Area

Executive Summary

Introduction

The South Florida Water Management District (District) is conducting research focused on determining the effectiveness and design criteria of potential advanced treatment technologies to support reduction of phosphorus (P) loads in surface waters entering the remaining Everglades (SFWMD, 2000). Particular focus is being placed on the treatment of surface waters from the Everglades Agricultural Area (EAA) as well as Lake Okeechobee water that is diverted through the primary canal system to the Lower East Coast of Florida.

Periphyton-based stormwater treatment areas (PSTAs) are one of the advanced treatment technologies being researched by the District for potential application downstream of the macrophyte-based stormwater treatment areas (STAs). The PSTA concept was proposed for P removal from EAA waters by Doren and Jones (1996). Evaluations remain focused on PSTAs as post-STA treatment units intended to help achieve compliance with the anticipated ultimate total phosphorus (TP) criterion of 10 parts per billion (ppb).

In concept, the periphyton complex is hypothesized as being capable of extracting available P in the water introduced into the system and incorporation of that P into the biomass of the periphyton mat. Settling of detrital matter contributes to the long-term P storage. Additionally, because of the high primary productivity of these periphyton systems, water quality conditions favor P precipitation and binding into the newly formed sediments. The result is a water outflow with much of the available P scavenged and retained in the system biomass and sediments. These concepts are depicted in Exhibit ES-1.

Prior to initiation of the District's PSTA project in July 1998, detailed research to evaluate PSTA feasibility had not been performed. The key study objectives, therefore, were to research and demonstrate (to the extent possible within the contract period) PSTA viability, effectiveness, and sustainability at several scales of application. The following specific questions were to be addressed:

- Viability: Can periphyton-dominated ecosystems for P control be established?
- Effectiveness: Can P removal and retention be achieved?

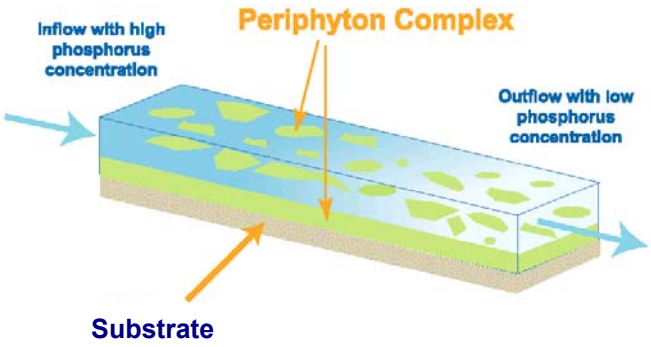


EXHIBIT ES-1
Schematic Diagram of the Periphyton Stormwater Treatment Area (PSTA) Concept

- Sustainability: Can PSTA viability and effectiveness be maintained for long-term periods?

Viability was assessed by documenting how long it took for the development of periphyton-dominated plant communities in the PSTA mesocosms, and whether they could be maintained for reasonable periods of time. Effectiveness as a water quality treatment approach was evaluated based on the ability of the PSTA test systems to achieve low TP outflow concentrations. The TP removal rate constant, a metric for phosphorus removal efficiency, was quantified for the various PSTA mesocosm conditions tested during the study. Because sustainability issues would not be fully addressable within the anticipated 3-year study period, this question was evaluated through development and application of a performance forecast model based on the empirical data generated by the field studies.

A two-phased approach was originally adopted to investigate the PSTA concept: an Experimental Phase (Phase 1), and a Validation/Optimization Phase (Phase 2). The project approach has been modified to include Phase 3, which includes a demonstration of PSTA viability, effectiveness, and sustainability at a larger, field scale. The types of activities that are included in each phase are described as follows:

- **Phase 1 (Experimental Phase)** included development of the work plan and experimental design, initial research in three experimental Test Cells (PSTA Test Cells) located at the southern end of the Everglades Nutrient Removal (ENR) project (see Exhibit ES-2 and SFWMD 2000 for location of sites), and construction and startup/monitoring of research using 24 portable experimental mesocosms (Porta-PSTAs). The Phase 1 experimental studies provided critically needed information for addressing basic issues associated with PSTA viability and treatment performance effectiveness. Development of a preliminary forecast model and preliminary model calibration were also completed.

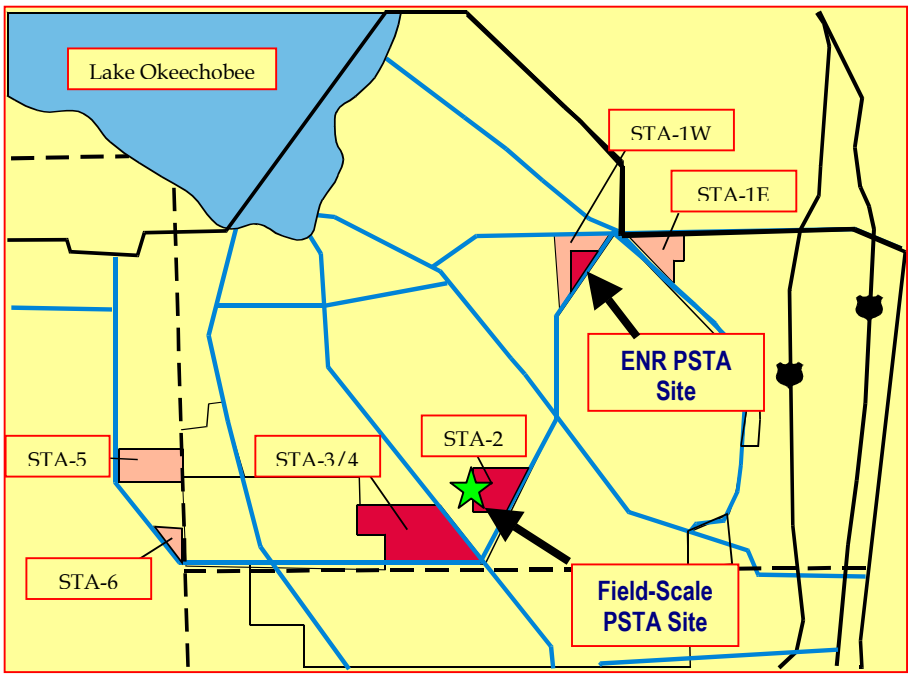


EXHIBIT ES-2
Location of District PSTA Research Sites

- **Phase 2 (Validation/Optimization Phase)** included continuing research in the ENR PSTA Test Cells and in the Porta-PSTAs, and design and observations during the District's construction of the field-scale demonstration PSTAs immediately west of STA-2. During Phase 2, the expanded PSTA operational database was used to further refine and calibrate the performance forecast model, and develop design criteria for a full-scale PSTA system. The forecast model was applied to support projections of the long-term cost of implementing PSTAs to meet ultimate P reduction goals under the Everglades Forever Act (EFA).
- **Phase 3 (Demonstration Phase)** includes operation and monitoring of four 5-acre field-scale PSTA cells located immediately west of STA-2. This demonstration will develop necessary design and construction information related to various methods and efficacy of substrate preparation (limerock fill, scrape-down , and existing peat-based soils), effects of cell configuration and flow velocity, and effects of groundwater exchanges.

In the aggregate, the PSTA Research and Demonstration Project is designed to develop defensible conclusions related to specific hypotheses that are relevant to key research questions and design issues described in the *PSTA Research Plan* (CH2M HILL, 1999). This report provides a summary of the Phase 1 and 2 findings.

Research Plan and Mesocosm Overview

Exhibit ES-3 summarizes the treatments used for Phase 1 and 2 and planned for Phase 3 of the PSTA Research and Demonstration Project. A more detailed description of the three mesocosm scales is provided below.

Porta-PSTA Mesocosms

Twenty-four Porta-PSTA mesocosm units were fabricated of fiberglass offsite and delivered to the South ENR Supplemental Technology Research Compound (STRC). Twenty-two of the fiberglass tanks were 6 m long by 1 m wide by 1 m deep. The remaining two tanks were 3 m wide to allow assessment of mesocosm configuration effects. Exhibit ES-4 shows the layout of typical 1- and 3-m-wide mesocosms in relation to the constant-head tank and inlet manifolds.

Porta-PSTA treatments focused on the following primary design variables:

- Substrate type –organic soils (peat) or calcareous material (shellrock)
- Water depth
- Hydraulic loading rate (HLR)

Substrate and water depth were replicated in a complete factorial design, while hydraulic loading was only varied on the shellrock substrate. All Porta-PSTA treatments were planted with an initial low density of emergent macrophytes (*Eleocharis*).

In addition to these primary treatment variables, these PSTA mesocosms were also screened for effects of:

- Scale (l x 6 meter vs. 3 x 6 meter)
- Sand substrate (relatively inert with respect to oxygen demand and TP content)
- Unvegetated controls with Aquashade (aquatic dye) to reduce periphyton growth

South ENR Test Cells

The South ENR Test Cells (STCs) consist of 15 rectangular, 0.2-hectare (ha) cells receiving flows from a single Head Cell. Water pumped into the Head Cell from ENR Cell 3 flows by gravity through a distribution manifold into each of the Test Cells. The District assigned three ENR Test Cells to the PSTA Research and Demonstration Project. During final construction, substrate within these PSTA Test Cells was modified by the District by placing the following layers of substrate over the cell liner:

- Macrophytes – *Eleocharis* planted to help provide 3-dimensional structure and periphyton mat stability.

EXHIBIT ES-3
PSTA Design Criteria and Experimental Treatments

PSTA Treatment	Phase	Cells	Area (m^2)	Substrate Type	Target Wtr Depth (cm)	Target HLR (cm/d)	Target Depth:Width Ratio	Other Considerations
Porta-PSTA Mesocosms								
PP-1	1	9, 11, 18	6	Peat	60	6	0.6	macrophytes
PP-2	1	4, 7, 8	6	Shellrock	60	6	0.6	macrophytes
PP-3	1, 2	12, 14, 17	6	Peat	30	6	0.3	macrophytes
PP-4	1, 2	3, 5, 10	6	Shellrock	30	6	0.3	macrophytes
PP-5	1	2, 13, 16	6	Shellrock	60	12	0.6	macrophytes
PP-6	1	1, 6, 15	6	Shellrock	0-60	0-12	0-0.6	macrophytes
PP-7	1, 2	19	6	Sand	30	6	0.3	macrophytes
PP-8	1	20	6	Sand	60	6	0.6	macrophytes
PP-9	1	21	6	Peat	60	6	0.6	Aquashade; no macrophytes
PP-10	1	22	6	Shellrock	60	6	0.6	Aquashade; no Macrophytes
PP-11	1, 2	23	18	Shellrock	30	6	0.1	macrophytes
PP-12	1, 2	24	18	Peat	30	6	0.1	macrophytes
PP-13	2	9, 11, 18	6	peat (Ca)	30	6	0.3	macrophytes
PP-14	2	4, 7, 8	6	Limerock	30	6	0.3	macrophytes
PP-15	2	2, 13, 16	6	Shellrock	30	6	0.3	macrophytes; recirculation
PP-16	2	1, 6, 15	6	Shellrock	0-30	0-6	0-0.3	macrophytes
PP-17	2	20	6	sand (HCl)	30	6	0.3	macrophytes
PP-18	2	21	6	None	30	6	0.3	no macrophytes
PP-19	2	22	6	Aquamat	30	6	0.3	no macrophytes
Test Cell PSTAs								
STC-1	1	13	2,240	Peat	60	6	0.02	macrophytes
STC-2	1	8	2,240	Shellrock	60	6	0.02	macrophytes
STC-3	1	3	2,240	shellrock	0-60	0-12	0-0.02	macrophytes
STC-4	2	13	2,240	peat (Ca)	30	6	0.01	macrophytes
STC-5	2	8	2,240	shellrock	30	6	0.01	macrophytes
STC-6	2	13	2,240	shellrock	0-30	0-12	0-0.01	macrophytes
Field-Scale Pilot PSTAs								
FSC-1	3	1	20,790	Limerock/Peat	0-60	0-12	0.005	macrophytes
FSC-2	3	2	20,790	Limerock/Peat	0-60	0-12	0.014	macrophytes
FSC-3	3	3	20,790	Caprock	0-60	0-12	0.005	macrophytes
FSC-4	3	4	20,790	Peat	0-60	0-12	0.005	macrophytes

Notes:
PP = Porta-PSTA
STC = South Test Cell
FSC = Field-Scale Cells

EXHIBIT ES-4
Porta-PSTA Tank 23 (Treatment PP-11) After 11 Months of Colonization
This 6 x 3 meter tank has shellrock soils and was operated at a 30-cm water depth. Floating periphyton mats are visible among the sparse emergent macrophytes. Narrow tanks can be seen in the background as well as the raised constant Head Tank used to feed all mesocosms at this site.

- **STC-1 (Test Cell 13)** – approximately 80 centimeters (cm) of sand surcharge plus 30 cm of locally mined shellrock plus 30 cm of peat taken from a local, unflooded, and former agricultural lands area
- **STC-2 (Test Cell 8)** – approximately 1 meter (m) of sand surcharge plus 30 cm of locally mined shellrock
- **STC-3 (Test Cell 3)** – approximately 1 m of sand surcharge plus 30 cm of locally mined shellrock

Exhibit ES-5 shows PSTA Test Cell 8 (PSTA Treatment STC-2), with shellrock substrate after nearly 1 year of colonization. Test Cell PSTA treatments addressed the following primary design variables:

- Substrate type organic soils (peat) or calcareous material (shellrock)
- Variable depth and hydraulic loading rage

No replication was possible for this scale of field investigation. All three Test Cells were planted with *Eleocharis*.

EXHIBIT ES-5
PSTA Test Cell 8 (Treatment STC-2) After Approximately 12 Months of Colonization
This photo is looking upstream from the outfall standpipes toward the inflow at the far end of the cell. Monitoring walkways are located at 1/3 and 2/3 points along the flow path.

Field-Scale Cells

Four field-scale pilot PSTA cells were constructed during Phase 2 at the site immediately adjacent to STA-2, Cell 3 (see Exhibit ES-6). These four cells are each approximately 20,000 m^2 (5 ac). Three of the cells are rectangular at 61 m wide by 317 m long (200 by 1,040 ft); the fourth cell is sinuous and has a length of 951 m (3,120 ft) and a width of 21 m (70 ft). Cells 1 and 2 have approximately 30 cm (12 in) of compacted limerock placed over the native peat soils. The native peat soils were excavated and removed from Cell 3 to expose the underlying caprock. Native peat soils with no amendments or other pre-treatments comprise the floor of Cell 4. The field-scale pilot PSTAs were developed to provide specific information regarding constructability issues as well as to demonstrate whether system viability and phosphorus removal effectiveness seen in the smaller-scale systems could be matched or improved upon. Substrate effects and the influence of surface and groundwater interaction on apparent treatment performance at this PSTA scale will be addressed by ongoing Phase 3 monitoring. Additionally, water velocity effects on treatment effectiveness are to be quantified through these investigations. Lastly, scale-up effects are to be evaluated as Phase 3 is performed.

EXHIBIT ES-6
Field-Scale Pilot PSTA Research Site West of STA-2

PSTA Phase 1 and 2 Key Findings

Key findings regarding PSTA viability, treatment effectiveness, and apparent sustainability based on the Phase 1 and 2 results are highlighted as follows.

PSTA Viability

The periphyton communities that became established within the PSTA mesocosms attained biomass levels and replicated normal periphyton algal species assemblages typical of low-P Everglades waters (Browder et al., 1994) within the first 2 years of operation. These experimental PSTA plant communities display community-level responses (gross primary productivity [GPP] and community respiration [CR]) in response to environmental forcing functions, such as sunlight and antecedent soil conditions, that are similar to natural Everglades plant communities.

A total of 371 algal taxa were identified in periphyton samples collected from the PSTA mesocosms during the 2-year period of data collection (Phases 1 and 2). Filamentous green algae were observed to occupy the front end of the mesocosms in areas of measurable dissolved reactive P (DRP), while filamentous blue-greens and diatoms dominated floating and benthic periphyton mats throughout the majority of the test systems. Initial colonization was typically by diatom species followed by gradual succession to filamentous blue-greens. PSTA periphyton communities were similar to those found in natural Everglades areas with low to moderate TP concentrations.

Ash-free dry weight (AFDW) biomass increased to sustainable levels (typically between 100 and 1,000 grams per square meter [g/m^2] in all mesocosms and Test Cells) within 4 to 5 months from startup. Chlorophyll *a* (corrected for phaeophytin) and algal biovolume continued to increase throughout the study period, indicating that a steady-state was not achieved during the duration of this study. Average chlorophyll *a* concentrations were between 30 and 250 milligrams per square meter (mg/m^2).

Eleocharis cellulosa (spikerush) and *Utricularia* spp. (bladderwort) were purposely added to most of the PSTA mesocosms. Natural Everglades periphyton-dominated plant communities include these macrophytes, and it was decided to include them in the test mesocosms because they provide periphyton attachment sites and stability against wind-induced periphyton mobility. *Typha latifolia* (cattail), *Hydrilla verticillata* (hydrilla), and *Chara* spp. (stonewort) invaded the PSTA mesocosms, with greatest invasion rates in mesocosms with peat soils. Macrophyte biomass estimates indicated that the peat soil mesocosms were overwhelmed by macrophyte growth (see Exhibit ES-7), dominating visual plant cover estimates. By the end of nearly 2 years of colonization, macrophyte cover dominance reduced the periphyton community importance in peat-based mesocosms. PSTA mesocosms with shellrock and sand soils maintained high periphyton biomass and relatively sparse macrophyte plant communities during the 2-year period. However, some form of macrophyte management will likely be required for PSTAs built on any substrate type.

EXHIBIT ES-7
Photograph of PP-12 (Tank 24) Showing Dense Colonization by Spikerush
Average live stem count in this tank was approximately 322 stems/m^2 by the end of Phase 2. Periphyton biomass and algal cell counts were reduced with high macrophyte cover.

Treatment Effectiveness

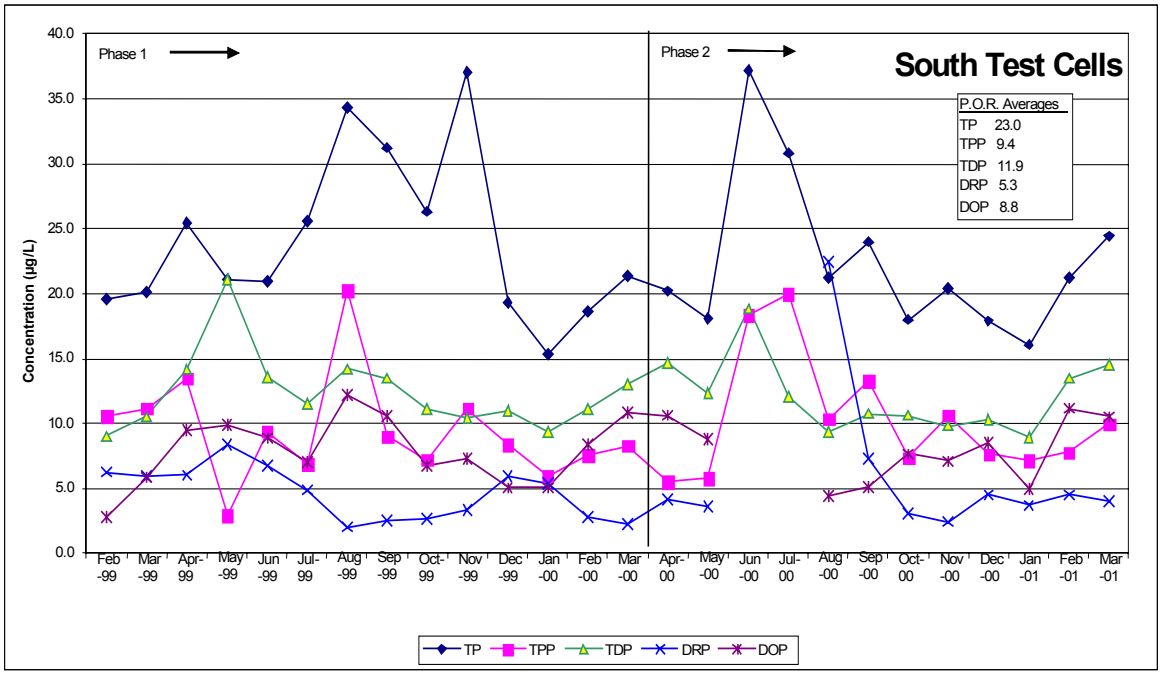
Based on the conditions selected for this research, these PSTA mesocosms were able to attain average TP outflow concentrations as low as 11 micrograms per liter (µg/L). These concentrations are considerably lower than the long-term average outflow TP concentration from the former ENR system of 22 µg/L (Walker, 1999) and are comparable to ENR Cell 4 averages during the past 2 years (13 to 15 µg/L) (DB Environmental Laboratories [DBEL], 2000).

Lower average TP concentrations have been observed in natural periphyton-dominated communities in Water Conservation Area 2A (McCormick et al., 1996), in the southern Everglades, and in outflow from experimental mesocosms built with limerock substrates (DBEL, 1999). The minimum TP values recorded during this research were clearly related to internal P loading from antecedent soils. Shellrock, limerock, and sand soils released less available P than peat soils. It is not currently known if these minimum outflow TP concentrations will continue to decline with increasing system maturity and eventual complete burial of antecedent soils.

The k_1 values recorded in this research are comparable to or higher than values recorded for emergent macrophyte and submerged aquatic vegetation (SAV)-dominated treatment wetlands in South Florida. Average PSTA k_1 values ranged from 2 to 27 meters per year (m/yr), depending on specific treatment variables. Walker (1999) determined that the overall ENR k_1 value was approximately 15.5 m/yr for the period from March 1995 through November 1998. The k_1 value for Cell 3 of the ENR is probably most comparable because of similar inflow water quality conditions as the PSTA research sites. This cell averaged k_1 = 9.5 m/yr during this operational period. Cell 4 of the ENR is dominated by SAV and averaged k_1 = 17.3 m/yr during this same period. Continuing research with the PSTA mesocosms needs to be conducted to validate and refine the TP performance estimates obtained during the project operational period.

Inflow Phosphorus Concentrations

Inlet P concentrations were variable throughout the project period (see Exhibits ES-8 and ES-9 for Test Cell and Porta-PSTA results, respectively). While mean TP concentrations were similar at the Porta-PSTA and Test Cell sites (23 µg/L at the Test Cells and 25 µg/L at the Porta-PSTAs), TP concentration ranges were variable between the two research sites. These differences in TP were largely attributable to complex seasonal variations in the concentrations of total dissolved P (TDP) and total particulate P (TPP) in the two water supplies. On the average, TDP comprised 52 and 62 percent of TP at the Test Cells and Porta-PSTAs, respectively. DRP was approximately 5 and 6 µg/L, respectively, while dissolved organic P (DOP) averaged 9 and 7 µg/L in the inflow waters, respectively.



Notes:
TP = total phosphorus
TDP = total dissolved phosphorus
DOP = dissolved organic phosphorus
TPP = total particulate phosphorus
DRP = dissolved reactive phosphorus

EXHIBIT ES-8
Time Series of Input Concentrations of TP, TDP, TPP, DOP, and DRP in Source Water at the PSTA Test Cells

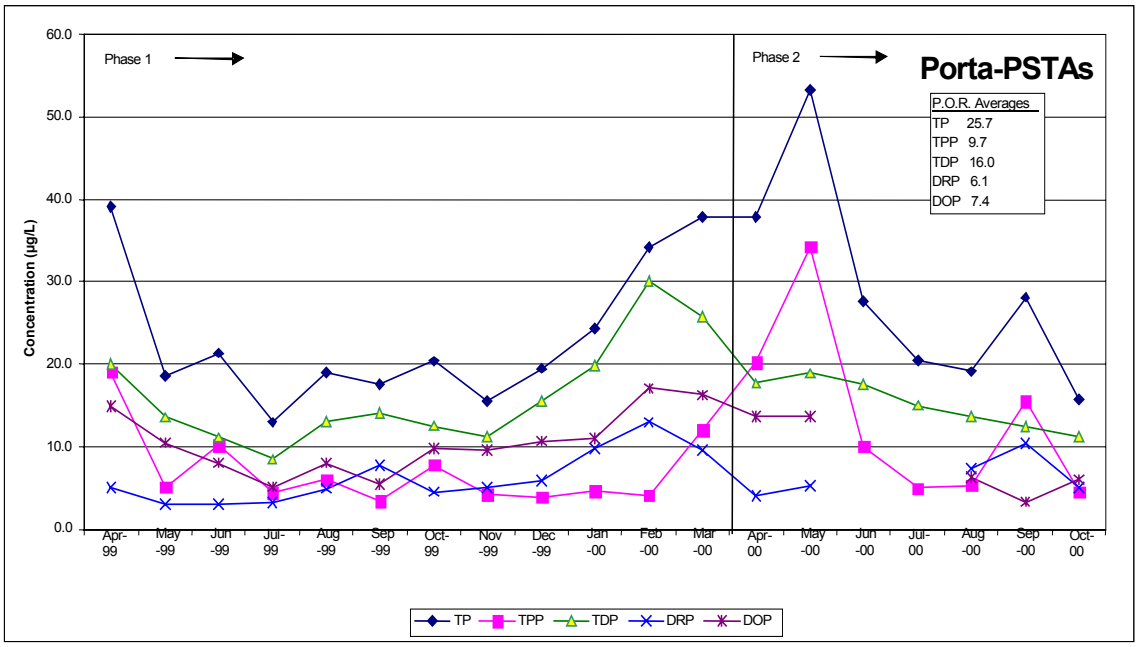
Phosphorus Removal Performance

Exhibit ES-10 summarizes the TP concentrations and estimated k-C* model parameters for each treatment during the optimal (post-startup) period-of-record. Values for k_1 are also summarized in Exhibit ES-10 and offer a normalized comparison between treatments.

P removal rate constants in constantly loaded shellrock mesocosms were generally consistent throughout the 2-year project. An initial startup period is evident in the data during the first 3 to 5 months of system operation, followed by apparent seasonal patterns in the PSTA mesocosms (Exhibit ES-11) for the rest of the Phase 1 and 2 periods. TP removal declined in some of the peat-based systems during the second year of operation.

The following conclusions concerning P removal effectiveness were drawn from these PSTA research data:

- Estimated values for C*, the effective background TP concentration resulting from internal and external loadings and removals, ranged from 6 to 16 µg/L
- Estimated TP k_1 values ranged from 1.6 to 27 m/yr



Notes:
TP = total phosphorus
TDP = total dissolved phosphorus
DOP = dissolved organic phosphorus
TPP = total particulate phosphorus
DRP = dissolved reactive phosphorus

EXHIBIT ES-9
Time Series of Input Concentrations of TP, TDP, TPP, DOP, and DRP in Source Water at the Porta-PSTA Mesocosms

- The lowest post-startup, treatment average TP outflow concentration was 11 µg/L, and lowest treatment monthly average was 7 µg/L
- There were no consistent effects of water depth (30- vs. 60-cm steady depth) on outflow TP concentration, but TP removal rate was slightly higher at the shallower depth
- Variable-water depths resulted in reduced TP removal performance compared to stable water depths
- Outflow TP concentrations were lower and k_1 values higher in mesocosms with shellrock substrates than in comparable mesocosms with peat soils (see Exhibit ES-12)
- Higher loading rates (hydraulic and TP mass) increased k_1 and average outflow TP concentration
- A slight effect of mesocosm scale was observed that indicated that smaller mesocosms underestimated outflow TP values and overestimated k_1 values
- In Aquashade control mesocosms, average outflow TP concentrations were higher, but k_1 values were not consistently higher or lower than vegetated treatments indicating the complexity of macrophyte and periphyton P cycling from soils and water

EXHIBIT ES-10

k-C* Model Parameters for the PSTA Treatments for the Optimal Performance Period

Treatment	Cell	Phase	Substrate	Depth	HLR	TP (mg/L) C1	TP (mg/L) C2	HLR (m/yr)	Wtr Temp (C)	k_1 (m/yr)	k_{20PFR} (m/yr)	k_{20TIS} (m/yr)	# TIS	C*	Theta
Porta-PSTAs															
PP-1	9,11,18	1	PE	D	L	0.020	0.014	34.9	22.7	11.1	61.9	99.6	***2.0***	0.015	0.87
PP-2	4,7,8	1	SR	D	L	0.020	0.013	33.4	22.0	13.9	46.5	67.2	***2.0***	0.011	0.98
PP-3	12,14,17	1, 2	PE	S	L	0.027	0.017	29.2	24.6	13.7	54.0	88.7	***2.0***	0.016	***1.00***
PP-4	3,5,10	1, 2	SR	S	L	0.027	0.014	30.5	24.7	19.6	43.2	62.9	***2.0***	0.011	1.02
PP-5	2,13,16	1	SR	D	H	0.025	0.017	62.8	21.7	27.0	68.1	90.4	***2.0***	0.011	0.90
PP-6	1,6,15	1	SR	V	V	0.026	0.015	16.5	21.1	9.1	39.6	76.5	***2.0***	0.013	0.95
PP-7	19	1, 2	SA	S	L	0.027	0.015	29.6	24.4	17.4	31.1	40.8	***2.0***	0.010	1.03
PP-8	20	1	SA	D	L	0.020	0.016	33.9	22.9	7.8	89.3	185.2	***2.0***	***0.015***	***1.00***
PP-9	21	1	PE (AS)	D	L	0.026	0.020	34.9	21.4	8.2	35.5	46.3	***2.0***	***0.016***	***1.00***
PP-10	22	1	SR (AS)	D	L	0.026	0.015	32.4	19.8	17.7	35.8	47.7	***2.0***	0.010	1.02
PP-11	23	1, 2	SR	S	L	0.027	0.017	32.3	24.4	14.4	39.6	54.6	***2.0***	0.013	0.96
PP-12	24	1, 2	PE	S	L	0.027	0.018	31.1	24.2	11.9	44.9	65.8	***2.0***	0.015	0.96
PP-13	9,11,18	2	PE (Ca)	S	L	0.022	0.015	31.8	28.1	13.0	20.4	24.1	***2.0***	***0.007***	***1.00***
PP-14	4,7,8	2	LR	S	L	0.022	0.014	32.0	28.3	14.5	27.6	34.6	***2.0***	***0.008***	***1.00***
PP-15	2,13,16	2	SR	S	R	0.022	0.014	29.4	31.0	14.3	26.4	33.3	***2.0***	***0.008***	***1.00***
PP-16	1,6,15	2	SR	V	V	0.022	0.016	64.1	28.7	20.2	45.0	53.9	***2.0***	0.006	0.96
PP-17	20	2	SA (HCl)	S	L	0.022	0.011	28.4	28.2	18.4	42.4	63.0	***2.0***	0.005	0.94
PP-18	21	2	None	S	L	0.023	0.013	29.5	28.0	16.8	32.8	43.9	***2.0***	***0.008***	***1.00***
PP-19	22	2	AM	S	L	0.022	0.013	31.6	28.1	17.8	28.6	36.2	***2.0***	***0.007***	***1.00***
South Test Cells															
STC-1	13	1	PE	D	L	0.027	0.016	16.2	24.6	8.3	34.9	51.1	***3.0***	0.013	0.92
STC-2	8	1	SR	D	L	0.025	0.013	16.3	25.2	10.5	31.7	44.6	***3.0***	0.010	0.96
STC-3	3	1	SR	V	V	0.025	0.018	13.2	23.8	4.4	42.5	76.2	***3.0***	0.016	0.93
STC-4	13	2	PE (Ca)	S	L	0.022	0.019	18.1	23.3	2.0	8.5	9.2	***3.0***	***0.013***	***1.00***
STC-5	8	2	SR	S	L	0.023	0.012	18.4	23.7	12.3	20.7	25.2	***3.0***	0.007	1.00
STC-6	3	2	SR	V	V	0.023	0.019	20.9	26.1	3.6	5.5	5.8	***3.0***	***0.010***	***1.00***
Porta-PSTA Summary															
	Peat					0.025	0.016	30.9	24.9	13.1	48.0	72.6	***2.0***	0.014	0.97
	Shellrock					0.024	0.015	40.1	24.7	17.9	56.7	82.5	***2.0***	0.013	0.97
	Sand					0.025	0.015	30.6	24.1	15.6	33.0	43.8	***2.0***	0.011	1.03
	Limerock					0.022	0.014	32.0	28.3	14.5	27.6	34.6	***2.0***	***0.008***	***1.00***
	Aquashade					0.026	0.018	33.7	20.6	12.8	95.5	210.8	***2.0***	0.016	0.82
	No Substrate					0.023	0.013	29.5	28.0	16.8	32.8	43.9	***2.0***	***0.008***	***1.00***
	Aquamat					0.022	0.013	31.6	28.1	17.8	28.6	36.2	***2.0***	***0.007***	***1.00***
South Test Cells Summary															
	Peat					0.024	0.018	17.3	23.9	5.0	58.5	108.5	***3.0***	0.018	1.03
	Shellrock					0.024	0.015	17.2	24.6	7.9	136.3	671.4	***3.0***	0.015	0.90

Notes:
Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells
Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade
Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)
HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate
TIS = tanks-in-series
bold and italic = values fixed in model

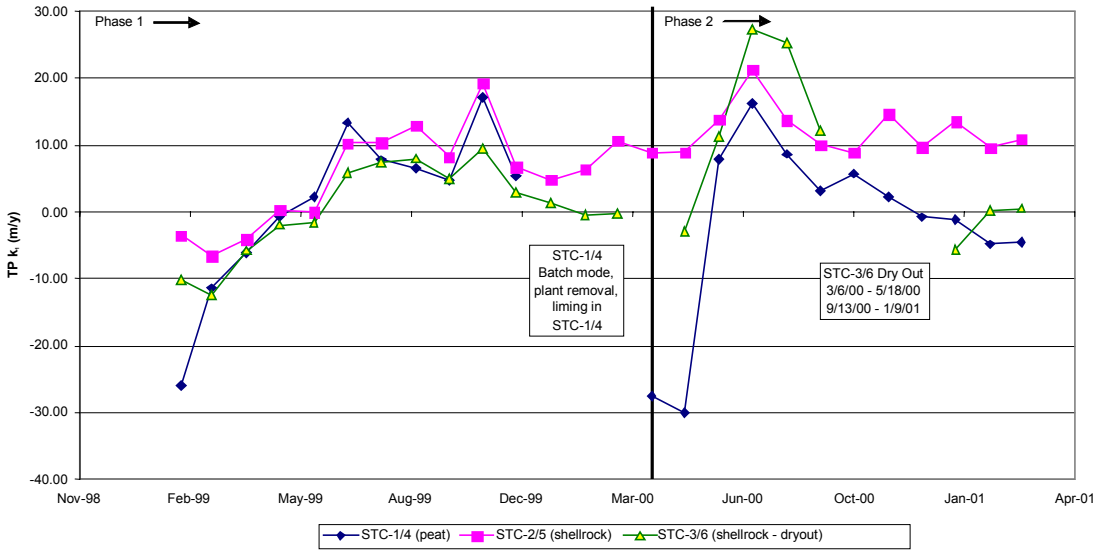


EXHIBIT ES-11

PSTA Test Cell k_{TP} Values in Treatments STC-1/4 (Peat), STC-2/5 (Shellrock), and STC-3/6 (Shellrock - dryout)

EXHIBIT ES-12
Effects of Soil Type on Average TP Outflow Concentration and k_1 During the Post-startup Optimal Performance Period

Treatment	Depth	Soil	TP Out (µg/L)	k_1 (m/yr)
PP-1	60-CM	Peat	14	10.6
PP-2		Shellrock	13	11.7
PP-8		Sand	16	6.4
PP-3	30-CM	Peat	17	12.7
PP-4		Shellrock	15	16.8
PP-7		Sand	15	15.3
STC-1/4	30 to 60 CM	Peat	18	5.0
STC-2/5		Shellrock	12	10.5

Note: Each group of treatments is identical except for soil type.

Phosphorus Dynamics and Fate

The PSTA research offers a variety of "clues" to the processes that are important in P retention in periphyton-dominated treatment units. While this research has focused on the overall input-output of TP, specific processes that have been studied include: the fate of P in the mesocosm soils, observed non-reactive P forms, gross P accretion rates, and the effects of snail grazing on P dynamics.

The soils represent the largest single P storage in the PSTA mesocosms. The reactivity of P in antecedent soils greatly affects the startup performance of a PSTA (as well as other "natural" technologies, such as emergent macrophyte and SAV-dominated STAs). The PSTA research observed a declining concentration of TP in peat soils during the first few months of flooding. Inorganic dissolved reactive forms of P were initially released from these soils. In addition, subsequent tests indicated that P continued to be released from these soils, probably through oxidation of soils in the relatively aerobic algal-dominated environment. P was also released from shellrock and sand soils, but at a much lower rate.

Net P accretion was assessed with sedimentation "traps". These shallow containers were placed on the soil surface for approximately 60 to 90 days, and measured accretion rates were a combination of deposited detrital material and new benthic periphyton growth. Average net dry matter and TP accretion rates during this period were greater in shellrock mesocosms than in peat- or sand-based systems (see Exhibit ES-13). The overall average dry matter accretion rate was 1,432 $g/m^2/yr$ with 0.66 g $TP/m^2/yr$ of which approximately 10 percent can be assumed to be non-reactive organic P (based on separate periphyton mat measurements). A large fraction of this dry matter is ash, including the majority of the inorganic P that consists of calcium-bound P forms.

Snails became the dominant grazer in some of the smaller PSTA mesocosms. Snail density was stochastic with no apparent relation to any of the treatment variables. High snail densities were linked to higher TP outflow concentrations

and reduced removal rate constants apparently because of grazing effects on the periphyton mat. It is hypothesized that snail densities were kept in check in the larger PSTA Test Cell mesocosms by natural predators, such as fish and birds.

EXHIBIT ES-13
Sediment Trap Data from the Porta-PSTA Mesocosms

Treatment	Wet Accretion (cm/yr)	Dry Accretion ($g/m^2/yr$)	TP Accretion ($g/m^2/yr$)	Dry Bulk Density (g/cm^3)	TP (mg/kg)	Ash (%)
all	5.0	1432	0.66	0.039	528	64
peat	1.0	312	0.18	0.032	661	38
sand	2.2	968	0.09	0.054	254	81
shellrock	5.2	1470	0.93	0.044	649	73

Note:
Gross accretion rates were estimated in 14-cm-diameter plastic traps for 2 to 3 months. Values are averages of all replicates within a treatment

PSTA Sustainability

PSTA sustainability and construction-related issues were addressed through the District's Supplemental Technology Standards of Comparison (STSOC) methodology and the simulation results of the PSTA Forecast Model. The STSOC evaluation is based on the data and modeling analyses described in this report. The STSOC comparison of technologies requires the use of the best available data related to P removal performance, flexible engineering and operational components to attain maximum P removal levels, and development of costs associated with the conceptual engineering design. The possible environmental effects of each technology in terms of disposal of by-products and effects on downstream waters are also addressed.

Data from selected treatments (optimal design variations including shellrock and peat soils) were used to design and calibrate a PSTA Forecast Model. The model was developed to allow prediction of long-term behavior and performance of a PSTA, with full recognition of the substantive levels of uncertainty associated with applying the model to predict system performance at scales beyond those for which actual performance data exist. Further, use of the model to estimate design features in some cases requires extrapolations beyond the range of data for which real values exist. These modeling projections remain the best available way of evaluating likely design features, but are preliminary at best. While there are currently no larger-scale PSTA datasets that could be used for additional model validation, it is notable that the District has elected to implement a third project phase at the field-scale pilot PSTAs west of STA-2. Ongoing monitoring of system performance will provide the data needed for model re-assessment with data for this substantively larger-scaled PSTA demonstration (four 5-acre cells).

The model results provide crucial information needed to support the STSOC analysis, which in turn is needed to allow comparison of PSTA feasibility to that of the other Advanced Treatment Technologies (ATTs). These objective compari

sons are required to allow information synthesis during the Everglades Construction Project (ECP) and Non-ECP Basins Feasibility Studies the District is conducting to meet the requirements of the EFA. Because of these interlinked planning and analytical needs, the calibrated PSTA Forecast Model was used to simulate treatment performance for a 10-year period-of-record (POR), using a synthetic dataset of TP concentrations and flows from STA-2 (post-STA) provided by the District. These datasets are to be used in all ATT STSOC evaluations to standardize the analyses. Thus, it should be clearly understood that the resultant designs and planning level costs are not envisioned as leading to technology implementation scenarios. Rather, these datasets merely are to be used to establish consistency in design and cost information that can then be used to compare the relative merits of the subject treatment technologies.

As noted above, PSTAs were not tested at higher inflow TP concentrations. Therefore, this STSOC analysis does not include an evaluation of design and costs to treat post-Best Management Practices (BMP) waters. Requirements of the STSOC methodology include using the PSTA Forecast Model to determine the PSTA footprint area necessary to achieve 10 and 20 µg/L flow-weighted mean outflow TP concentrations under 0, 10, and 20 percent inflow bypass scenarios. In accordance with the STSOC guidelines, because a sustained outflow TP level of 10 µg/L was not attained with the Test Cell PSTAs during the study period, this post-STA evaluation is based on the lowest sustained mean flow-weighted outflow concentration (12 µg/L) demonstrated by the Test Cell PSTA mesocosms rather than 10 µg/L.

Field data collection for STSOC verification was conducted from February 26 to April 4, 2001. Water samples were collected for chemistry analysis, and physical parameters were also measured at the time of sampling. PSTA research was conducted at three Test Cells within the ENR project for slightly more than 2 years. STSOC verification period monitoring was performed at two of these cells, South Test Cell 8 (PSTA Treatment STC-5: shellrock base, 30-cm water depth) and South Test Cell 13 (PSTA Treatment STC-4: peat base with calcium amendment, 30-cm water depth). These Test Cells represent the largest scale PSTAs tested to date and were representative of the other PSTA mesocosms, in terms of operational conditions and treatment performance. Water quality was monitored at the south head Cell outlet and at the outlets from the two individual PSTA Test Cells.

PSTA Footprint

PSTAs are a relatively low-management but land-intensive treatment option that depends on environmental energy inputs from the sun and the atmosphere. The primary energy input is solar radiation (insolation). This radiation provides key wavelengths necessary for primary productivity of the periphyton and other plants and maintains the ambient temperature of the water and biological material. The PSTA heat balance is in turn maintained in a quasi-equilibrium by evapotranspiration (ET), the evaporation of water and transpiration by vascular plants, such as emergent macrophytes within the PSTA.

Because the PSTA is a solar-powered system, it must have a large aerial extent to grow enough periphyton and other plants to capture very low TP concentrations through biological uptake and to sequester that TP in the form of calcium- and carbon-bound accreted sediments. No harvesting of biomass or sediments is envisioned for this process, so TP must be effectively stored within the PSTA footprint to achieve a useful project life (e.g., in excess of 50 years). As described above, the PSTA has been shown to be able to achieve TP outflow concentrations as low as 12 µg/L on a 2-year flow-weighted average basis, and possibly lower concentrations (8 to 10 µg/L) at low inlet loadings and for relatively shorter periods of time (up to a few months). Because 12 µg/L was the lowest flow-weighted average achieved on a sustained basis during PSTA demonstration testing, this is the lowest value used for conceptual design and cost estimating. The mass action rule (first order process) indicates that the area required to accomplish this low TP outflow concentration and possible lower concentrations is vastly greater than the area needed to achieve higher outflow concentrations.

Actual inflow TP concentrations to the PSTA research cells were typically well below 50 µg/L and averaged less than half that value. This means that modeling PSTA performance starting at an inflow flow-weighted mean TP of 50 µg/L requires extrapolation outside the mean input TP dataset (but not outside individual recorded TP input concentrations) used for model calibration. This adds an additional level of uncertainty related to model estimates of the necessary PSTA footprint area.

Six specific scenarios were tested with the PSTA Forecast Model:

- Flow-weighted mean outflow TP of 12 µg/L with 0, 10, and 20 percent inflow bypass
- Flow-weighted mean outflow TP of 20 µg/L with 0, 10, and 20 percent inflow bypass

The benefits of constructing an upstream flow equalization basin (FEB) for possibly reducing the PSTA footprint were investigated by use of the PSTA Forecast Model. Water depths in the FEB were limited to 4.5 feet. Model runs determined that addition of flow equalization did not significantly reduce the overall footprint (FEB+PSTA) needed to achieve the target TP goals downstream. For this reason, the PSTA conceptual design did not include flow equalization.

Exhibit ES-14 summarizes the estimated PSTA footprint areas needed for each of the six post-STA-2 discharge scenarios. These estimated areas range from 2,026 to 6,198 hectares (5,006 to 15,316 acres). Assumptions related to the correct number of tanks-in-series (TIS) to assume in PSTA design may lower these estimated footprints by up to 50 percent. Model estimates of PSTA areas, flows, and water depths were used to develop the cost estimates for full-scale PSTA construction and operation.

EXHIBIT ES-14
Estimated PSTA Areas Based on Alternate Post-STA Average Inflow TP Concentrations

Area Needed In Acres				
Flow Wt Avg. TP Inflow (µg/L)	Flow Wt Avg. TP Outflow	Percent Bypass		
		0	10	20
	Range			
25		5,391	4,581	4,069
30		7,414	6,346	5,635
40		11,410	9,855	8,766
50		15,316	13,241	11,791
	20 µg/L			
25		1,109	885	790
30		2,214	1,842	1,637
40		4,423	3,741	3,321
50		6,603	5,639	5,006

Note:
Results are based on the PSTA forecast model. Parameters for the optimum performance period. Post STA-2 10-Year Simulation with 0 bypass.

Additional modeling was conducted to evaluate the effect of reducing the assumed inflow TP concentration on the resulting estimated PSTA footprint area. Inflow concentrations were reduced in the post-STA-2 dataset, and the PSTA Forecast Model was simulated for the various target outflow TP concentrations and bypass scenarios. For example, lowering the input TP from 50 to 25 µg/L lowered the estimated PSTA area from approximately 2,670 to 450 hectares (6,600 to 1,100 acres) for an outflow goal of 20 µg/L and 0 percent bypass, and from approximately 6,200 to 2,180 hectares (15,300 to 5,400 acres) for an outflow goal of 12 µg/L and 0 percent bypass. This analysis highlights the importance of using the best possible input water quality and flow estimates and modeling techniques during final design of a PSTA.

One additional sensitivity analysis was conducted with the PSTA Forecast Model. Full-scale PSTA areas needed to achieve 20 and 12 µg/L with 0 percent bypass were estimated based on effects of deep percolation losses of water with associated TP (no recycle). The effects of average leakance between 0 (base case) and 0.6 centimeters per day (cm/d) were estimated with the PSTA Forecast Model. The estimated PSTA footprint area needed to reduce flow-weighted TP from 50 to 20 µg/L was reduced from approximately 2,670 to 2,226 hectares (6,600 to 5,500 acres) and from 6,200 to 4,371 hectares (15,300 to 10,800 acres) for a goal of 12 µg/L.

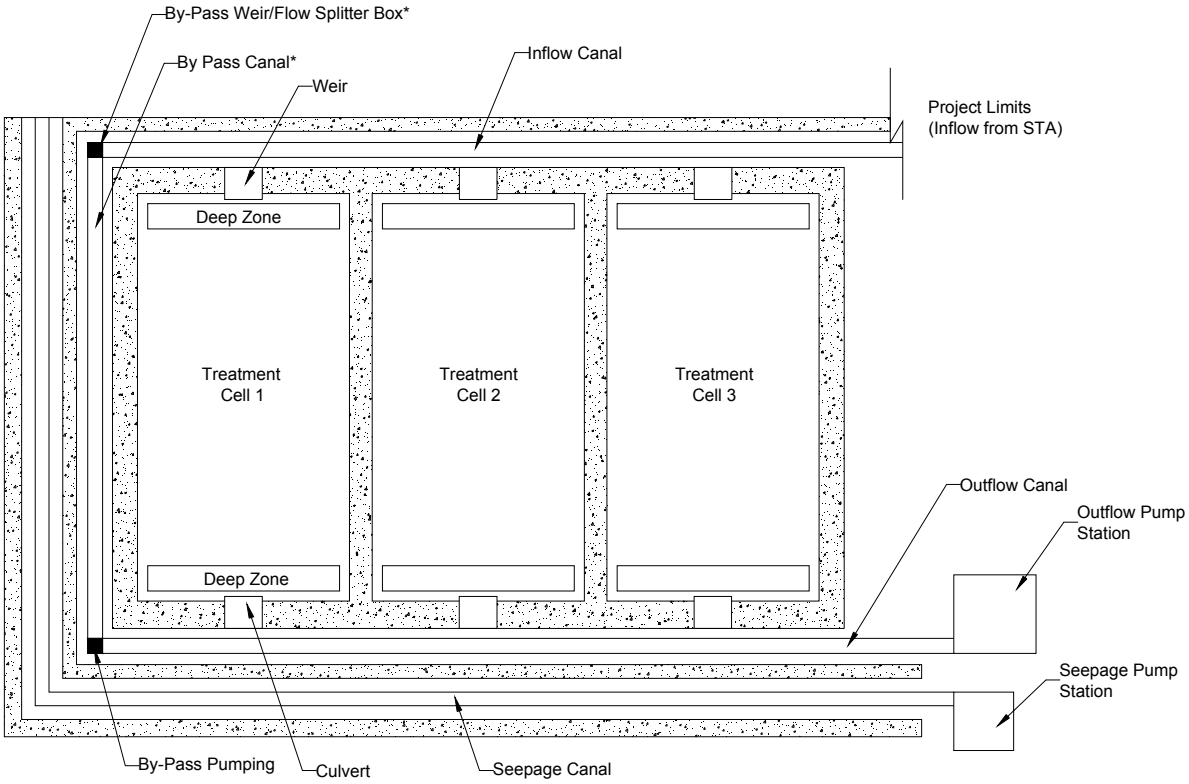
PSTA Conceptual Design

Exhibit ES-15 provides a plan and profile view of a conceptual post-STA-2 PSTA needed to meet the expectations required by the STSOC analysis. This conceptual design includes:

- An inflow canal
- Multiple gated inlet weirs for each treatment cell to convey water from the inlet canal into the PSTA cells
- Three parallel PSTA treatment cells with inlet and outlet deep zones for flow distribution and collection
- A bypass pumping station
- A bypass structure with weir
- A bypass canal to convey bypasses around the PSTA
- Double-barreled culverts with gates to convey water from the treatment cells to the outflow canal
- An outflow canal
- An outflow pump station
- A seepage control canal
- A seepage pump station

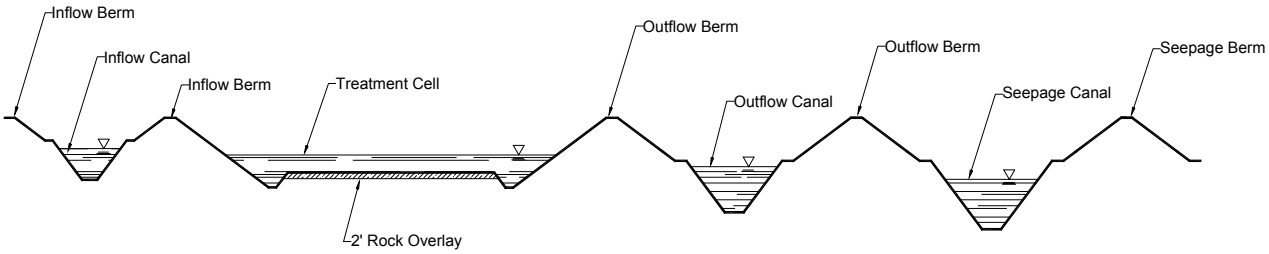
No inflow pumping station was incorporated into the conceptual design based upon the assumption that the outflow pumping station from STA-2 would be utilized to provide inflow to the PSTA treatment system. No periphyton or macrophyte planting is envisioned for the full-scale PSTA cells. Development of calcareous periphyton and sparse emergent macrophyte cover will be encouraged through water depth management.

The nature of the on-site soils has a significant impact on PSTA performance. If existing soils have low available (water soluble) P levels (< 2 mg/kg), then minimal P leaching from the soil should occur and no soil amendment is necessary. However, if existing soils are higher in available P, then leaching of P is probable, and the site must be modified either by adding limerock over the surface of the entire PSTA or by removing the existing soils down to the underlying caprock. Another potential, intermediate option is the use of soil amendments to lock available P in the soils to prevent its release. The efficacy of each of these soil pre-treatment options has not been previously investigated at a field scale, but research has recently commenced on some of them (CH2M HILL, 2001). For the STSOC analysis, a worst-case scenario requiring application of a 2-foot thick cap of limerock (compacted to approximately 1 foot) placed over the onsite soils was evaluated.



* Not Required for "No By-Pass" Scenarios

Plan View



Cross Section

EXHIBIT ES-15
Plan View and Cross Section of Conceptual Full-Scale PSTA System

At the average flow rate (177,000 cubic meters per day [m^3/d] per cell), the outlet weir controls system hydraulics. This is indicated by the calculated inlet depth being lower than the outlet depth. Kadlec and Knight (1996) refer to this condition as "distance-thickening" flow. At the peak flow rate (2,089,000 m^3/d), the inlet depth is more strongly influenced by Manning's "n." Within the range of likely "n" values (0.2 to 0.5) that might be observed in a full-scale PSTA, the inlet depth increases to about 65 cm (2.1 feet). Under maximum flow conditions the weir design used in the PSTA Forecast Model results in water depths at the downstream end of the PSTA to about 0.8 to 1.0 m (2.6 to 3.3 feet) (Exhibit 4-2). The total water depth at the upstream end of the PSTA under maximum flow conditions, would be less than 1.5 m (5 feet) for short durations. The planned inflow levee height is 2.7 to 2.9 m (9 to 9.5 feet), which should provide adequate freeboard and protection against overtopping.

Cost Estimates

Cost estimates were developed using a unit cost spreadsheet provided by the District. The estimated range of total capital costs associated with achieving a TP level of 20 µg/L is approximately $321,886,000 to $408,515,000. With a target finished water TP level of 12 µg/L, this cost range increases to approximately $663,698,000 to $843,799,000 (see Exhibit ES-16).

EXHIBIT ES-16
Costs for Full-Scale PSTA Implementation Including 2 Feet of Limerock Fill

Cost Component	12 µg/L, No by-pass	12 µg/L, 10% by-pass	12 µg/L, 20% by-pass	20 µg/L, No by-pass	20 µg/L, 10% by-pass	20 µg/L, 20% by-pass
Capital Costs	$843,798,569	$737,832,446	$663,697,737	$408,514,840	$357,406,344	$321,886,004
Operating Costs	$1,581,898	$1,483,448	$1,417,593	$1,367,755	$1,292,178	$1,255,048
Demolition/ Replacement Costs	$20,691,746	$16,867,324	$15,739,170	$20,935,504	$16,971,599	$14,797,671
Salvage Costs	($73,210,339)	($63,342,812)	($56,483,392)	($32,050,978)	($27,407,667)	($24,378,828)
Lump Sum/ Contingency Items	$764,320	$814,320	$814,320	$764,320	$814,320	$814,320

The detailed analysis of operation and maintenance (O&M) costs for the PSTA is also provided. Estimated annual costs range from approximately $1,418,000 to $1,582,000 for a system with an outflow TP of 12 µg/L and from approximately $1,255,000 to $1,368,000 for a system with an outflow TP of 20 µg/L. These O&M costs are expected to include any costs associated with management of emergent macrophytes.

Present worth costs were calculated for a 50-year period based on an interest rate of 4 percent. Exhibit ES-17 provides a summary of the 50-year present worth costs for the PSTA alternatives described above. These costs range from $361,033,000 to $888,945,000. These costs are equivalent to unit costs of $0.17 to $0.35 per thousand gallons treated and $699 to $1,096 per pound of TP removed.

EXHIBIT ES-17
Present Worth Costs for PSTA Conceptual Design Scenarios

		Without STA2 Costs			With STA2 Costs		
Target	**Bypass**	**50-Year Present Worth Cost**	**$/lb. TP removed**	**$/1,000 gallons treated**	**50-Year Present Worth Cost**	**$/LB TP removed**	**$/1,000 gallons treated**
12 ppb	0	$888,945,000	$1,076	$0.35	$1,051,748,000	$1,273	$0.41
	10	$778,477,000	$1,078	$0.34	$941,279,000	$1,303	$0.41
	20	$702,764,000	$1,096	$0.35	$865,566,000	$1,350	$0.43
20 ppb	0	$455,092,000	$699	$0.18	$617,894,000	$949	$0.24
	10	$399,099,000	$705	$0.17	$561,901,000	$992	$0.25
	20	$361,033,000	$718	$0.18	$523,835,000	$1,042	$0.26

The limerock placement comprises approximately 80 to 90 percent of the PSTA construction cost. Total present worth costs would be reduced by approximately 60 to 70 percent if PSTA performance could be assured without the limerock fill and, to a lesser extent, if the amount of limerock fill could be reduced. Based on research conducted to-date, it appears that the limerock would *not* be necessary if antecedent soils have low available TP concentrations or if a chemical soil amendment could be used to tie up existing soluble TP in the soil column. Preliminary estimates of the cost of a hydrated lime soil amendment for soils in the vicinity of STA-2 is approximately $1,300 per acre (as opposed to the $31,000 per acre assumed for 2 feet of limerock fill). An approximate cost estimate was also prepared assuming a lime soil amendment. This assumption reduces the estimated present worth costs for a full-scale PSTA to $173,000,000 for the 20 µg/L TP goal and $234,000,000 for the 12 µg/L goal. Because of the major cost impact of this limerock fill, additional work to minimize the costs associated with initial labile TP concentrations should be undertaken prior to final PSTA alternative analysis and design.

Implementation Schedule

The startup period for PSTA was assessed in a total of 27 mesocosm studies (Test Cells and Porta-PSTAs). While there was some variability between treatments, the typical time from commencement of inflows to stable performance was from 3 to 6 months. The optimal seasons for startup were spring and summer. It is likely that startup through the fall and winter months would require a longer stabilization period.

The time needed for implementation of a full-scale PSTA depends on the treatment alternative selected, the site selection and acquisition process, preliminary and final engineering and design completion, bidding and contractor selection, construction completion, and startup. The time required for each of these components is estimated based on observations from prior District projects, such as the implementation of STA-3/4, the largest of the existing STAs. Based on a start date of January 1, 1999, the estimated time required for final completion and compliance with water quality standards is December 2004 (72 months).

Feasibility and Functionality of Full-Scale Design

In some ways, PSTA is the least developed of the supplemental technologies. Significant research on design and performance of PSTAs has only been underway for approximately 3 years. No full-scale PSTA systems have been designed, constructed, or operated nor are any of the existing PSTA systems operated to meet specific outflow discharge permit requirements. For these reasons, the feasibility, costs, and reliability of full-scale PSTA implementation should be evaluated cautiously. On the other hand, large-scale, periphyton-dominated areas have been providing water with a low TP concentration for decades. The southern area of WCA 2A is dominated by a mixture of calcareous periphyton and sawgrass plant communities. This area has produced a long-term average TP concentration of approximately 14.3 µg/L (arithmetic average) or 10.5 µg/L (geometric mean) (Kadlec, 1999). Further downstream in WCA-2A, annual average TP concentrations range between 5 and 12 µg/L. Payne et al. (2001) reported the median annual TP geometric mean as 8.5 µg/L at the reference stations located in WCA-2A. Wet prairie and slough areas of WCA-1 had a median geometric mean TP concentration of approximately 9.1 µg/L (Payne et al., 2001). Areas of the Everglades National Park are also dominated by calcareous periphyton plant communities and have low ambient concentrations of TP. It is important to note that none of these existing full-scale systems were specifically designed to optimize TP removal and, therefore, their greater or lesser performance in relation to an engineered PSTA is not known.

Additional Research Issues Important for Final Design

There are many potential research issues that could provide additional certainty prior to full-scale PSTA design and implementation. These items have been previously summarized as part of ongoing ATT team meetings. Critical research topics related to PSTA implementation include:

- Response of the PSTA periphyton and sparse macrophyte plant communities to a range of inlet TP concentrations and flow rates
- Management issues related to maintaining periphyton dominance over emergent and submerged aquatic macrophytes
- Soil pre-treatment options and effectiveness
- Effects/benefits of placing multiple PSTA cells in series
- Benefits/liabilities of high current velocities and winds on PSTAs
- Effects of long-term soil accretion on PSTA performance and engineering design

Additional information related to some of these topics will continue to be gathered from the District's Field-Scale PSTA Demonstration Project currently underway. A plan to use the District's STA 1-W Test Cells to quantify the effects of cells-in-series, pulsed inlet loading, and combination of PSTA with other natural wetland treatment technologies (emergent and submerged macrophytes) has recently been developed. Use of the PSTA portable mesocosms might be the best research platform to test alternative management techniques and soil amendments.

Summary of Phase 1 and 2 PSTA Results

Engineered PSTAs have only been studied during a 3-year research and demonstration period and only at a relatively small scale (mesocosms and Test Cells with areas ranging from 65 to 22,000 ft^2). Larger-scale (5-acre) PSTA demonstration cells are in an early operational stage, and are ongoing at the time of preparation of this report. Assessment of the cost and reliability of full-scale PSTAs intended to treat very large volumes of stormwater runoff is based on this existing database, model simulations, and cost and construction assumptions described in this report. These estimates of system design and performance are subject to considerable uncertainty until additional information is gathered and analyzed. Thus, while the information generated during the study period has dramatically increased our understanding of the engineer-ability of PSTAs, and this data has supported the preliminary STSOC analysis, it is premature to conclude that sufficient information is in hand to support detailed design and technology application full scale.

Results to-date for performance of PSTAs for post-STA TP load reduction are promising. TP mass reduction rates depend on TP load and are as high as or higher than removal rates of other natural wetland-based technologies. In addition, PSTAs offer the potential to achieve lower TP outflow concentrations than emergent macrophyte STAs and wetlands dominated by SAV and have the ability to recover relatively quickly following drought. They are not subject to fire or significant impairment from hurricanes or other foreseeable natural disasters. They are not likely to create an ecological imbalance in adjacent aquatic environments.

PSTAs do have limitations for full-scale application for TP load reduction. Land area requirements estimated by the STSOC analysis are large, requiring many thousands of acres to meet low TP concentration targets downstream from the existing STAs. Area estimates for PSTAs are subject to the uncertainty described above, and additional research on effects of pulsing, cells-in-series design, and antecedent soil conditions on TP removal performance is sorely needed.

In addition to their relatively large footprint, PSTAs will require an undetermined amount of plant management and/or alteration of pre-existing soil conditions. Placement of relatively inert soils to cover agricultural lands with high antecedent concentrations of available P may not be practical on a large scale. However, it is clear from the existing research that, at least during the early operational phase, relatively small amounts of available soil P will offset P removal potential of any of the natural wetland treatment technologies near background TP concentrations. An additional effect of these elevated soil TP levels for PSTA is their apparent stimulatory effect on colonization and growth of emergent macrophytes that may out-compete the desired calcareous periphyton plant communities. While we have not yet identified how to optimize PSTA

design and operations on peat substrates, the reality is that this is the system that prevails in the natural Everglades. Further research on peat-based PSTAs is strongly recommended in spite of the early results obtained to date.

Because there are few potential tools available to the regulator who wishes to achieve very low TP standards and Everglades protection, it is prudent to continue to refine knowledge of PSTA design and the potential of PSTAs for TP control. Their best use might be in conjunction with other "pre-treatment" technologies, such as emergent macrophyte STAs or SAV wetlands. Whether as standalone or integrated treatment units, PSTAs offer the potential to help achieve the environmental goals in the Everglades of South Florida.

SECTION 1

Project Background

1.1 Introduction

The South Florida Water Management District (District) is conducting research focused on potential advanced treatment technologies to support reduction of phosphorus (P) loads in surface waters entering the remaining Everglades. Periphyton-based stormwater treatment areas (PSTAs) are one of the advanced treatment technologies being researched by the District for potential application downstream of the macrophyte-based stormwater-treatment areas (STAs). In short, PSTAs to date have only been considered as candidate treatment units for post-STA waters. Prior to initiation of the District's PSTA project in July 1998, detailed research to evaluate treatment performance issues and the long-term viability of the PSTA approach to P reduction in Everglades Agricultural Area (EAA) surface waters had not been performed.

The PSTA concept was proposed for P removal from EAA waters by Doren and Jones (1996) and further described and evaluated by Kadlec (1996a) and Kadlec and Walker (1996). Evaluations remain focused on PSTAs as post-STA treatment units intended to help achieve compliance with the anticipated target total phosphorus (TP) concentrations of 10 parts per billion (ppb). PSTAs are intended to emulate the nutrient uptake functions observed in oligotrophic Everglades marsh habitats, but are not expected to necessarily be structurally similar to periphyton-dominated communities.

In concept, the periphyton complex is hypothesized as being capable of extracting available P in the water introduced into the system and incorporation of that P into biomass of the periphyton. Additionally, because of the relatively high primary productivity of these periphyton systems, water quality conditions favor P precipitation and binding into the newly formed sediments. The result is a water outflow with much of the available P scavenged and retained in the system. These concepts are depicted in Exhibit 1-1.

With the guidance of internal and external experts (van der Valk and Crumpton, 1997; Goforth, 1997a and 1997b; Nearhoof and Aziz, 1997; SFWMD, 1997), the District developed a scope of services for the PSTA project in 1998.

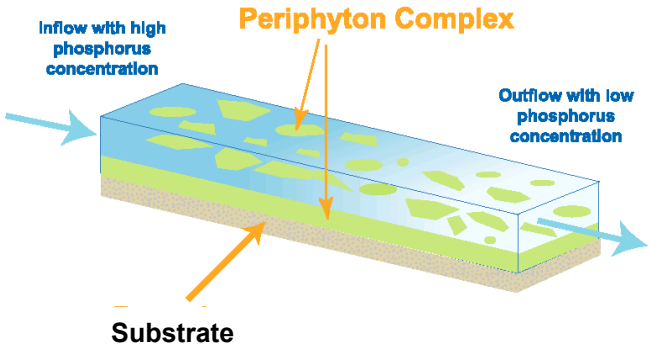


EXHIBIT 1-1
Schematic Diagram of the Periphyton Stormwater Treatment Area (PSTA) Concept

Originally, a two-phased approach was adopted. The two phases included the following activities:

- **Phase 1 (Experimental Phase)** included development of the work plan and experimental design, initial research in three experimental test cells (PSTA Test Cells) located at the southern end of the Everglades Nutrient Removal (ENR) project (see SFWMD 2000 for location of sites), and construction and startup/monitoring of research using 24 portable experimental mesocosms (Porta-PSTAs). The Phase 1 experimental studies yielded critical information needed to plan for field-scale mesocosm (PSTA Field-Scale Cells) design and construction in Phase 2. Development of a forecast model and associated predictive tools was initiated in Phase 1, along with preliminary model calibration with the Phase 1 experimental data.

- **Phase 2 (Validation/Optimization Phase)** included continued research in the ENR PSTA Test Cells and in the Porta-PSTAs, and design/construction of the PSTA Field-Scale Cells. During Phase 2, the expanded database was used to validate the performance forecast model, and to develop the design criteria for a full-scale PSTA system through the District-mandated Standards of Comparison (PEER Consultants/Brown and Caldwell, 1999). The PSTA Forecast Model has been applied to provide projections of the long-term cost of implementing PSTAs to meet ultimate P reduction goals under the Everglades Forever Act (EFA).

As a slight revision to this original plan and because of the prolonged construction schedule for the PSTA Field-Scale Cells, a third phase of the PSTA Research and Demonstration Project has begun to test the PSTA concept at a larger scale:

- **Phase 3 (Demonstration Phase)** includes operation of four PSTA Field-Scale Cells located to the west of STA-2. This phase will develop information related to larger-scale construction costs, operational issues related to unlined cells and groundwater exchanges, and effects of higher water velocities and wind on PSTA development and performance. Phase 3 is currently

scheduled to continue through December 2002. A description of Field-Scale monitoring activities is provided in Section 5.

In the aggregate, the PSTA Research and Demonstration Project was designed to develop defensible conclusions related to specific hypotheses that are relevant to key research questions and design issues described in the initial *PSTA Research Plan* (CH2M HILL, 1999).

This document is the final summary report of PSTA Research and Demonstration Project Phases 1 and 2 (February 1999–April 2001), prepared under Task 10 of the PSTA study program contract held by CH2M HILL. The following information is presented in this document:

- Section 2 – Community Development and Viability
- Section 3 – Phosphorus Removal Performance and Effectiveness
- Section 4 – PSTA Forecast Model, Conceptual Design, and Sustainability
- Section 5 – Remaining PSTA Issues
- Section 6 – Works Cited

The following information is provided as appendices to this document:

- Appendix A – Methods Summary/Standard Operating Procedures/Key Date Summary/Quality Assurance Data
- Appendix B – Meteorological Data
- Appendix C – Test Cell Detailed Data, Trend Charts, and Diel Study
- Appendix D – Porta-PSTA Detailed Data, Trend Charts, Diel Study, and Batch Study Data Summary
- Appendix E – Periphyton Taxonomic and Abundance Data Analysis
- Appendix F – Hydraulic Tracer Test Data
- Appendix G – Statistical Analyses
- Appendix H – Field-Scale Construction Review
- Appendix I – Reviewer Comments
- Appendix J – Post STA-2 STSOC Cost Estimates

1.2.1 Overview of Periphyton Ecology and Other Studies of TP Removal by Periphyton

1.2.1.1 Periphyton Ecology

Periphyton (also referred to as aufwuchs and including benthic algae) are a complex assemblage of attached-growth algae, fungi, bacteria, and invertebrates that grow in response to sunlight in shallow aquatic environments (Vymazal, 1995). Everglades periphyton can be operationally sub-divided into the following groups (McCormick et al., 1998): floating mats, epiphyton (growing on plant

Benthic Mat

Epiphyton
"Sweaters"

Floating Mat

EXHIBIT 1-2
Representative Examples of PSTA Periphyton

surfaces), metaphyton (growing in the water column and not attached to surfaces), and benthic mats or epipelon (growing in contact with the sediments) (see Exhibit 1-2). Tychoplankton are free-floating algae derived from the periphyton. These tychoplanktonic algae as well as some filamentous metaphyton forms are most likely to be exported in outflows from the PSTA to downstream waters. Everglades periphyton have also been classified according to environmental conditions (Browder et al., 1994). Water chemistry and hydroperiod are important factors that affect the taxonomic composition and biomass of these periphyton. Short hydroperiod, low TP concentrations (<20 micrograms per liter [µg/L]), high calcium saturation (hard water, calcium >50 milligrams per liter [mg/L]), and high pH (6.9 to 7.5) lead to calcareous periphyton dominance. Long hydroperiod and low calcium saturation (soft water, calcium <5 mg/L) and low pH [5 to 7]) result in desmid-rich periphyton assemblages. P concentration is another important environmental variable that affects periphyton species occurrence. Low P results in dominance by blue-green algae while higher P results in dominance by filamentous green species. Intermediate periphyton communities with mixtures of species characteristic of both extremes are found along all of these environmental gradients.

Periphyton initially colonize surfaces of submerged macrophytes and other natural debris, such as woody vegetation, organic and mineral soils, rocks, and plant litter. Some of the periphyton may float or drift from their initial attachment sites and become free-living masses (metaphyton) and floating mats.

Periphyton/Macrophyte Interactions

In natural Everglades ecosystems and in other aquatic environments, periphyton and wetland macrophytes are intimately connected. Periphyton typically grows on the surfaces of macrophytes that serve as increased attachment resources in otherwise two-dimensional environments (Browder et al., 1994; Duke Wetland Center, 1995; Vymazal and Richardson, 1995; McCormick et al., 1998). Macrophytes are also known to release cell fluids or exudates, which contain nutrients that stimulate periphyton growth (Wetzel, 1983; Burkholder, 1996). In many macrophyte-dominated wetland and aquatic environments, periphyton contribute a significant portion of the total primary productivity. This contribution to the autotrophic food chain is especially important in Everglades slough ecosystems (Browder, 1995).

It is hypothesized that sparsely vegetated macrophyte beds support significantly higher periphyton productivity on an areal basis compared to open water because of increased surface area for colonization. However, at higher macrophyte densities, light attenuation from shading results in reduced periphyton productivity (Grimshaw et al., 1996; McCormick et al., 1998). Determination of the optimal macrophyte density is an important design variable for maximizing PSTA removal of P. The importance of this relationship for the periphyton-dominated ecosystems of the Everglades is highly relevant to the PSTA concept.

The PSTA Research and Demonstration Project addressed the overall effect of this interaction through the incorporation of low-density macrophyte planting in experimental units. Plant species that were purposefully tested were *Eleocharis cellulosa* (spikerush), an emergent macrophyte, and *Utricularia* spp. (bladderwort), a submerged aquatic plant. Both of these wetland plant species are known to support significant periphyton populations (Vymazal and Richardson, 1995; Havens et al., in review; McCormick et al., 1998). Volunteer plant species (primarily cattails [*Typha latifolia*] and hydrilla [*Hydrilla verticillata*]) also colonized the PSTA mesocosms, resulting in additional new information about the interaction of these species with periphyton community development.

Macrophyte colonization of full-scale PSTAs may be inevitable on soils with high antecedent available P concentrations. If high macrophyte density occurs, it is likely to lead to replacement of an algal-dominated treatment unit to a treatment wetland similar to the existing STAs. Macrophyte colonization rate and growth rate, as well as dominant species, were investigated in the experimental PSTAs to determine the nature and speed of macrophyte colonization, and to indicate practical methods to manage macrophytes in a PSTA environment.

Importance of Soil Type on Periphyton/Macrophyte Community Development and Competition

As originally envisioned (Doren and Jones, 1996), PSTA systems would be constructed with calcium-rich substrates (shellrock, limerock, or weathered limestone) to increase the opportunity for P mineralization, and to decrease the rate of macrophyte invasion (Kadlec and Walker, 1996; van der Valk and Crumpton, 1997). The process of macrophyte succession might lead to displacement of periphyton-dominated systems by emergent wetland macrophyte-dominated systems, limiting P removal rates and minimum achievable P concentrations to levels comparable to the existing macrophyte-based STAs. It is notable that organic soils are typical of periphyton-rich areas in Water Conservation Area (WCA) 2A and WCA-3. David (1996) found that average substrate depths in WCA 3A in macrophyte stands, including *E. cellulosa*, *Rhyncospora tracyi*, and *Utricularia* spp., was between 43 and 48 centimeters (cm). It has also been widely observed that periphyton-dominated communities do occur extensively in WCA-2A and elsewhere over organic soils (Browder et al., 1994). Thus, it is clear that peat-based PSTAs should be feasible. Our understanding of the relationships between periphyton dominance and substrate type remains incomplete.

Net P Accretion Rate

Numerous research projects have determined that periphyton can rapidly assimilate available P (Havens et al., 1996; Borchardt, 1996; Wetzel, 1996). This P uptake is accelerated by the relatively small scale and diffusional gradients associated with these microscopic organisms and by phosphatase enzymes and other metabolic adaptations. While P uptake is extremely rapid during short-term laboratory and mesocosm studies, other research has indicated that periphyton net production and accrual are maximum during successional com-

munity development and lower under mature conditions (Knight, 1980). The effect of this ecosystem-level response on TP removal may result in the need for periodic disturbance of PSTA periphyton communities to maintain high accretion rates. Assessment of long-term P uptake in periphyton-dominated plant communities was one of the key objectives of the District's PSTA Research and Demonstration Project.

Effects of Flow Velocity

Flow velocity is known to affect periphyton growth with respect to community thickness, species composition, and primary productivity (Stevenson and Glover, 1993; Stevenson, 1996; Ghosh and Gaur, 1998). Flow velocity is known to affect periphyton in two ways: replenishment of growth nutrients and removal of waste products, and creation of sloughing and downstream export (Stevenson, 1996).

Current velocity has been shown to increase periphyton productivity at low levels and to reduce productivity at higher levels. Simmons (2001) studied the effects of flow velocity on periphyton in bench-scale mesocosms located at the south ENR advanced treatment technology research site. His 0.5 m^2 and 6-cm-deep mesocosms had baffles that allowed side-by-side comparison of periphyton biomass growth, biomass export, and TP reduction rates at HLRs of 7.7 meters per day (m/d), and nominal velocities of 0.11 centimeters per second (cm/s) (slow treatment) and 1.0 cm/s (fast treatment). Based on physical observations, the periphyton community structure was dominated by filamentous green algal species. Biomass accrual was 27 percent greater in the fast treatment during the 22-day, flow-through study period. The respective net rates of dry weight (dw) accumulation were approximately 7.5 and 6.0 g dw/m^2/d. Biomass export was also approximately 25 percent higher in the fast treatment compared to the control (1.3 vs. 1.0 g dw/m^2/d). During an 8-day recirculation period, there was no additional net increase in the periphyton biomass values. TP concentration was reduced from approximately 23 to 18 µg/L in both treatments during the first 15 hours of recirculation. TP concentrations did not decline further during the next 5 days of recirculation and then increased to near starting levels during the last 2 days of the recirculation phase of the study. TP in the periphyton was estimated as approximately 650 milligrams per kilogram (mg/kg) and 648 mg/kg in the fast and slow treatments, respectively.

Effects of Temperature

Natural Everglades slough communities undergo significant temperature variation in response to insolation, water depth, and color (related to light attenuation). Diel temperature measurements at the Duke University dosing site in WCA-2A indicated daily ranges of 4 to 5 degrees Celsius (°C) during July and August 1995, with maximum and minimum temperatures of approximately 32.0 and 26.5°C, respectively (Duke Wetland Center, 1995). Diel water temperatures varied by approximately 6 to 14°C during October 1980 at a reference slough site in WCA-1, with a median water depth of approximately 30 to 50 cm

and maximum and minimum temperature readings of 28 and 14°C, respectively, during a 5-day period (McCormick et al., 1997). During the same week at this site, the diel temperature range was approximately 2 to 4°C, and the minimum and maximum values were 21 and 26°C, respectively. The authors reported a diel temperature range from approximately 26 to 28°C at an enriched slough site in WCA-2A during August 1985. In a comprehensive study of the three WCA-periphyton communities in 1978–1979, Swift (1981) reported that the mean water temperature was 23.8°C, with an annual variation from 13.4 to 35.7°C. In the Lake Okeechobee littoral zone slough communities, Havens et al. (1996) reported water temperatures from 25 to 30°C, with a maximum of 40°C recorded under a periphyton mat. Littoral mesocosms had temperatures typically between 28.2 and 30.9°C, with peaks up to 37°C and a diel change of 3 to 7°C (Havens et al., 1996).

This review indicates that Everglades periphyton-dominated ecosystems typically experience temperature extremes ranging between 13 to 37°C, with typical diel variation between 2 to 7°C.

Effects of Water Regime

Maximum water depths in natural Everglades periphyton-dominated sloughs are generally less than 1.5 meters (m), and average water depths are typically approximately 0.6 m (Browder et al., 1994; Vymazal and Richardson, 1995).

Everglades macrophytes are known to be distributed in response to water regime and water column TP concentrations. David (1996) found typical Everglades slough macrophyte stands at average water depths ranging from 33 to 37 cm in WCA 3A, and 25 to 28 cm in the Dupuis Reserve (David, unpublished). Average inundation frequencies at these sites were approximately 45 to 100 percent in WCA 3A, and 71 to 85 percent in the Dupuis Reserve.

Effects of Ambient TP Concentrations

Ambient TP in Everglades areas colonized by periphyton-dominated plant communities are in the range of 5 to 15 micrograms TP per liter (µg TP/L) (McCormick et al., 1996).

Populations of *Utricularia* spp. and *E. cellulosa* were found to be limited to TP water concentrations less than 30 µg/L, while another common slough macrophyte, *Nymphea odorata,* had maximum plant cover at 50 µg TP/L (Duke Wetland Center, 1997). These results indicate that it may be challenging to obtain growth and propagation of these species at influent TP concentrations anticipated in a PSTA. Macrophytes are generally more dependent on sediments than on the water column for growth nutrients, such as P. If PSTAs tend to accumulate P in their sediments, macrophyte growth may be better than in oligotrophic Everglades slough plant communities. There is considerable concern that undesirable colonization by macrophytes, such as cattails (*Typha* spp.), may result in a need for plant eradication or periodic management (Kadlec and Walker, 1996; van der Valk and Crumpton, 1997) within a PSTA system.

In addition to their influence on P concentrations, algal-dominated systems are known to alter other chemical aspects of water quality. Of particular relevance is the effect of primary productivity on pH and dissolved oxygen (DO) conditions. Relatively wide variations of these parameters are typical of Everglades slough environments (Duke Wetland Center, 1995; Vymazal and Richardson, 1995; McCormick et al., 1997).

1.2.1.2 Periphyton P Removal Performance in Shallow Raceways

Complementary research has been conducted on periphyton-dominated mesocosms by DB Environmental Laboratories, Inc. (DBEL) as part of the District's SAV/LR advanced treatment technology project since July 1998 (DBEL, 1999; 2000a,b,c; 2001a,b). The submerged aquatic vegetation/limerock (SAV/LR) project has tested post-STA water P removal in several long and narrow raceways at the South ENR Supplemental Technology Research Compound (STRC), the same site used for the PSTA mesocosm testing described in this report. Three parallel replicate periphyton-dominated troughs (44 m in length and 30 cm wide) were designed to convey water at two depths: 2 and 9 cm (high and low velocity), at widely different HLRs (low = 11 cm/d and high = 220 to 440 cm/d). All of these troughs were filled with a layer of crushed limerock. The low-velocity periphyton mesocosms were able to provide a mean TP outflow concentration of 10 µg/L at an average inflow concentration of 17 µg/L (DBEL, 1999). The TP settling rate (k_1) was 21 m/yr, and the average mass removal rate was 0.29 g P/m^2/yr. Periphyton biomass in the 9-cm raceways was 867 g dw/m^2 at the end of the 8-month study. Approximately 166 mg P/m^2 was stored in this periphyton, or approximately 97 percent of the observed TP removal. TP concentrations in this periphyton varied from approximately 1,095 mg/kg in the front end of the mesocosms to approximately 190 mg/kg in the downstream end.

The high-velocity raceways reduced TP from 17 to 14 µg/L at a nominal hydraulic residence time (HRT) of 6.5 to 13 minutes. High algal sloughing was observed in these high velocity mesocosms. Dry matter net production averaged 5.9 g dw/m^2/d in the front end of the mesocosms and 2.4 g dw/m^2/d in the outlet region. TP in the periphyton was 1,201 mg/kg in the front end to 764 mg/kg in the downstream area.

Follow-on studies have been conducted in these raceways, beginning in February 2000. The hydraulic loading rate (HLR) to the 9-cm raceways (slow) was doubled and inflow TP concentration increased at the same time, resulting in an approximate four-fold increased TP loading. Effluent TP concentrations from these periphyton-dominated raceways increased to approximately 20 µg/L in response to these operational changes. Two months later, inflow rates were reduced back to 11 cm/d, yet high outflow TP concentrations continued for several weeks before declining to approximately 15 µg/L. HLR was doubled again in May 2000 and outflow TP concentrations continued between approximately 10 and 20 µg/L until the end of the 29-month experi-

ment in November 2000. The long-term average inflow and outflow TP concentrations for these raceways at 11 cm/d were 20 and 11 µg/L, respectively. During the period of higher loading (22 cm/d), the average inflow and outflow concentrations were 23 and 15 µg/L.

One-parameter TP removal rate constants for these two periods were estimated as 24 and 34 m/yr, respectively. Calibration of the two-parameter k-C* model with the raceway data returned a k_{PFR} (plug flow k value) of 60 m/yr at a C* of 8 µg/L. Calibration with the two-parameter tanks-in-series model returned a k_{TIS} (tanks-in-series k value) of 61 m/yr with an estimated 2.8 tanks-in-series and C* equal to 7 µg/L. Long-term trend analysis indicates a slight decreasing trend in k_1 values for these raceways. No seasonal trend in k_1 values is evident.

In November 2000, the three raceways were joined in series to provide a 132-m flowpath. The inflow HLR was also tripled to 66 cm/d, resulting in a nominal velocity of 0.36 cm/s. Preliminary results (DBEL, 2000b) demonstrate an average TP reduction from 19 to 16 µg/L. This system will be operated during a 6-month period to see if increased flow velocity changes P removal performance in these periphyton-dominated mesocosms. Other data from this test are not yet available to assess performance of this periphyton-dominated mesocosm.

1.2.1.3 Periphyton P Removal Performance in the Vicinity of C-111

Limited data have been collected in the vicinity of C-111, a large water control canal constructed in the eastern Everglades in Miami-Dade County. This area is reported to be dominated by a calcareous periphyton plant community. Inflow and outflow TP data and estimated HLRs are available for the period from August 1998 through December 2000. These data have been analyzed to determine the possible effectiveness of a large-scale periphyton-dominated wetland for TP reduction (Walker, 2001). The average inflow TP during this period was 7 µg/L, and the average outflow concentration was 6 µg/L. Based on an average HLR of 22.3 m/yr, the estimated k-C* parameters for the plug-flow model are 29 m/yr and 5 µg/L. The estimated value for k_{TIS} is 31 m/yr with five tanks-in-series (Walker, 2001).

1.2.2 Experimental Hypotheses

The PSTA research program was established to address the following three critical issues:

- **Viability** refers to establishment and maintenance of the desired periphyton-dominated ecological community. Although the location of periphyton-dominated ecosystems in the Everglades is known, there is a need to refine the basic understanding of how to create this ecosystem, how long it takes to establish mature periphyton communities, and how to maintain these systems against shifting dominance by macrophytes (floating, submerged, or emergent) and phytoplankton (free-floating algae).

- **Effectiveness** refers to the ability of a PSTA to consistently and predictably remove P. Net P removal is dependent upon sustainable gross P removal rates, chemical and biological transformations of the P into non-reactive forms, and ultimate burial of P in newly accreted sediments or biomass. A number of design considerations are likely to determine the effectiveness of a full-scale PSTA. These include such factors such as flow velocity, water depth, presence/absence of macrophytes at low densities, and the nature of underlying antecedent soils.

- **Sustainability** refers to the long-term maintenance and operational cost of a periphyton-dominated treatment system. The most important sustainability issue is the expected useful life of a PSTA-dominated treatment system. The PSTA Forecast Model was developed to provide a basis for extrapolation from the relatively short operational period covered by this research. Other sustainability questions include: Will these systems require intervention for removal of accreted P? Will they restart and operate smoothly after a dry-down or flood event? Will they create water quality problems downstream in receiving waters from release of chronically or acutely toxic environmental pollutants?

The following research hypotheses—detailed in the *PSTA Research Plan* (CH2M HILL, April 2001)—are related to the three critical issues described above, and were tested by one or more of the research components:

- Hypothesis #1: PSTAs can be colonized and operational in less than 1 year following basin construction (**viability**).
- Hypothesis #2: The presence of low-density stands of emergent macrophytes and submerged aquatics will increase the PSTA sustainable TP settling rate (**viability** and **effectiveness**).
- Hypothesis #3: Substrate type significantly affects PSTA sustainable TP settling rate (**effectiveness**).
- Hypothesis #4: The sustainable TP settling rate for PSTAs is >35 m/yr (**effectiveness**).
- Hypothesis #5: PSTA annual average TP export concentration can be sustained below 10 µg/L (**effectiveness**).
- Hypothesis #6: PSTA maximum monthly average export TP can be sustained at less than two times annual average TP export (**effectiveness**).
- Hypothesis #7: PSTA TP export concentration is highly correlated with HLR for a given TP inflow concentration (**effectiveness**).
- Hypothesis #8: PSTA sediment and macrophyte biomass accretion rates will dictate major operation and maintenance (O&M) requirements in less than 10 years (**sustainability**).
- Hypothesis #9: Flow velocity exhibits a subsidy-stress effect on PSTA sustainable TP settling rate (**effectiveness**).

- Hypothesis #10: Water depth in the range between 30 and 60 cm does not significantly affect PSTA sustainable TP settling rate (**viability** and **effectiveness**).
- Hypothesis #11: Outflow water from full-scale PSTAs will not be chronically toxic to indigenous Everglades flora or fauna and will not include unacceptably high concentrations of methyl-mercury (**sustainability**).

Phase 1 and 2 PSTA research provided preliminary evidence for acceptance or rejection of the 11 hypotheses as summarized in Sections 2 through 4. Phase 3 plans are described in Section 5 for the Field-Scale Cells. Detailed data supporting the conclusions in this report are included in the appendices.

1.3 Summary of PSTA Experimental Design and Treatments

This section provides some key information related to the experimental design used in Phases 1 and 2 of this PSTA Research and Demonstration Project. Exhibit 1-3 summarizes the PSTA mesocosm design criteria and treatments tested during Phases 1 and 2. The two PSTA mesocosm scales (Porta-PSTAs and ENR Test Cells) used during Phases 1 and 2 are described below.

1.3.1 South ENR Test Cells

The District assigned three South ENR Test Cells (STCs) to the PSTA Research and Demonstration Project. During final construction, substrate in these PSTA Test Cells was modified by the District by placing the following layers of substrate over the cell liner:

- **Test Cell 13–**2.5 feet (ft) of sand surcharge plus 1.0 ft of shellrock (locally mined) plus 1.0 ft of peat (taken from area of STA 1W, Cell 5 – unflooded, former agriculturally worked lands)
- **Test Cell 8–**3.5 ft of sand surcharge plus 1.0 ft of shellrock (locally mined)
- **Test Cell 3–**3.5 ft of sand surcharge plus 1.0 ft of shellrock (locally mined)

Exhibit 1-4 provides a plan view of a typical PSTA Test Cell showing sampling locations and walkways. Exhibit 1-5 summarizes detailed design criteria and treatments for the PSTA Test Cells during the two project phases.

The effects of three treatments (substrate, water depth, and HLR) were tested in the Test Cells during Phase 1 (February 1999 to March 2000). The treatments were renumbered for Phase 2 with monitoring beginning in April 2000 and continuing through early April 2001.

For Phase 2, the Test Cells underwent changes, including peat soil amendment, water regime, and water depth. Treatment STC-4 (Test Cell 13) was amended with calcium to attempt to decrease the amount of soluble P being released from

EXHIBIT 1-3

PSTA Design Criteria and Experimental Treatments (Phases 1 and 2)

PSTA Treatment	Phase	Cells	Area (m^2)	Substrate Type	Target Wtr Depth (cm)	Target HLR (cm/d)	Target Depth:Width Ratio	Other Considerations
PP-1	1	9, 11, 18	6	peat	60	6	0.6	macrophytes
PP-2	1	4, 7, 8	6	shellrock	60	6	0.6	macrophytes
PP-3	1, 2	12, 14, 17	6	peat	30	6	0.3	macrophytes
PP-4	1, 2	3, 5, 10	6	shellrock	30	6	0.3	macrophytes
PP-5	1	2, 13, 16	6	shellrock	60	12	0.6	macrophytes
PP-6	1	1, 6, 15	6	shellrock	0-60	0-12	0-0.6	macrophytes
PP-7	1, 2	19	6	sand	30	6	0.3	macrophytes
PP-8	1	20	6	sand	60	6	0.6	macrophytes
PP-9	1	21	6	peat	60	6	0.6	Aquashade; no macrophytes
PP-10	1	22	6	shellrock	60	6	0.6	Aquashade; no macrophytes
PP-11	1, 2	23	18	shellrock	30	6	0.1	macrophytes
PP-12	1, 2	24	18	peat	30	6	0.1	macrophytes
PP-13	2	9, 11, 18	6	peat (Ca)	30	6	0.3	macrophytes
PP-14	2	4, 7, 8	6	limerock	30	6	0.3	macrophytes
PP-15	2	2, 13, 16	6	shellrock	30	6	0.3	macrophytes; recirculation
PP-16	2	1, 6, 15	6	shellrock	0-30	0-6	0-0.3	macrophytes
PP-17	2	20	6	sand (HCl)	30	6	0.3	macrophytes
PP-18	2	21	6	none	30	6	0.3	no macrophytes
PP-19	2	22	6	Aquamat	30	6	0.3	no macrophytes
STC-1	1	13	2,240	peat	60	6	0.02	macrophytes
STC-2	1	8	2,240	shellrock	60	6	0.02	macrophytes
STC-3	1	3	2,240	shellrock	0-60	0-12	0-0.02	macrophytes
STC-4	2	13	2,240	peat (Ca)	30	6	0.01	macrophytes
STC-5	2	8	2,240	shellrock	30	6	0.01	macrophytes
STC-6	2	13	2,240	shellrock	0-30	0-12	0-0.01	macrophytes

Notes:
PP=Porta-PSTA
STC = South Test Cell

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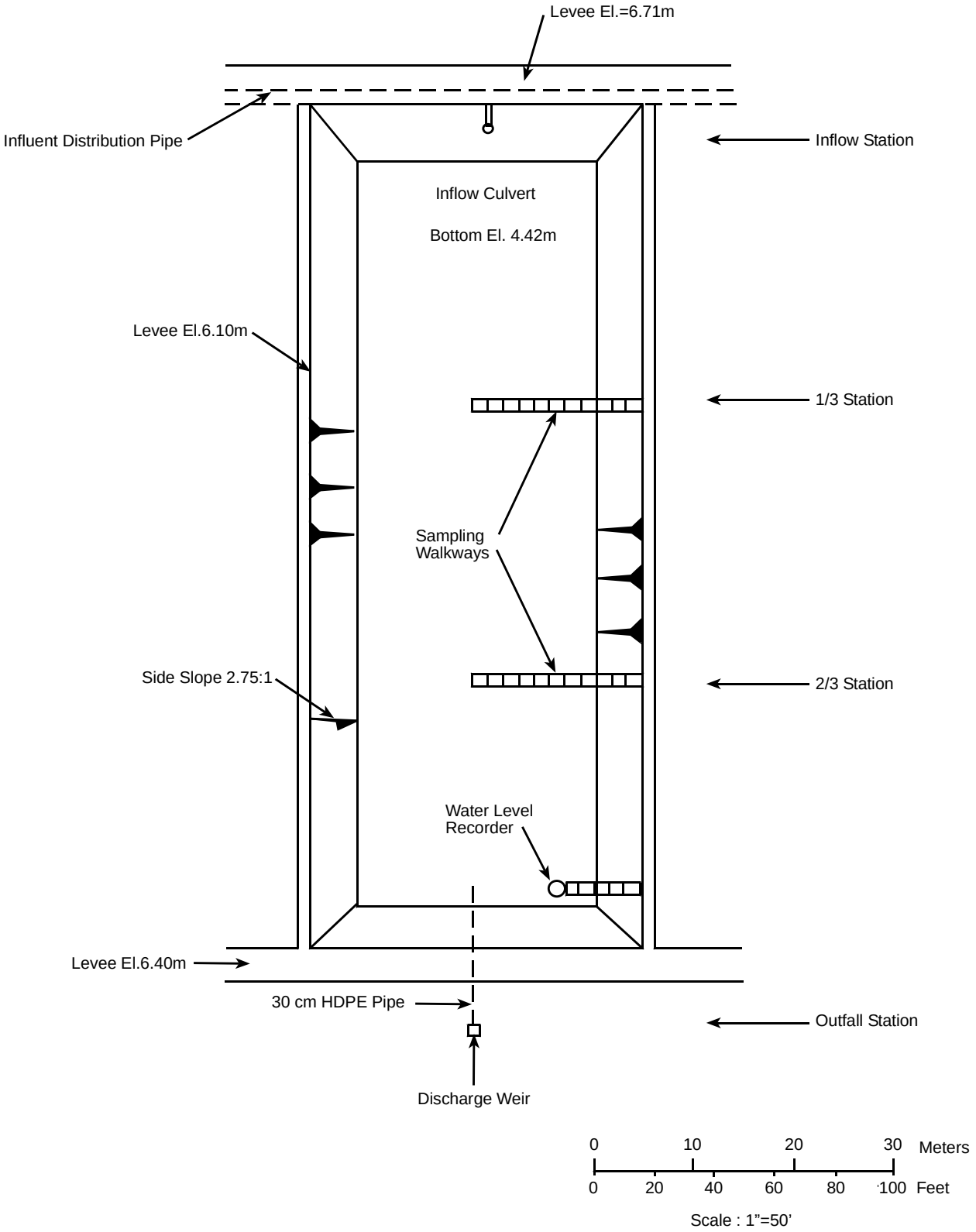

Exhibit 1-4. Plan View of Typical ENR PSTA Test Cell Showing Sampling Locations

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EXHIBIT 1-5
Comparison of PSTA ENR South Test Cell Phase 1 and Phase 2 Treatments

TC #	Phase 1 (February 1999 - March 2000)		Phase 1 to Phase 2 Alterations (March - April 2000)	Phase 2 (April 2000 - April 2001)	
TC 13	**STC-1**			**STC-4**	
	Substrate:	Peat	• Vegetation herbicided and removed	Substrate:	Peat + Ca
	Depth:	60 cm	• Cell floor wetted and peat soil amended with lime (7mt/ha)	Depth:	30 cm
	HLR (cm/d):	6		HLR (cm/d):	6
	Average Velocity (cm/s):	0.0093	• Cell reflooded, but operated at 30 cm	Average Velocity (cm/s):	0.0185
	Depth:Width Ratio:	0.02	• Vegetation replanted	Depth:Width Ratio:	0.01
	Vegetation:	Periphyton, *Eleocharis, Utricularia*	• Cell inoculated with periphyton	Vegetation:	Periphyton, *Eleocharis, Utricularia*
TC 8	**STC-2**			**STC-5**	
	Substrate:	Shellrock	• Water depth reduced to 30 cm	Substrate:	Shellrock
	Depth:	60 cm	• No other changes made	Depth:	30 cm
	HLR (cm/d):	6		HLR (cm/d):	6
	Average Velocity (cm/s):	0.0093		Average Velocity (cm/s):	0.0185
	Depth:Width Ratio:	0.02		Depth:Width Ratio:	0.01
	Vegetation:	Periphyton, *Eleocharis, Utricularia*		Vegetation:	Periphyton, *Eleocharis, Utricularia*
TC 3	**STC-3**			**STC-6**	
	Substrate:	Shellrock	• Two complete dry-outs scheduled for the cell with subsequent reflooding	Substrate:	Shellrock
	Depth:	0- 60 cm	• Maximum water depth of 30 cm	Depth:	0- 30 cm
	HLR (cm/d):	0- 12		HLR (cm/d):	0- 12
	Average Velocity (cm/s):	0.0093		Average Velocity (cm/s):	0.0185
	Depth:Width Ratio:	0.02		Depth:Width Ratio:	0.01
	Vegetation:	Periphyton, *Eleocharis, Utricularia*		Vegetation:	Periphyton, *Eleocharis, Utricularia*

Note:
mt/ha = metric tonnes per hectare

the peat soils after reflooding. Average water depth was reduced from 60 to 30 cm, and the target HLR remained at 6 cm/d. Water depth in Treatment STC-5 (South Test Cell 8) was reduced from 60 to 30 cm.

The operation schedule for Treatment STC-6 (South Test Cell 3) was revised during Phase 2 to include two prolonged dry-outs, a maximum HLR of 11.4 cm/d, a maximum operational water depth of 60 cm, and an average depth of approximately 30 cm. Monthly average HLRs actually achieved in the PSTA Test Cells are summarized in Exhibit 1-6. Average monthly water depths are provided in Exhibit 1-7.

1.3.2 Porta-PSTA Mesocosms

Twenty-four Porta-PSTA mesocosm units were constructed offsite of fiberglass and delivered to the South ENR STRC. Twenty-two of the fiberglass tanks were 6 m long by 1 m wide and 1 m deep. The remaining two tanks were the same length and depth as the other tanks, but were 3 m wide to allow assessment of mesocosm configuration effects.

Exhibit 1-8 provides a schematic view of the Porta-PSTA experimental setup showing the layout of typical 1- and 3-m-wide mesocosms in relation to the constant-head tank and inlet manifolds.

Twelve treatments were tested in the Porta-PSTAs during Phase 1. These included variations in water depth, soil type, HLR, mesocosm width, and presence of periphyton. During Phase 2, five treatments continued unaltered and 7 new treatments replaced Phase 1 treatments. This resulted in a total of 19 numbered treatments in the 18-month Porta-PSTA study. Detailed design and operational criteria for the Porta-PSTAs are summarized in Exhibit 1-9. Monthly average HLRs achieved in the Porta-PSTAs are summarized in Exhibit 1-10. Average monthly water depths achieved are provided in Exhibit 1-11.

1.4 Summary of Environmental Forcing Functions

External environmental forcing functions that affected the growth and performance of the PSTA mesocosms include:

- Sunlight (measured as total insolation and photosynthetically active radiation [PAR])
- Rain inputs
- ET outputs
- Inflow P concentrations (described in Section 3)

The general history of each of these forcing functions for the Phase 1 and 2 periods-of-record (POR) is presented in Exhibits 1-12 and 1-13.

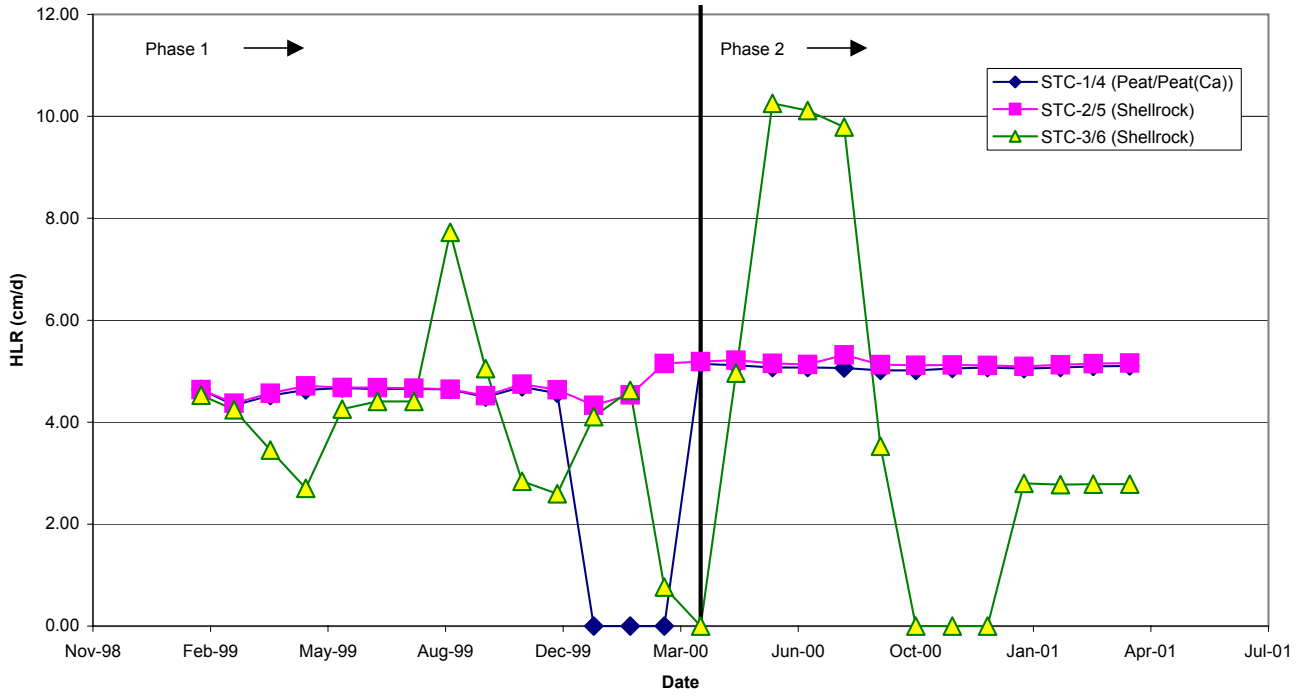


EXHIBIT 1-6
Average Monthly Inlet Hydraulic Loading Rates in the PSTA Test Cells during Phases 1 and 2

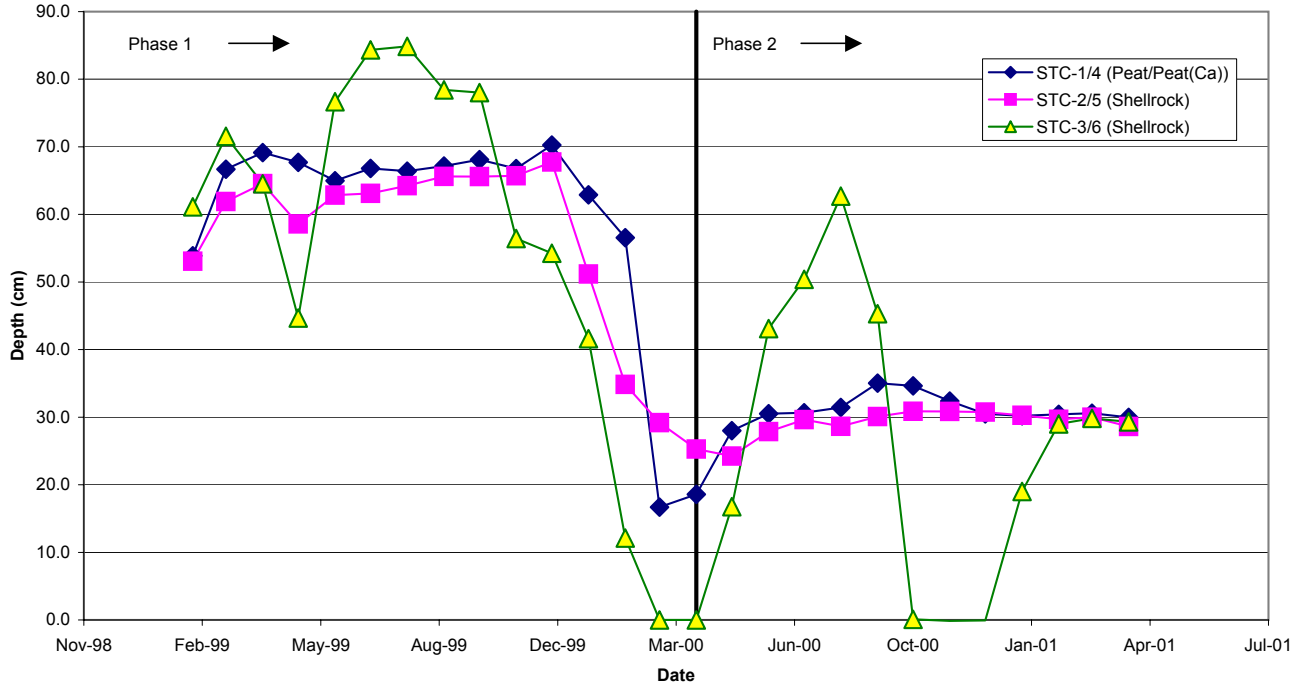


EXHIBIT 1-7
Average Monthly Water Depth in the PSTA Test Cells during Phases 1 and 2

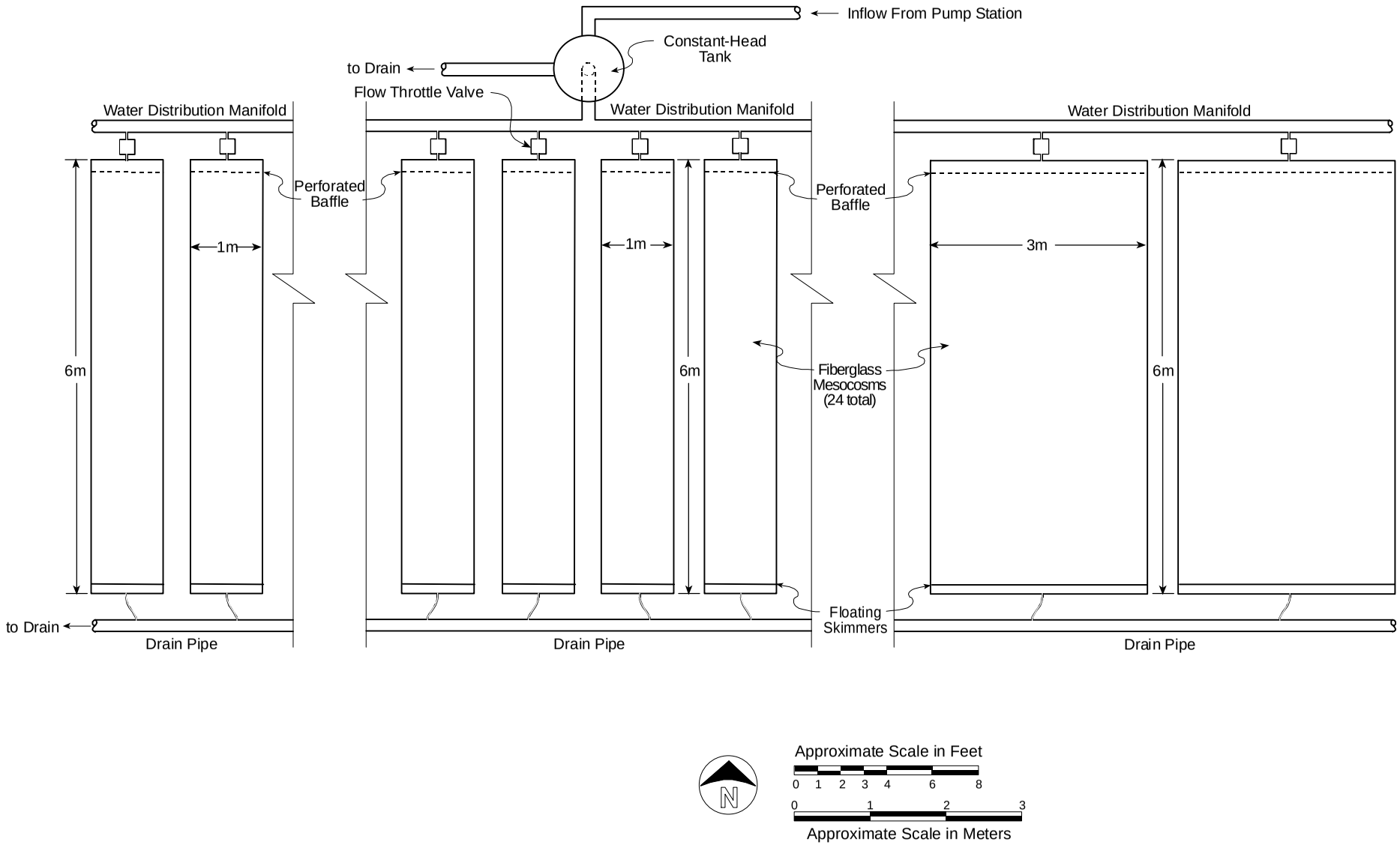


Exhibit 1-8. Porta-PSTA Experimental Mesocosm Site Plan

EXHIBIT 1-9

Comparison of Porta-PSTA Mesocosm Phase 1 and Phase 2 Treatments

	Phase 1 (April 1999 - March 2000)	Phase 1 to Phase 2 Alterations (March - April 2000)	Phase 2 (April 2000 - October 2001)
Porta-PSTAs 9, 11, 18	**PP-1** Substrate: Peat Depth: 60 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0007 Depth:Width Ratio: 0.6 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Tanks drained and vegetation removed • Sediment wetted and peat soil amended with lime (7mt/ha) • Vegetation replanted • Tank reflooded, but operated at 30 cm • Tank inoculated with periphyton	**PP-13** Substrate: Peat + Ca Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis* *Utricularia*
Porta-PSTAs 7, 4, 8	**PP-2** Substrate: Shellrock Depth: 60 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0007 Depth:Width Ratio: 0.6 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Tanks drained and vegetation removed • Shellrock removed and tank rinsed with dilute HCl • 20 cm of washed limerock added to tank • Tank replanted with spikerush • Tank reflooded, but operated at 30 cm • Tank inoculated with periphyton	**PP-14** Substrate: Limerock Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTAs 12, 14, 17	**PP-3** Substrate: Peat Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Continue routine monitoring with no changes	**PP-3** Substrate: Peat Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTAs 3, 5, 10	**PP-4** Substrate: Shellrock Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Continue routine monitoring with no changes	**PP-4** Substrate: Shellrock Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTAs 2, 13, 16	**PP-5** Substrate: Shellrock Depth: 60 HLR (cm/d): 12 Average Velocity (cm/s): 0.0007 Depth:Width Ratio: 0.6 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• HLR reduced to 6 cm/d • Water depth reduced to 30 cm • Recirculation pumps installed to increase velocity to 0.5 cm/s	**PP-15** Substrate: Shellrock Depth: 30 cm HLR (cm/d): (recirc) Average Velocity (cm/s): 0.5 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTAs 1, 6, 15	**PP-6** Substrate: Shellrock Depth: 0- 60cm HLR (cm/d): 0- 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0- 0.6 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• One complete dry out scheduled with subsequent reflooding • Variation in water regime scheduled • Maximum water depth reduced to 30 cm	**PP-16** Substrate: Shellrock Depth: 0- 30 cm HLR (cm/d): 0- 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0- 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTA 19	**PP-7** Substrate: Sand Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Continue routine monitoring with no changes	**PP-7** Substrate: Sand Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTA 20	**PP-8** Substrate: Sand Depth: 60 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0007 Depth:Width Ratio: 0.6 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Tank drained and vegetation removed • Sand thoroughly washed with dilute HCl to remove available P • Tank rinsed • Tank replanted with spikerush • Tank reflooded, but operated at 30 cm • Tank inoculated with periphyton	**PP-17** Substrate: Sand- HCl Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Eleocharis, Utricularia*
Porta-PSTA 21	**PP-9** Substrate: Peat- Aquashade Depth: 60 HLR (cm/d): 6 Average Velocity (cm/s): 0.0007 Depth:Width Ratio: 0.6 Vegetation: None	• Tank drained and substrate removed • Tank thoroughly rinsed with dilute HCl • Tank rinsed • Tank reflooded, but operated at 30 cm • Tank inoculated with periphyton	**PP-18** Substrate: None Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Utricularia*
Porta-PSTA 22	**PP-10** Substrate: Shellrock- Aquashade Depth: 60 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0007 Depth:Width Ratio: 0.6 Vegetation: None	• Tank drained and substrate removed • Tank thoroughly rinsed with dilute HCl • Tank rinsed • Tank reflooded, but operated at 30 cm • Synthetic substrate (Aquamat) added • Tank inoculated with periphyton	**PP-19** Substrate: None- Aquamat Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.3 Vegetation: Periphyton, *Utricularia*
Porta-PSTA 23	**PP-11** Substrate: Shellrock Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.1 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Continue routine monitoring with no changes	**PP-11** Substrate: Shellrock Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.1 Vegetation: Periphyton, *Eleocharis* , *Utricularia*
Porta-PSTA 24	**PP-12** Substrate: Peat Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.1 Vegetation: Periphyton, *Eleocharis* , *Utricularia*	• Continue routine monitoring with no changes	**PP-12** Substrate: Peat Depth: 30 cm HLR (cm/d): 6 Average Velocity (cm/s): 0.0014 Depth:Width Ratio: 0.1 Vegetation: Periphyton, *Eleocharis* , *Utricularia*

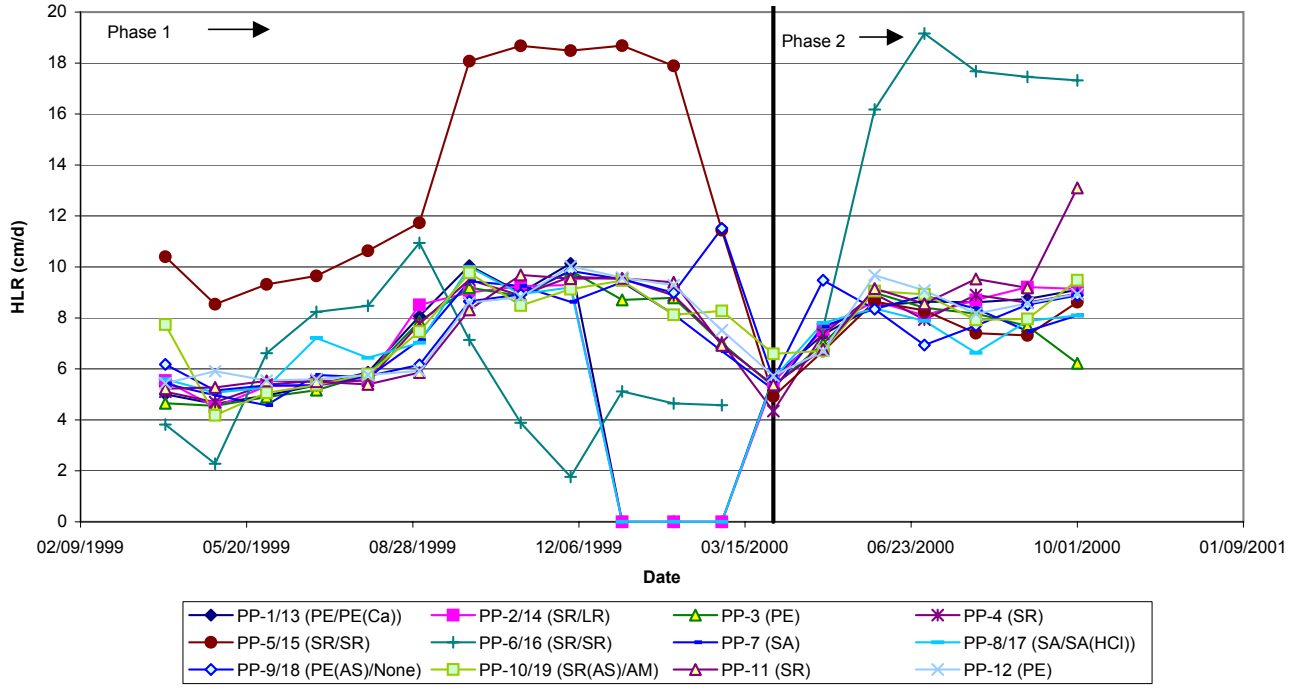


EXHIBIT 1-10
Average Monthly Inlet Hydraulic Loading Rates in the Porta-PSTAs during Phases 1 and 2

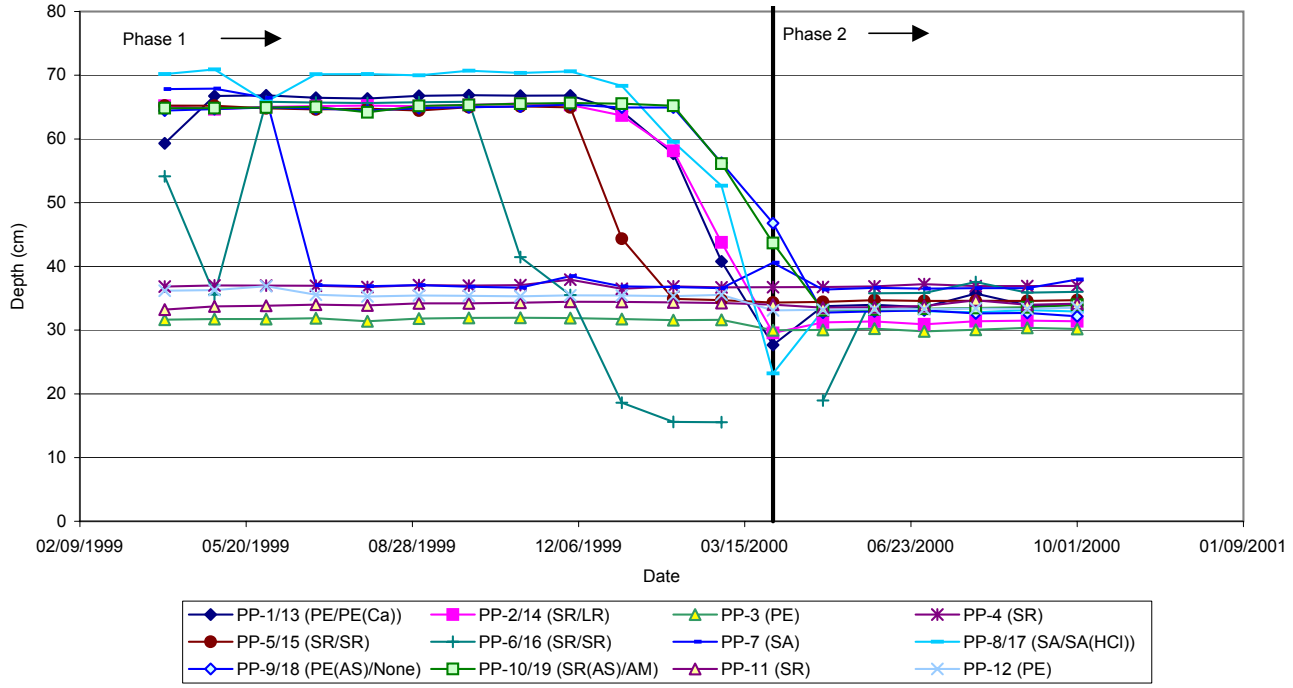
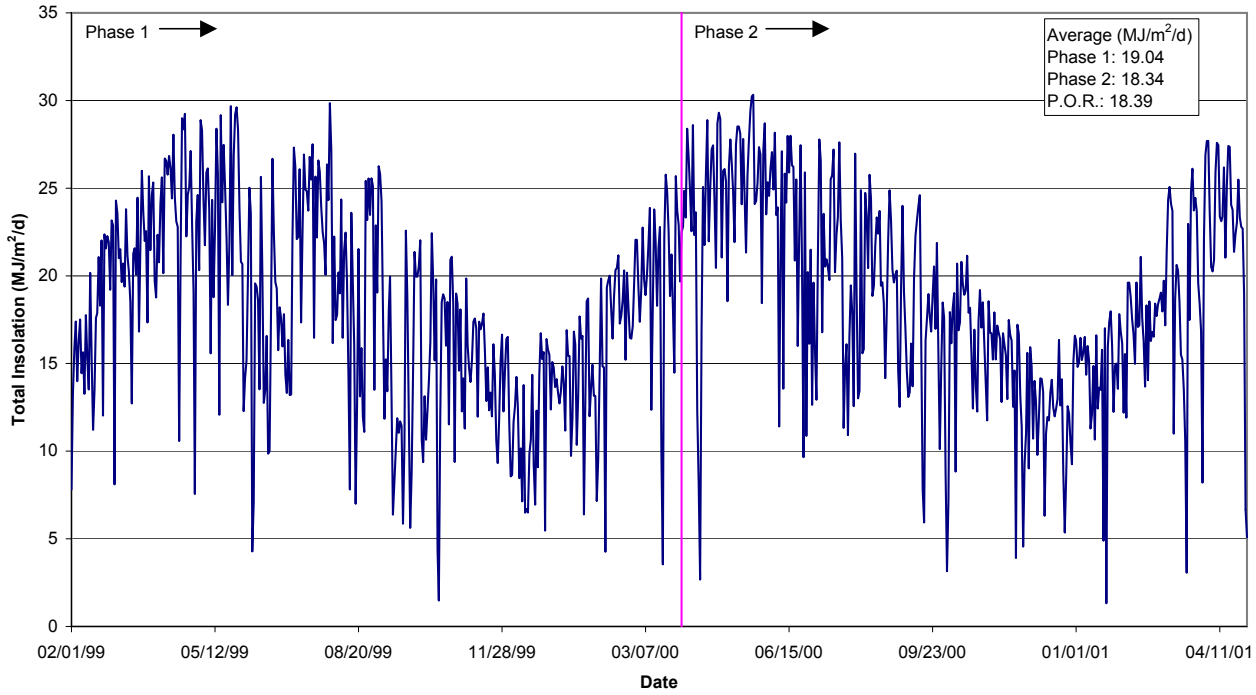
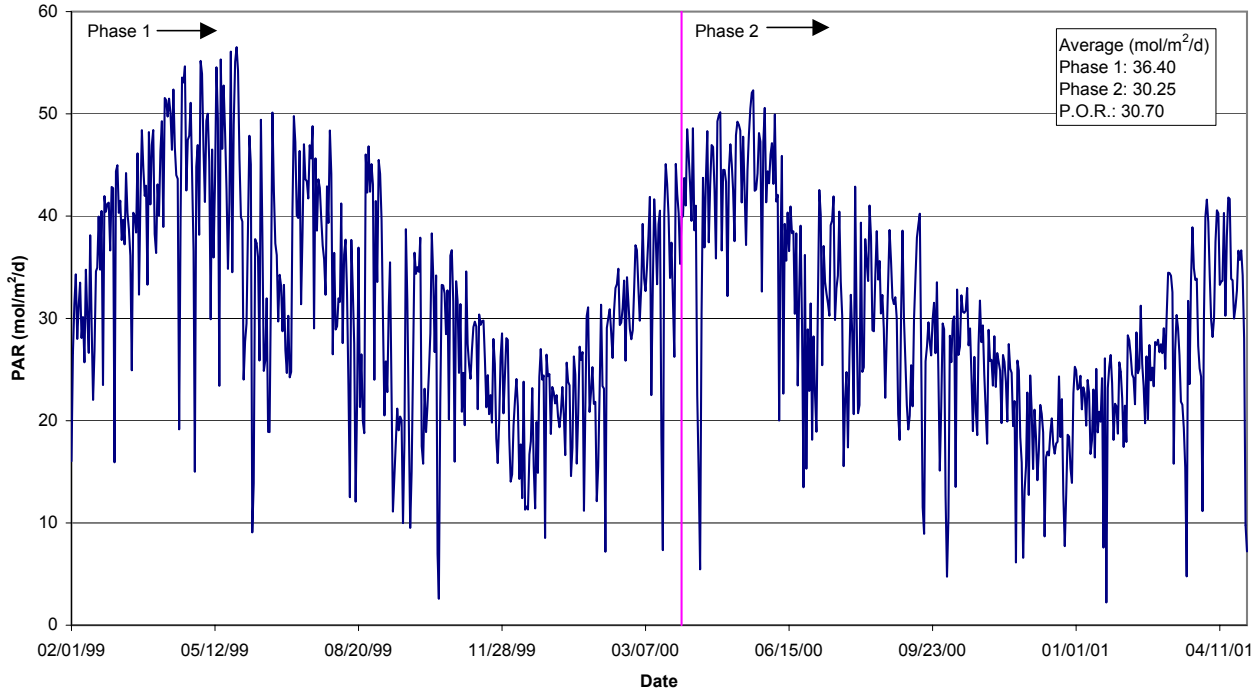


EXHIBIT 1-11
Average Monthly Water Depth in the Porta-PSTAs during Phases 1 and 2

EXHIBIT 1-12

Solar Energy Inputs to the PSTA Mesocosms During Phases 1 and 2





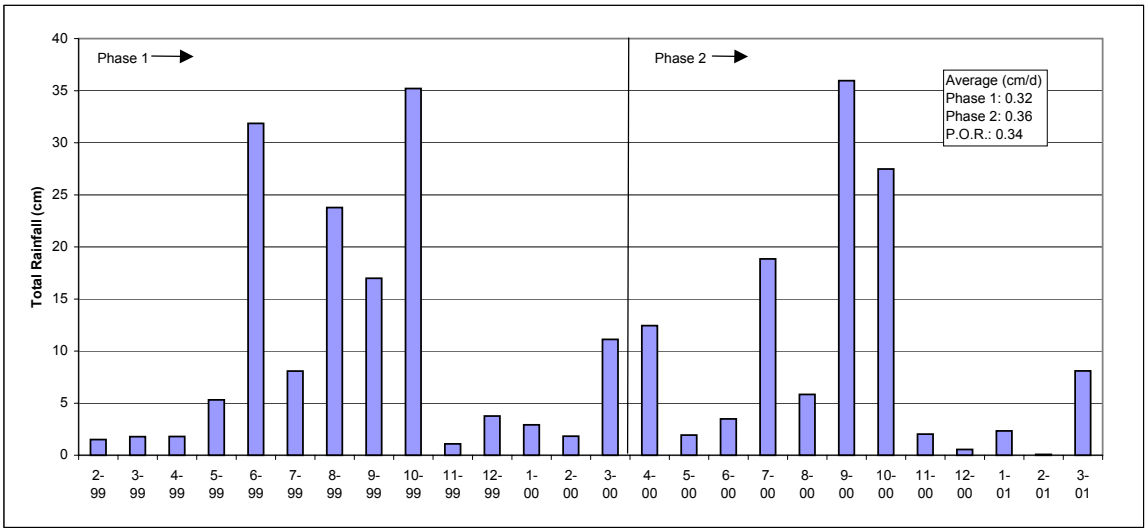
1.4.1 Solar Inputs

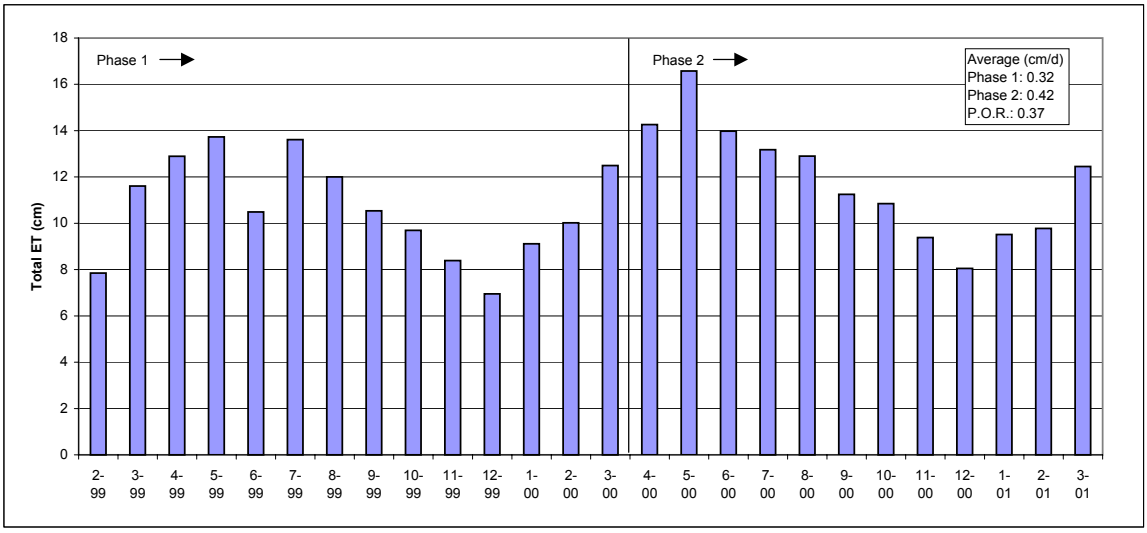
Exhibit 1-12 summarizes the total insolation and PAR received at the project site during the Phase 1 and 2 periods. Total insolation averaged 18.4 megajoules (MJ) per m^2/d, and PAR averaged 30.7 mols per m^2/d. Sunlight inputs are clearly seasonal with short-term effects attributable to the presence of cloud cover.

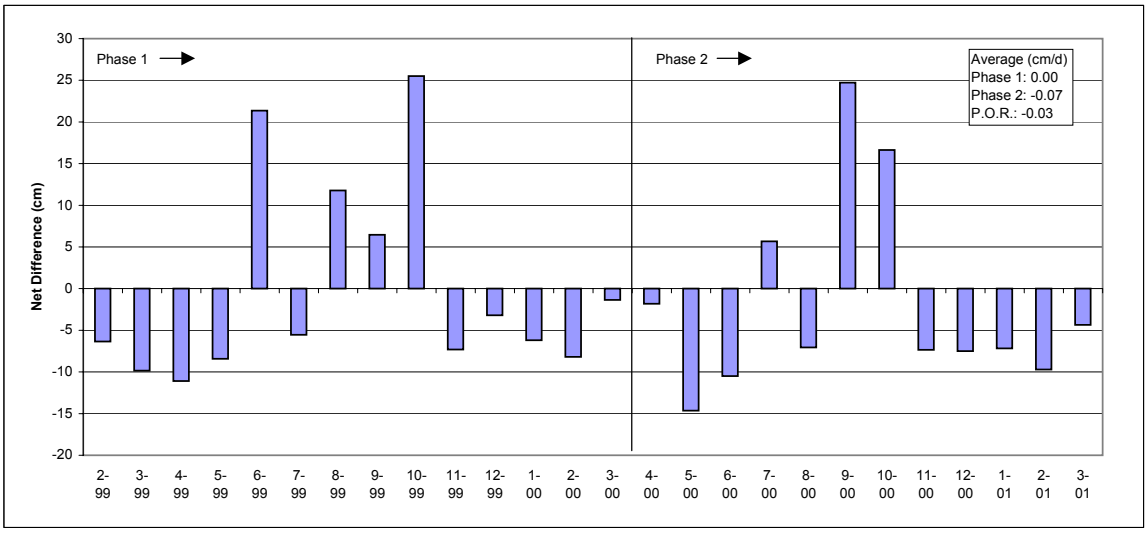
1.4.2 Precipitation and Evapotranspiration

Exhibit 1-13 compares the measured rainfall and estimated evapotranspiration (ET) and their net difference. The total rainfall for the 788-day POR was 268 cm (105 inches [in]), which is equal to approximately 0.34 cm/d (0.13 in/d), while ET was 292 cm (115 in), or 0.37 cm/d (0.15 in/d). These data indicate that there was a slight net ET water loss to the atmosphere (0.03 cm/d) [0.01 in/d] from the PSTA mesocosms during the POR.

EXHIBIT 1-13
Rainfall and Evapotranspiration at the PSTA Mesocosms During Phases 1 and 2







Note: Phase 1: 424 days, Phase 2: 364 days

SECTION 2

Community Development and Viability

2.1 Introduction

PSTA technology development depends on being able to create and maintain a periphyton-dominated ecosystem that has some characteristics of a typical Everglades periphyton assemblage. It is hypothesized that PSTAs must have the following general characteristics to be considered viable:

- Biomass and primary productivity levels that approximate those of natural, low nutrient adapted periphyton assemblages
- Algal species dominance and diversity similar to natural periphyton assemblages that have the ability to capture and sequester P at low surface water concentrations and in stable forms
- Able to recover from dry-down periods relatively quickly and reestablish high productivity rates and P sequestration
- Resistant to wash-out and wind transport under varying climatic regimes
- Relatively immune to biological upsets caused by population explosions of consumers

PSTA research has provided information that addresses most of these questions related to PSTA viability. This section reports specific findings related to periphyton ecology, macrophyte growth in the PSTA mesocosms, and overall ecological processes in these systems.

2.2 Periphyton Ecology

2.2.1 Background

A typical adapted periphyton community is as complex as any other ecosystem and includes a high diversity of primary producers, various levels of grazers and consumers, and a detrital food web (Lowe, 1996; Bott, 1996). As with other eco-systems, the periphyton can be studied as an assemblage of mutually dependent organisms (population approach) and/or

based on overall ecological form and function (systems-level or "green-box" approach). Studies focused solely on the algal component of the periphyton are too narrow to assess the function of the entire ecosystem of producers and consumers. Population studies are time-consuming and costly, and may not be able alone to provide answers to the questions most relevant to PSTA design. The PSTA Research and Demonstration Project utilized an experimental and engineering approach that includes measurements of both population and system-level properties of the periphyton.

2.2.2 Periphyton Sampling Methods

Detailed sampling and research methods are provided in the *PSTA Research Plan* (CH2M HILL, April 2001) and are briefly described in this section as well as in Appendix A. Periphyton species dominance and succession were documented through routine algal species identification, cell counts, and cell volume estimates throughout the PSTA project period. These cell counts encompassed algal population conditions during typical successional periods and during a range of seasonal conditions. Identification, cell counts, and algal biovolume estimates were made using mixed periphyton samples collected by coring the entire mesocosm water column. Periphyton populations were not studied on artificial substrates, such as glass slides, because these devices commonly underestimate natural periphyton biomass and diversity (Swift, 1981). However, mesocosm walls have been periodically sampled to quantify the effect of this excess surface area on overall mesocosm ecological function. System-level measurements of periphyton community structure also include routine sampling for chlorophyll *a*, *b*, and *c*, phaeophytin, dry weight biomass and ash-free dry weight (AFDW).

The majority of taxa (36 percent) were diatoms, followed closely by greens (30 percent), and blue-greens (29 percent). This relatively even distribution of taxa was generally consistent in all of the shellrock and peat-based PSTA mesocosms.

Sloughing and downstream export of periphyton were measured by filtration of water exiting experimental PSTAs. Grab samples were filtered on a routine basis (monthly) to measure particulate matter and particulate P export. One diel study was conducted to provide samples for export dry weight, AFDW, species composition, cell numbers, and cell volume.

2.2.3 Algal Taxonomic Composition

A total of 371 algal taxa were identified in PSTA periphyton samples collected in the Porta-PSTAs and in the PSTA Test Cells (see Exhibit 2-1). Detailed lists of the algal cell counts and monthly totals by individual taxa for the PSTA Test Cells are provided in Appendix C. Based on cell counts, the majority of taxa (36 percent) were diatoms, followed closely by greens (30 percent), and blue-greens (29 percent). This relatively even distribution of taxa was generally consistent in all of the shellrock and peat-based PSTA mesocosms. A total of 220 algal taxa were recorded in the shellrock Test Cell treatments, and 174 taxa were recorded in the peat-based Test Cell.

EXHIBIT 2-1

Algal Species Diversity in PSTA Mesocosms During Phases 1 and 2

	No. Species Observed									
	Test Cells			Porta-PSTAs						Combined
Phylum	Shellrock	Peat	Total	Shellrock	Peat	Sand	Limerock	None	Total	Total
Cyanobacteria (blue-greens)	68	54	77	98	74	60	39	32	106	108
Chlorophyta (greens)	59	55	73	84	65	39	29	13	98	110
Bacillariophyceae (diatoms)	80	60	91	87	101	47	25	15	116	135
Chrysomonodales (dinobroyon)	0	0	0	2	0	0	0	0	2	2
Xanthophyceae (yellow greens)	2	0	2	0	1	0	0	0	1	3
Euglenophyta (euglenoids)	3	1	3	2	2	0	1	0	2	3
Cryptophyta (cryptomonads)	5	4	5	5	4	2	0	0	5	5
Pyrrhophyta (dinoflagellates)	3	0	3	3	2	1	2	1	5	5
Total No. Spp.	**220**	**174**	**254**	**281**	**249**	**149**	**96**	**61**	**335**	**371**

A total of 281 algal species were reported in the shellrock Porta-PSTAs, 249 species in the peat Porta-PSTAs, and lower numbers in the other soil treatments (see Exhibit 2-1 and Appendix D). Part of these differences is attributable to the number of replicates and the longer POR in the shellrock and peat-based systems. Only 61 algal taxa were observed in the non-substrate control Porta-PSTAs. Blue-greens were dominant in terms of number of taxa only in the sand and non-substrate control mesocosms.

Exhibit 2-2 summarizes the PSTA mesocosm monthly average algal cell densities and biovolumes by major taxa for the entire POR. In terms of cell counts, the blue-green (Cyanophyceae) algal taxa dominated in all treatments. Biovolumes provide an index of algal biomass. This parameter indicated that populations of diatoms (Bacillariophyceae) or blue-greens were typically dominant in these periphyton communities, followed by green (Chlorophyta) algae species. These relationships were highly variable for different treatments and over time.

Time series trends for algal biovolume are shown on Exhibits 2-3 to 2-5 for shellrock, peat, and other substrate treatments, respectively. As shown on Exhibit 2-3, algal biovolumes for the shellrock treatments were variable because of the patchiness of periphyton mats intersected by core samples and the variability within mats. Algal biovolumes for these treatments were typically less than 60 cm^3/m^2. Mean values varied from approximately 3 to 30 cm^3/m^2. No apparent trend in these biovolumes was observed during the 2-year research period.

Algal biovolumes for the peat-based mesocosms show an increasing trend over time (see Exhibit 2-4). Biovolume decreased markedly in the peat Test Cell when it was restarted in May 2000 and then rapidly recovered to higher monthly averages. Mean algal biovolumes for the peat-based cells ranged from approximately 7 to 39 cm^3/m^2.

Vymazal concluded that the periphyton communities colonizing the PSTA mesocosms are similar to those found in unimpacted areas of WCA-2A. The dominant species are those typically reported from oligotrophic (low P) to slightly eutrophic areas of the conservation area.

No clear temporal trends in algal biovolume are apparent for the sand treatments. Long-term average values for these treatments were between 18 and 34 cm^3/m^2. Average algal biovolumes for the shellrock treatments were relatively low in the Aquashade treatments during Phase 1 (PP-9, 6.3 cm^3/m^2 and PP-10, 7.2 cm^3/m^2). Average algal biovolumes in the non-soil treatments during Phase 2 were higher, at 104 cm^3/m^2 for the tank with no substrate and 25 cm^3/m^2 for the tank with Aquamat (see Exhibit 2-5).

Jan Vymazal (Ecology and Use of Wetlands) examined the PSTA periphyton data for similarities and differences with respect to other Everglades periphyton communities (see Appendix E). Vymazal concluded that the periphyton communities colonizing the PSTA mesocosms are similar to those found in unimpacted areas of WCA-2A. The dominant species are those typically reported from oligotrophic (low P) to slightly eutrophic areas of the

EXHIBIT 2-2

Average PSTA Mesocosm Periphyton Community Data - Algal Populations

				Blue-Green Algae			Diatoms			Green Algae			Other Taxa			Total Taxa				
Treatment	Substrate	Depth	HLR	cells/ m^2*10^9	# taxa	Biovolume cm^3/m^2	cells/ m^2*10^9	# taxa	Biovolume cm^3/m^2	cells/ m^2*10^9	# taxa	Biovolume cm^3/m^2	cells/ m^2*10^9	# taxa	Biovolume cm^3/m^2	cells/ m^2*10^9	# taxa	Biovolume cm^3/m^2	Evenness	SWDI
PP-1	PE	D	L	20.4	11	0.65	2.23	15	3.18	1.06	4	2.94	0.01	<1	0.07	23.7	30	6.84	0.73	3.56
PP-2	SR	D	L	96.5	15	4.46	4.72	10	8.36	1.28	4	0.34	0.02	1	0.07	103	30	13.24	0.71	3.48
PP-3	PE	S	L	64.5	13	4.33	2.04	12	5.25	1.33	5	1.48	0.03	1	0.05	67.8	31	11.11	0.72	3.53
PP-4	SR	S	L	156	14	12.41	5.12	9	16.08	14.7	3	0.31	0.01	<1	0.07	173	27	28.87	0.68	3.20
PP-5	SR	D	H	157	14	5.00	5.41	9	10.22	16.5	4	1.30	0.01	1	0.03	179	27	16.56	0.75	3.53
PP-6	SR	V	V	183	15	3.42	3.61	10	5.78	5.16	4	0.61	0.05	<1	0.49	189	29	10.30	0.72	3.49
PP-7	SA	D/S	L	362	16	11.10	8.12	10	18.95	2.97	4	1.23	0.01	<1	0.01	373	30	31.28	0.72	3.52
PP-8	SA	S	L	298	17	8.31	3.45	8	8.10	5.56	5	1.42	0.06	<1	0.07	307	31	17.91	0.70	3.44
PP-9	PE (AS)	D	L	5.57	2	0.15	1.09	15	2.20	0.26	2	3.48	0.05	1	0.50	6.96	20	6.34	0.62	2.73
PP-10	SR (AS)	D	L	10.3	8	0.20	4.55	17	5.12	1.10	4	1.82	0.04	1	0.05	16.0	29	7.19	0.76	3.68
PP-11	SR	S	L	222	14	6.41	6.04	8	7.18	1.96	5	0.78	0.01	<1	0.04	200	27	14.41	0.69	3.28
PP-12	PE	S	L	19.4	10	0.61	1.34	12	2.19	0.57	4	0.07	0.01	1	0.09	21.3	27	2.96	0.64	3.01
PP-13	PE (Ca)	S	L	38.7	10	1.12	2.77	9	2.39	1.91	5	4.31	0.08	1	0.05	43.4	24	7.87	0.70	3.19
PP-14	LR	S	L	306	16	10.52	6.66	6	10.65	3.28	5	4.00	0.01	1	0.01	316	27	25.17	0.69	3.39
PP-15	SR	S	R	203	14	5.72	4.67	7	5.91	3.15	5	12.92	0.03	<1	0.19	211	26	24.73	0.71	3.30
PP-16	SR	V	V	400	17	15.83	5.65	5	5.87	4.47	3	7.36	0.06	<1	0.00	406	25	29.06	0.72	3.31
PP-17	SA (HCl)	S	L	533	16	10.04	4.17	5	4.91	6.26	3	18.84	0.00	<1	0.01	544	25	33.79	0.73	3.38
PP-18	None	S	L	815	13	30.87	12.59	5	24.92	13.3	3	47.71	0.06	1	0.03	841	22	103.54	0.65	2.86
PP-19	AM	S	L	477	14	15.47	3.42	5	5.96	1.75	3	3.84	0.00	<1	0.00	482	21	25.27	0.65	2.86
STC-1	PE	D	L	54.7	9	17.09	2.03	10	6.58	5.55	9	1.50	0.10	1	0.42	62.3	28	25.59	0.70	3.27
STC-2	SR	D	L	112	13	2.60	3.86	10	6.93	1.63	6	1.46	0.12	2	0.06	118	30	11.05	0.72	3.48
STC-3	SR	V	V	36.5	12	0.67	1.48	11	1.56	1.77	7	0.69	0.13	3	0.16	39.5	31	3.08	0.74	3.63
STC-4	PE (Ca)	D	L	162	11	31.26	9.51	8	5.04	2.59	5	2.25	0.33	1	0.27	168	21	38.82	0.66	2.87
STC-5	SR	D	L	254	15	19.96	7.91	8	8.29	1.48	3	2.13	0.00	<1	0.00	264	26	30.37	0.70	3.27
STC-6	SR	V	V	222	13	6.08	22.0	7	3.20	3.40	3	0.70	0.00	<1	0.00	227	22	9.98	0.69	3.04

Notes:

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

SWDI = Shannon-Weaver Diversity Index

Periphyton taxonomy conducted on a quarterly basis for PP-3, 4, 11, and 12 and STC-5 beginning in July 2000.

EXHIBIT 2-3

Ash-Free Dry Weight Biomass, Chlorophyll *a*, and Algal Biovolumes for the Shellrock-Based PSTA Treatments

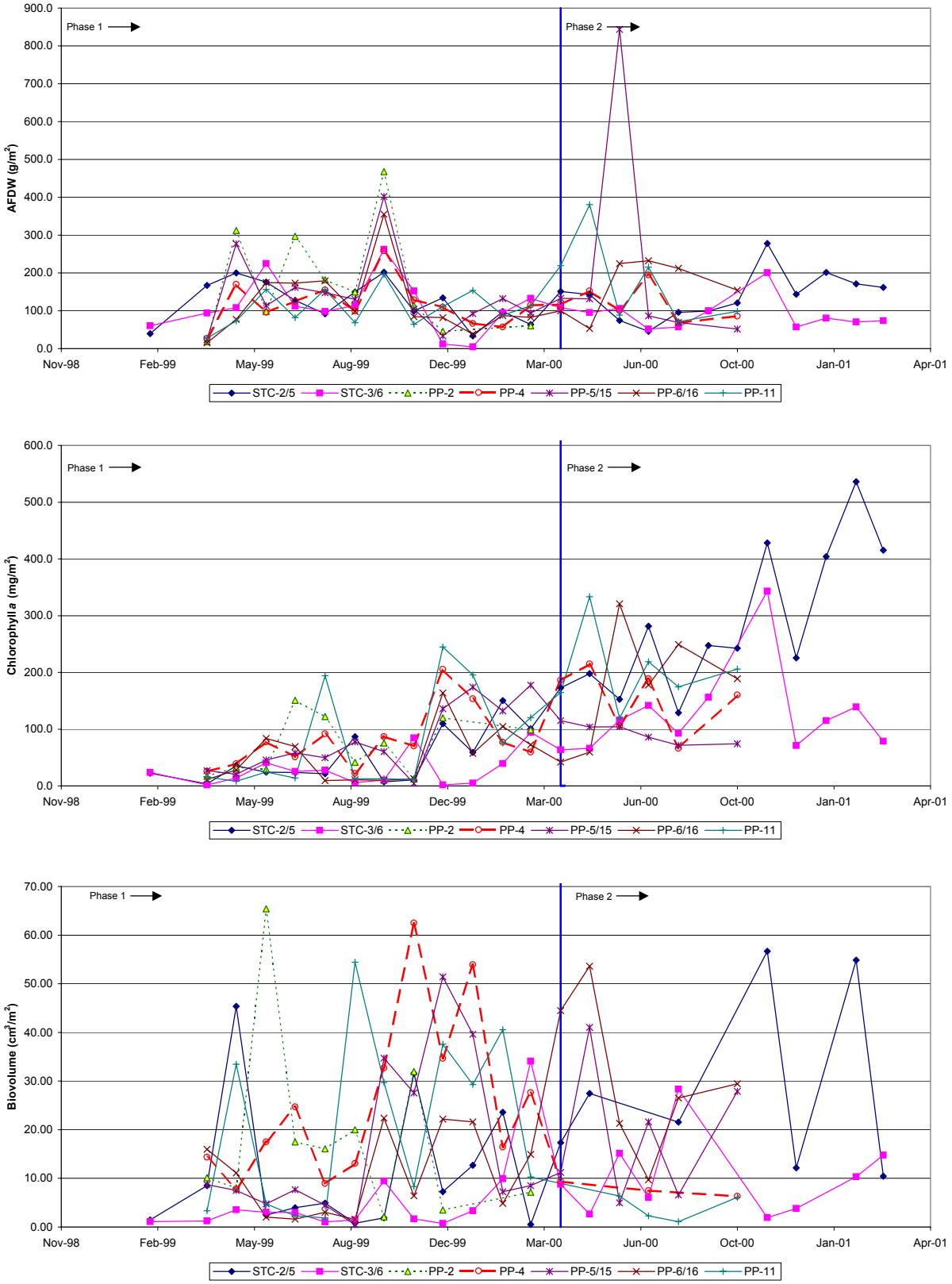
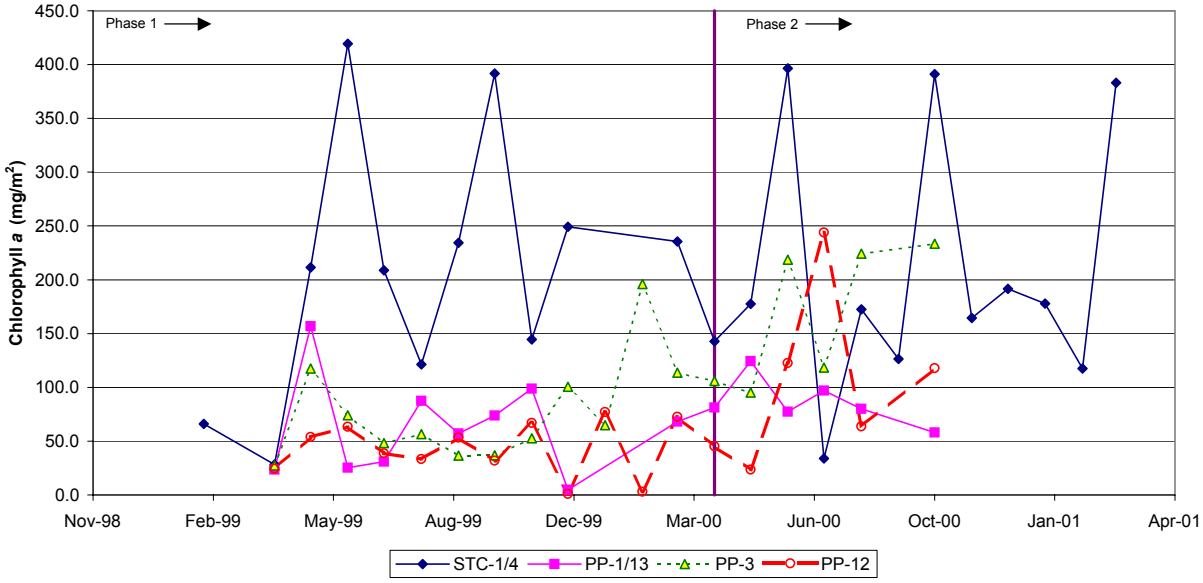


Exhibit 2-4

Chlorophyll *a* and Algal Biovolumes for the Peat-Based PSTA Treatments



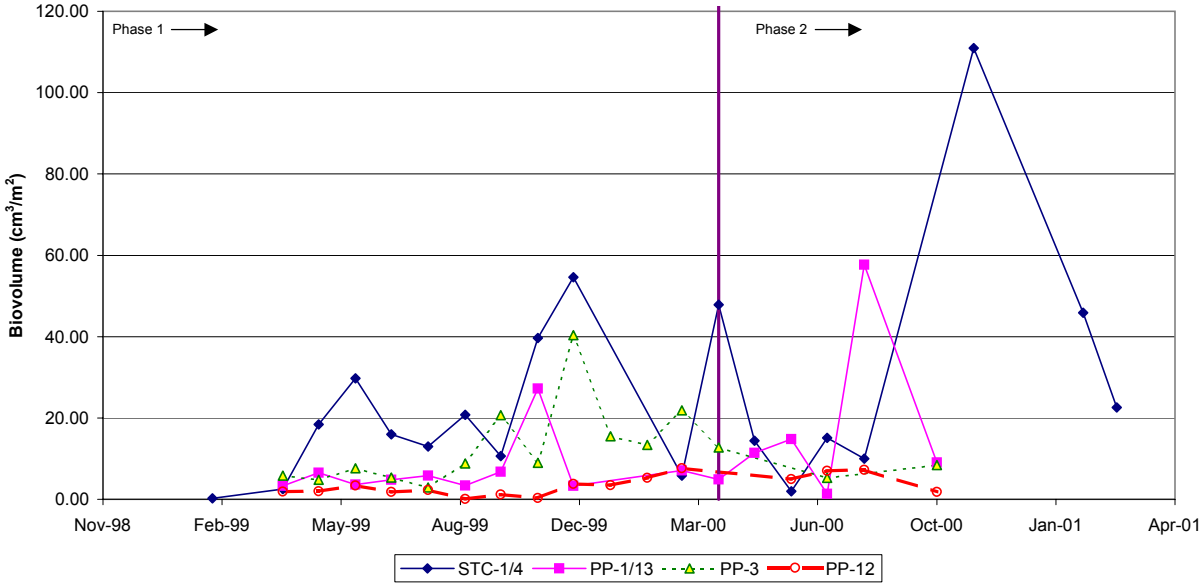
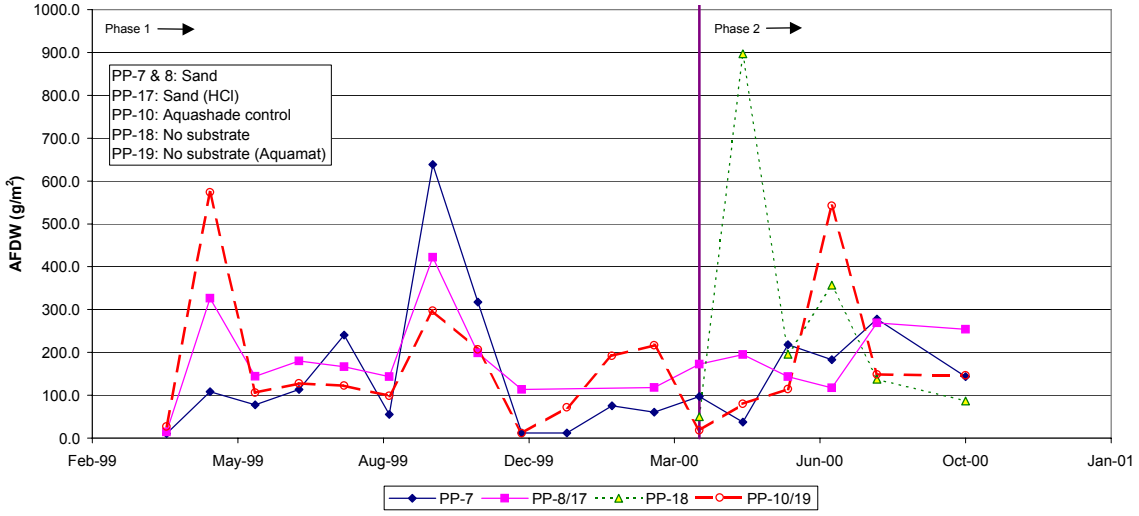
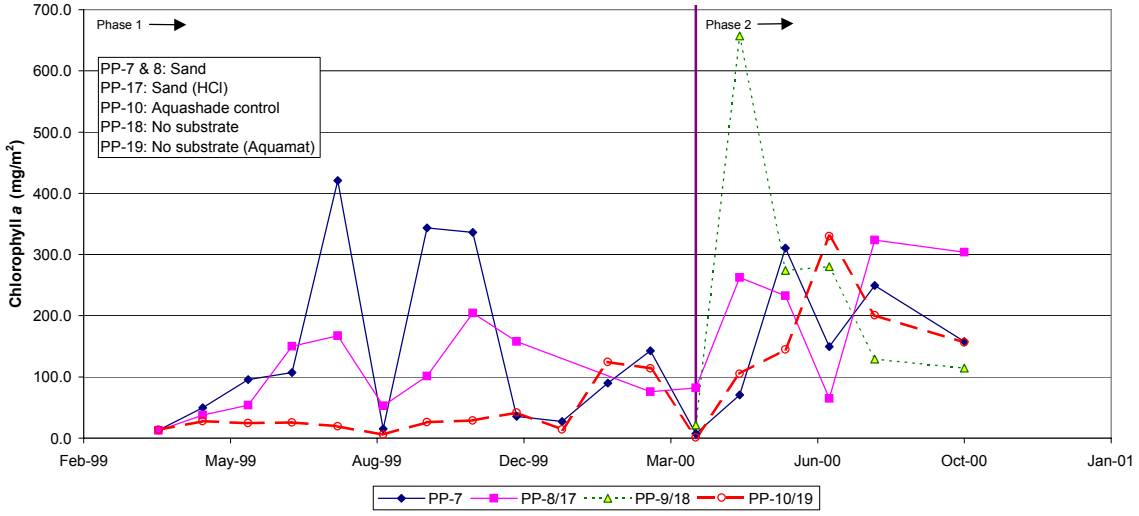
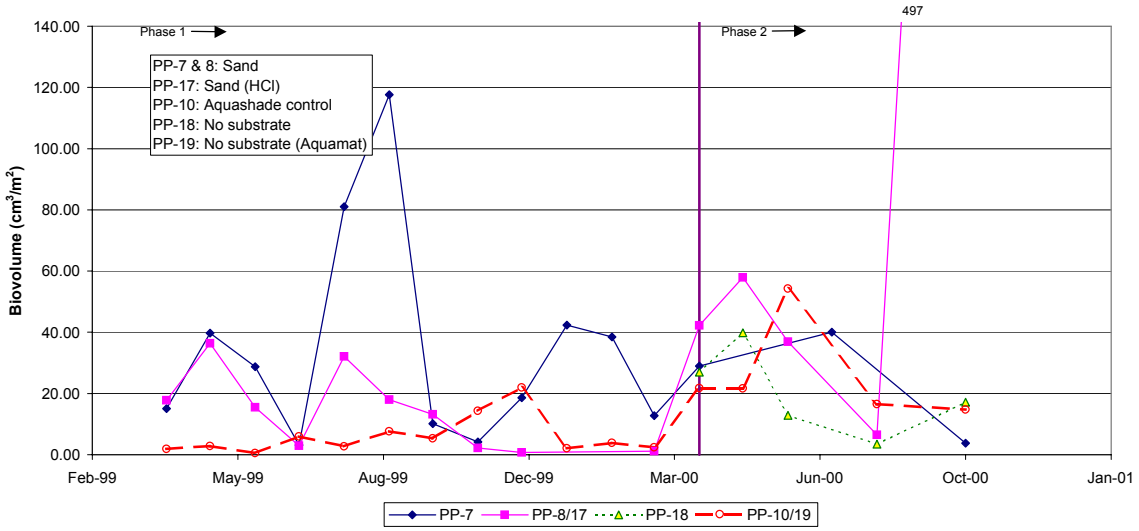


EXHIBIT 2-5

Ash-Free Dry Weight Biomass, Chlorophyll *a*, and Algal Biovolumes for the Sand-Based, Aquashade, and No Substrate Control PSTA Treatments







conservation area (McCormick and Stevenson, 1998). These species are characterized by a normal succession of dominants, beginning with *Mastogloia smithii* and other diatoms, followed by replacement by blue-green algal species, including *Scytonema*. The time needed for replacement of diatom dominance by blue-greens may be as long as 1 year under the low P concentrations tested in this research. Faster succession is observed under higher nutrient loads. Vymazal noted little effect of peat vs. shellrock substrate on the algal species composition. In sand treatments, the proportion of blue-green algae was higher. Aquashade reduced the populations and dominance of blue-greens and decreased periphyton calcification. Diatom dominance was maintained longer in shallow water compared to deeper water systems.

2.2.4 Periphyton Biomass and Chlorophyll Content

Periphyton core samples were also analyzed for dry and AFDW biomass, chlorophyll *a*, and phaeophytin. Exhibit 2-6 summarizes the monthly average data for these parameters by treatment.

Average periphyton dry weight biomass varied from a low of 303 grams dry weight per square meter (g DW/m^2) in the dry-down PSTA Test Cell (STC-6) to 2,066 g DW/m^2 in the calcium-amended peat Test Cell (STC-4). Periphyton dry weight biomass varied between 303 and 947 g DW/m^2 in the shellrock treatments, 657 to 2,066 g DW/m^2 in the peat treatments, 416 g DW/m^2 in the limerock treatment, 663 to 877 g DW/m^2 in the sand treatments, and 663 to 924 g DW/m^2 in the non-sediment control treatments. The Phase 1 Aquashade treatments (PP-9 and PP-10) averaged between 713 and 1,641 g DW/m^2. This indicates that the Aquashade treatments were not effective at reducing the estimated biomass in the Porta-PSTA mesocosms, even though algal cell counts and biovolume were typically much lower in these cells (see Exhibit 2-2).

In the final destructive sampling of six Porta-PSTA treatments, the benthic periphyton was the main contributor to periphyton biomass in all but one treatment (Aquamat control).

Final periphyton dry weight biomass was determined in the final destructive sampling of six Porta-PSTA treatments (CH2M HILL, August 2001). These data are summarized in Exhibit 2-7. Total final average periphyton dry weight ranged from 135 g/DW/m^2 in the peat-based treatment (PP-3) to 2,170 g DW/m^2 in one of the sand-based treatments (PP-7). The benthic periphyton was the main contributor to this biomass in all but one treatment (Aquamat control). In the non-substrate control (PP-18), there were approximately equal portions of floating and benthic periphyton mats. These data verify that the routine periphyton biomass results for the peat-based mesocosms (average DW biomass of 657 to 2,066 g/m^2 in routine samples compared to 135 g/m^2 in the final destructive sampling) probably overestimated the overall community biomass in those treatments.

EXHIBIT 2-6

Average PSTA Periphyton Community Biomass, Chlorophyll, and Chemistry Data

Treatment	Substrate	Depth	HLR	Periphyton Biomass (g/m^2) Ash Wt	Dry Wt	AFDW	Ca (g/m^2)	Chl_a (corr) (mg/m^2)	Pheo_a (mg/m^2)	TP (g/m^2)	TIP (g/m^2)	TKN (g/m^2)
PP-1	PE	D	L	565	1101	535	93	67	24.5	0.298	0.087	10.59
PP-2	SR	D	L	555	741	189	110	70	3.3	0.313	0.130	1.23
PP-3	PE	S	L	327	733	406	66	107	33.0	0.322	0.084	6.96
PP-4	SR	S	L	536	641	118	155	104	4.5	0.674	0.162	1.24
PP-5	SR	D	H	517	660	143	122	80	6.0	0.430	0.116	1.60
PP-6	SR	V	V	468	588	120	114	52	4.5	0.346	0.136	0.66
PP-7	SA	D/S	L	514	663	149	95	146	3.9	0.152	0.019	0.99
PP-8	SA	S	L	475	665	190	70	104	6.2	0.135	0.014	1.63
PP-9	PE (AS)	D	L	1035	1641	918	180	96	62.7	0.555	0.165	16.07
PP-10	SR (AS)	D	L	542	713	171	124	39	1.3	0.395	0.242	0.68
PP-11	SR	S	L	661	792	131	166	119	4.1	1.055	0.413	1.94
PP-12	PE	S	L	321	657	363	58	63	22.2	0.259	0.084	5.23
PP-13	PE (Ca)	S	L	912	1990	1041	259	86	31.3	0.759	0.458	5.04
PP-14	LR	S	L	301	416	115	98	120	5.9	0.093	0.031	2.20
PP-15	SR	S	R	321	415	219	89	92	4.5	0.256	0.100	1.72
PP-16	SR	V	V	785	947	163	225	173	17.7	0.640	0.361	3.89
PP-17	SA (HCl)	S	L	684	877	192	154	212	7.8	0.153	0.046	5.21
PP-18	None	S	L	637	924	287	198	246	3.9	0.187	0.102	3.01
PP-19	AM	S	L	488	663	175	118	156	4.3	0.216	0.137	1.52
STC-1	PE	D	L	1348	2066	711	300	208	39.7	0.838	0.199	7.59
STC-2	SR	D	L	417	535	118	97	51	8.1	0.286	0.097	3.98
STC-3	SR	V	V	344	461	117	67	30	6.4	0.175	0.043	0.99
STC-4	PE (Ca)	D	L	716	1046	330	214	206	43.1	0.700	0.283	7.98
STC-5	SR	D	L	282	409	127	107	256	30.0	0.263	0.048	4.25
STC-6	SR	V	V	204	303	101	91	138	20.1	0.332	0.084	3.42

Notes:

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

TKN analyzed on a quarterly basis.

EXHIBIT 2-7

Porta-PSTA Periphyton Final Mass Balance Sampling, February 2001

Treatment No.	PP-3	PP-4	PP-7	PP-17	PP-18	PP-19
Soil Type	Peat	Shellrock	Sand	Sand	None	AquaMat
Tank Bottom Area (m^2)	6	6	6	6	6	6
Dry Weight (g/m^2)						
Floating Mat/Metaphyton	25.2	158.2	238.8	229.9	386.0	482.5
Benthic Mat	92.4	552.4	1814.3	810.2	622.0	534.6
Wall Mat	17.2	185.4	116.4	3.3	137.4	203.0
Total	134.8	896.0	2169.5	1043.4	1145.5	1220.0
Ash-Free Dry Weight (g/m^2)						
Floating Mat/Metaphyton	13.0	40.0	58.8	54.6	99.4	126.8
Benthic Mat	58.3	121.7	167.5	121.2	160.7	129.4
Wall Mat	6.7	52.9	23.1	1.2	35.6	52.6
Total	78.0	214.7	249.4	177.0	295.7	308.7
Ash Weight (g/m^2)						
Floating Mat/Metaphyton	12.2	118.2	180.1	175.3	286.7	355.7
Benthic Mat	34.1	430.6	1645.5	688.4	461.3	383.4
Wall Mat	10.5	132.5	93.2	19.0	101.9	150.4
Total	56.7	681.3	1918.9	882.8	849.8	889.4
Total Phosphorus (mg/m^2)						
Floating Mat/Metaphyton	17.5	48.8	53.4	65.0	66.8	86.1
Benthic Mat	68.7	307.4	554.7	152.3	96.0	151.5
Wall Mat	8.8	35.3	18.3	2.3	21.0	35.1
Total	95.0	391.5	626.5	219.6	183.7	272.6
TIP (mg/m^2)						
Floating Mat/Metaphyton	0.07	0.76	0.28	0.50	0.73	1.21
Benthic Mat	0.60	8.09	3.84	1.78	0.71	1.67
Wall Mat	0.06	0.67	0.21	0.00	0.11	0.19
Total	0.73	9.52	4.33	2.29	1.55	3.07
Calcium (g/m^2)						
Floating Mat/Metaphyton	4.2	40.4	44.7	43.6	89.7	108.3
Benthic Mat	7.3	99.7	167.7	72.5	145.7	136.5
Wall Mat	3.6	62.7	23.3	0.6	33.2	50.6
Total	15.1	202.9	235.8	116.8	268.5	295.4

AFDW biomass varied from a low of 101 g AFDW/m^2 in the shellrock dryout treatment (STC-6) to a high of 1,041 g AFDW/m^2 in the Porta-PSTA calcium-amended peat treatment (PP-13). AFDW biomass in shellrock treatments ranged from 101 to 219 g AFDW/m^2, while peat-based systems had average values between 330 and 1,041 g AFDW/m^2. AFDW biomass for the sand treatments was between 149 and 192 g AFDW/m^2, for the limerock treatment 115 g AFDW/m^2, from 171 to 918 g AFDW/m^2 in the Aquashade controls, and 175 to 287 g AFDW/m^2 in the non-substrate controls.

Final periphyton AFDW biomass, also measured in the final Porta-PSTA destructive sampling, was much lower in the peat-based treatment (PP-3) than in the other treatments and also much lower than that measured in the routine monthly cores (see Exhibit 2-7). As noted in the *Phase 1 Summary Report* (CH2M HILL, August 2000), the routine peat biomass estimates were high because of the unavoidable inclusion of some peat sediment in the samples.

Chlorophyll and phaeophytin values provide an estimate of the amount of photosynthetic matter present in the periphyton samples and avoid the sampling artifact for biomass estimation in the peat mesocosms. Average chlorophyll *a* densities ranged from 30 to 256 mg/m^2 in the shellrock treatments (Exhibit2-6). Average chlorophyll *a* production ranged from 63 to 206 mg/m^2 in the peat-based mesocosms, from 104 to 212 mg/m^2 in the sand treatments, from 39 to 96 mg/m^2 in the Aquashade controls, 120 mg/m^2 in the limerock treatment, and 156 to 246 mg/m^2 in the non-substrate controls. In an earlier analysis, chlorophyll *a* was found to strongly correlate with algal cell biovolume (CH2M HILL, 2000).

Average phaeophytin estimates were typically highest in the peat-based mesocosms, probably indicating that chlorophyll decomposition products were being incorporated in these samples with the surface peat soils.

A limited number of periphyton samples were collected from the Porta-PSTA walls during Phase 1 and in February 2001, during the final destructive sampling. Visual differences were apparent between mesocosms with and without high snail densities, with different water depths, and with different emergent macrophyte densities. The overall Phase 1 average AFDW biomass of wall periphyton was approximately 36 g AFDW/m^2 of wall. Biomass values were typically greater than 50 g AFDW/m^2 in the shellrock treatments, the sand treatments, and the Aquashade controls. Lower wall periphyton biomass amounts were obtained from Tank 1 (high snail density), Tank 15 (variable water depth), and Tank 14 (high macrophyte density). This observed wall periphyton biomass had a high algal component with an average chlorophyll *a* of approximately 56 mg/m^2, an algal biovolume of 125 cm^3/m^2, and cell count of approximately 79 billion cells/m^2. Final wall sampling in six Porta-PSTA treatments found that from 0.3 to 21.0 percent of the entire periphyton DW biomass and from 0.7 to 25.0 percent of the AFDW biomass was associated with wall periphyton (Exhibit 2-7).

Ash weight was a significant portion of the total dry weight in most periphyton samples, typically accounting for 40 to nearly 90 percent of the total dry biomass. As a result, PSTA periphyton are placed in the highly calcareous category according to the classification proposed by Browder et al. (1994) for Everglades periphyton.

Ash weight was a significant portion of the total dry weight. As a result, PSTA periphyton are placed in the highly calcareous category according to the classification proposed by Browder et al. (1994) for Everglades periphyton.

Time series trends for AFDW biomass and chlorophyll *a* are illustrated in Exhibits 2-3 to 2-5 for shellrock, peat, and other treatments, respectively. Shellrock mesocosms were at relatively constant AFDW biomass levels within 3 months of startup (see Exhibit 2-3). Except in the dry-out treatments, little seasonal variation in periphyton biomass was observed. Unlike AFDW biomass, chlorophyll *a* density continued to increase throughout the POR, except in the dry-out Test Cell treatment (STC-6). As described above, algal biovolume was highly variable in all of the shellrock treatments and did not display the clear increasing trend observed in the chlorophyll *a* results.

AFDW biomass for peat-based treatments is not displayed in Exhibit 2-4 because of the sampling problems described above. Chlorophyll *a* was higher in the peat-based Test Cell treatments than in the Porta-PSTAs. No apparent trend in these data was observed after a preliminary grow-in phase. Chlorophyll *a* estimates showed an apparent increasing trend in the other peat-based treatments.

Shellrock mesocosms were at relatively constant AFDW biomass levels within 3 months of startup.

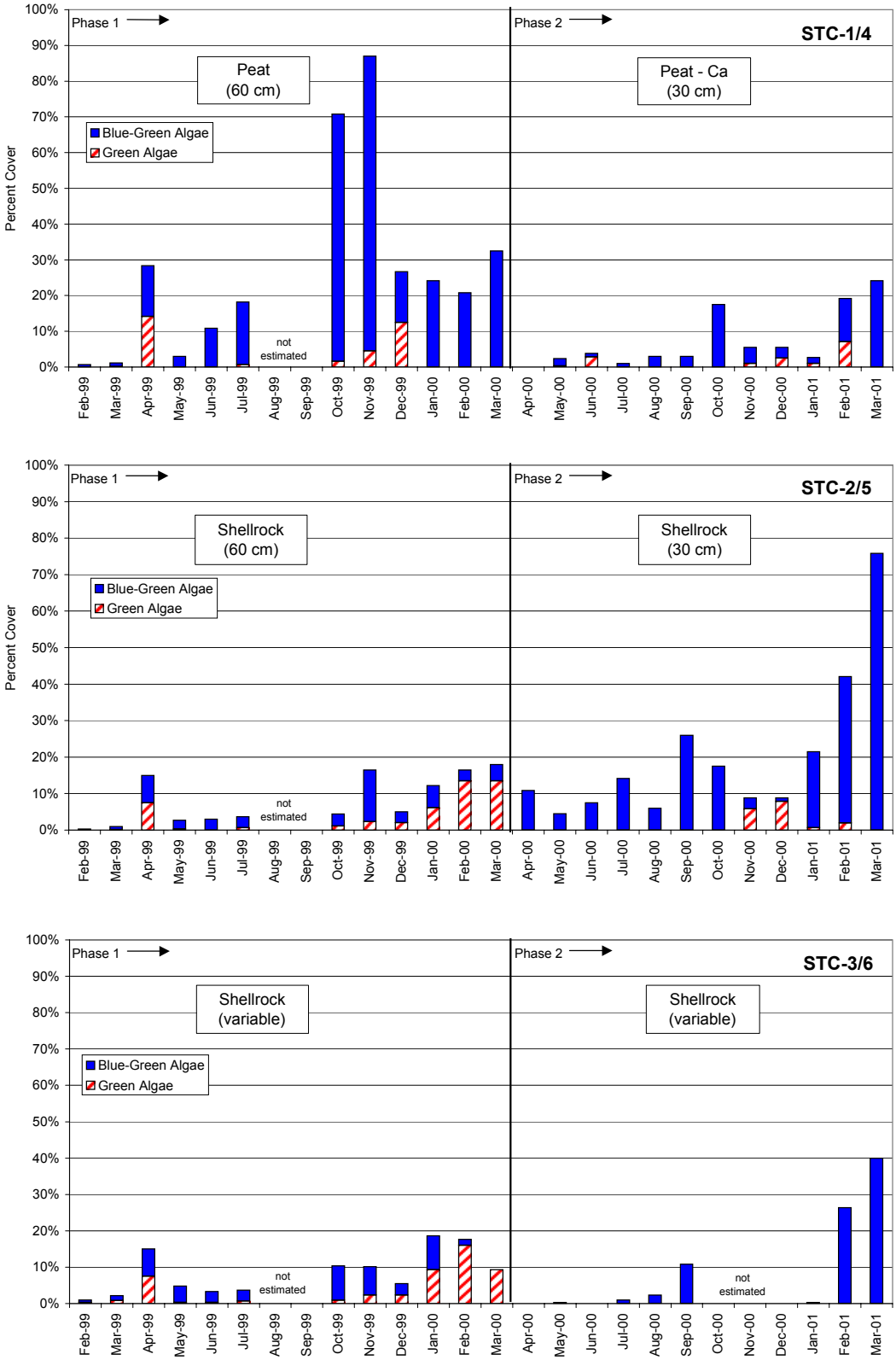
No apparent trend in the AFDW estimates was observed in the sand and non-substrate treatments, but chlorophyll *a* displayed an apparent increasing trend (see Exhibit 2-5).

In addition to the quantitative periphyton biomass and cell count samples, semi-quantitative estimates of percent algal mat cover were made. These estimates were made for floating algal mats and do not include submerged metaphyton or benthic algal mats. Therefore, these algal mat percent cover estimates are only an indicator of the prevalence of floating periphyton in these systems. Floating mats were visually recorded by blue-green (grayish to bluish-green) and green (bright green) algal dominance.

Exhibit 2-8 illustrates the algal mat percent cover monthly estimates for the three PSTA Test Cell treatments. Algal mat percent cover was typically dominated by blue-greens rather than greens. Algal mat percent cover increased more rapidly in the peat treatment than in the two shellrock treatments and then was re-started during the second project phase. Algal mat percent cover was higher in the shellrock treatment during the second year than during the first year. In the dry-out shellrock treatment the algal mat percent cover was clearly reduced by each of the two dry outs.

EXHIBIT 2-8

Monthly Algal Mat Percent Cover Estimates in the PSTA Test Cells



2.2.5 Periphyton Chemical Storages and Composition

Concentrations of calcium, P, and N were routinely measured in the periphyton samples. Exhibit 2-6 summarizes data for calcium, P (total and total inorganic), and total Kjeldahl nitrogen (TKN) content of the periphyton. Average periphyton calcium content ranged from 66 to 300 g/m^2, which was confirmed by the final destructive sampling in selected Porta-PSTA treatments (range of final average values from 15 to 295 g/m^2) (see Exhibit 2-7).

Average periphyton TP ranged from 93 to 1,055 mg/m^2, and total inorganic phosphorus (TIP) ranged from 19 to 458 mg/m^2. Final destructive sampling generally confirmed this range of TP values (95 to 626 mg/m^2); however, TIP had a much lower range (0.73 to 9.5 mg/m^2). Average periphyton TKN mass ranged from approximately 0.66 to 16.1 g/m^2.

Exhibit 2-9 presents time-series plots of the concentrations of these elements in the periphyton core samples from selected treatments during the POR. Periphyton calcium concentrations were relatively consistent between approximately 50 and 300 g/kg (5 to 30 percent).

Calcium concentrations were generally slightly greater in periphyton in shellrock treatments than in organic soil and sand treatments.

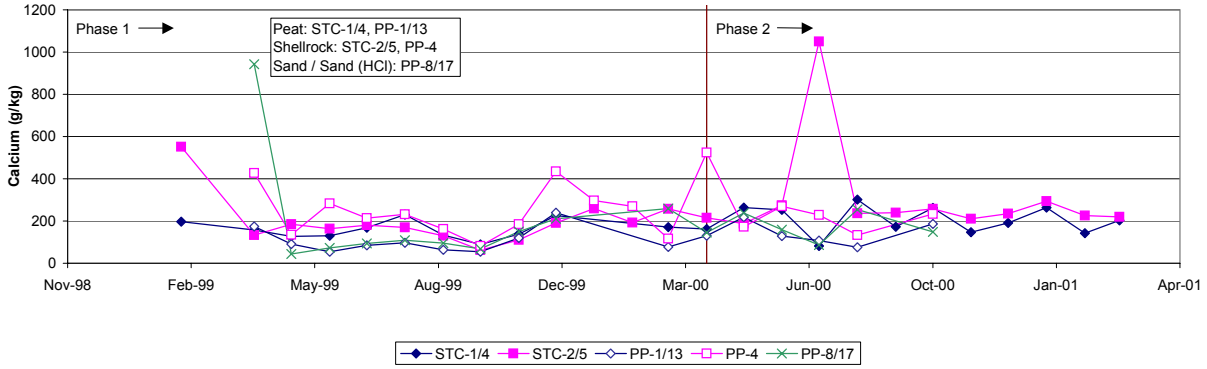
Calcium is relatively abundant in the EAA runoff with average inflow concentrations of 69 mg/L at the South ENR Test Cells and 60 mg/L at the Porta-PSTA mesocosm site. Calcium is important in P dynamics because of its potential for co-precipitation with P as a result of periphyton metabolism (Browder et al., 1994). Calcium concentrations were generally slightly greater in periphyton in shellrock treatments than in organic soil and sand treatments. Average calcium content on a DW basis increased from approximately 20 percent during Phase 1 to 30 percent during Phase 2 in the shellrock PSTA Test Cell (STC-2/5); in the peat Test Cell (STC-1/4), average calcium content increased from 16 to 20 percent. Average periphyton calcium concentration was approximately 10 to 14 percent in the Porta-PSTA peat treatments, 22 to 28 percent in the shellrock treatments, 17 to 20 percent in the sand treatments, and 22 percent in the limerock treatment. Calcium content of periphyton in the non-soil controls was 21 percent. Calcium in the periphyton of selected Porta-PSTAs was inventoried in February 2001 as part of the destructive sampling (CH2M HILL, August 2001). Average calcium content was 15 percent in the peat treatment, 22 percent in the shellrock treatment, 11 percent in the sand treatment, and 23 to 24 percent in the treatments without soils. The wall and floating mat periphyton typically had two to three times as much calcium as the benthic periphyton in these systems, except for the non-soil controls where the concentrations were approximately equal.

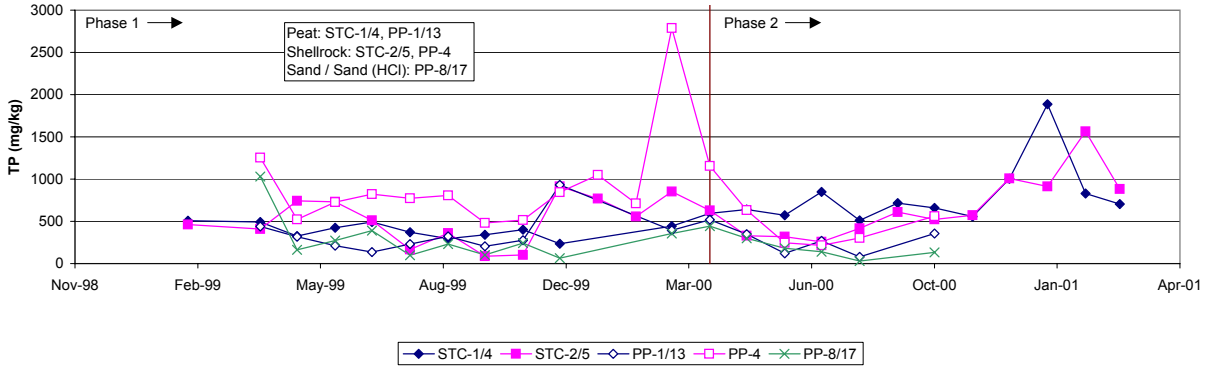
Periphyton TP and TIP time series data are presented in Exhibit 2-9 for representative Test Cells and Porta-PSTA treatments. Monthly periphyton TP estimates were typically lowest in the peat and sand treatments and highest in

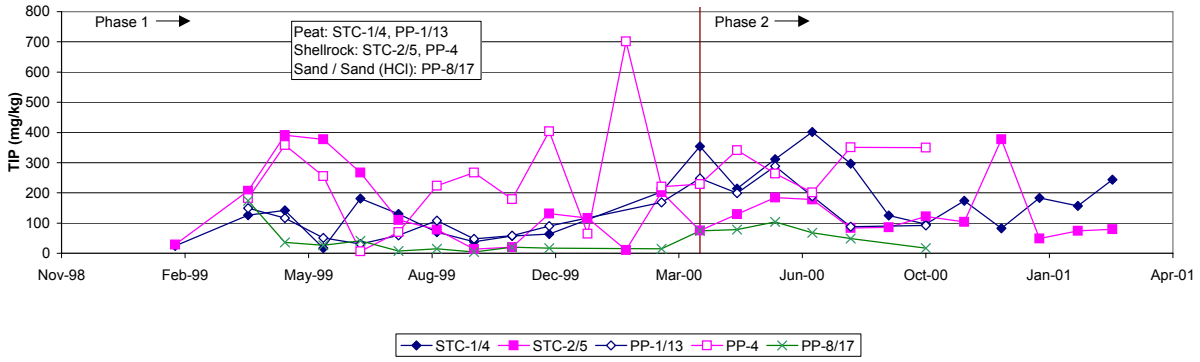
EXHIBIT 2-9

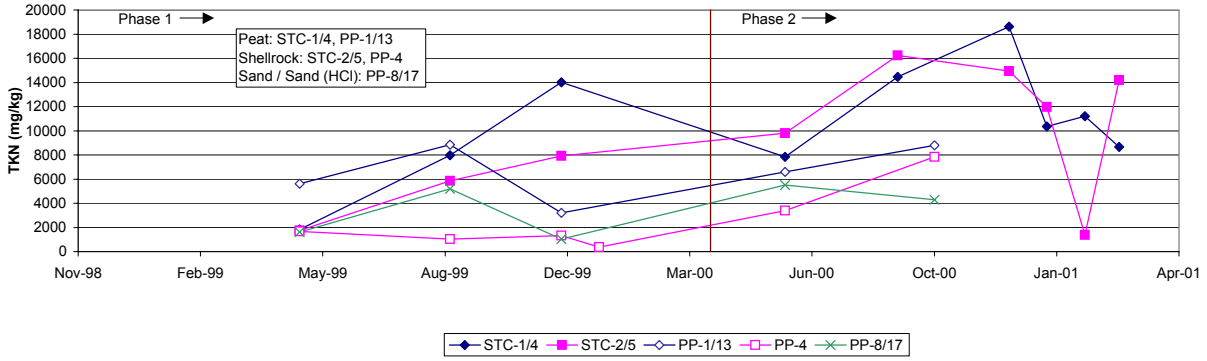
Trends for Calcium, TP, TIP, and TKN in Periphyton Samples from Selected PSTA Mesocosms

(STC-1/4 and PP-1/13: Peat/Peat (Ca); STC-2/5 and PP-2: Shellrock; PP-14: Limerock; PP-8/17: Sand/Sand (HCl,









the shellrock treatments. No consistent trend in periphyton P concentrations was observed; however, an increasing trend was apparent for some treatments. Average TP concentrations for shellrock treatments were between 554 and 1,440 mg/kg, and average TIP ranged from 212 to 479 mg/kg. In the peat treatments, the average TP in the periphyton ranged from 346 to 793 mg/kg, and TIP ranged from 88 to 220 mg/kg. TP in the sand treatment ranged from 205 to 385 mg/kg, and TIP averaged 36 to 65 mg/kg. Final destructive sampling in selected Porta-PSTAs in February 2001 found an average of 561 mg/kg TP in the peat treatment, 435 mg/kg in the shellrock treatment, 289 mg/kg in the sand treatment, and 223 to 230 mg/kg in the non-soil treatments. Final TIP concentration was 94 mg/kg in the peat treatment, 180 mg/kg in the shellrock treatment, 21 to 41 mg/kg in the sand treatments, and 43 to 72 mg/kg in the non-soil treatments. The benthic periphyton typically had higher TP and TIP concentrations than the wall and floating periphyton in these treatments, with the exception of the acid-rinsed sand treatment.

Monthly periphyton TP estimates were typically lowest in the peat and sand treatments and highest in the shellrock treatments. The benthic periphyton typically had higher TP and TIP concentrations than the wall and floating periphyton.

Time series data for periphyton TKN from selected PSTA treatments are also presented in Exhibit 2-9. TKN concentrations in the periphyton generally increased over time. Average TKN concentrations ranged from 5,889 to 21,242 mg/kg in the peat treatments, 1,462 to 11,425 mg/kg in the shellrock treatments, 2,614 to 4,897 mg/kg in the sand treatments, and 3,320 to 6,925 mg/kg in the non-soil treatments. These periphyton TKN averages are low for algae (typically greater than 1 to 3 percent or 10,000 to 30,000 mg/kg [Vymazal, 1995]) and provide an indication that a general lack of N availability may be contributing to low algal growth rates in these mesocosms (discussed in Section 2.5).

Time series data for periphyton TKN from selected PSTA treatments provide an indication that a general lack of N availability may be contributing to low algal growth rates in these mesocosms.

2.2.6 Algal and Suspended Solids Export

Algal export can be estimated from measurements of total suspended solids (TSS) in the outflow from the PSTA mesocosms. Exhibit 2-10 summarizes the treatment means for inflow and outflow TSS during the operational period. Long-term average outflow TSS concentrations typically ranged from 2.3 to 6.3 mg/L. The average outflow TSS concentration was greater than the average inflow level for several treatments. The results of the diel sampling study conducted in selected Porta-PSTAs on October 5 and 6, 1999 (CH2M HILL, August 2000), indicated a living algal cell component in these exported solids. Based on this single diel study, no clear pattern of algal export as a function of the day-night cycle was observed.

EXHIBIT 2-10

Average Inflow and Outflow TSS Concentrations in the PSTA Mesocosms

Treatment	Phase	Substrate	Depth	HLR	Total Suspended Solids (mg/L)		
					In	Out	Net Change
PP-1	1	PE	D	L	2.0	3.7	-1.7
PP-2	1	SR	D	L	2.1	4.5	-2.4
PP-3	1, 2	PE	S	L	2.5	2.9	-0.4
PP-4	1, 2	SR	S	L	2.7	3.5	-0.8
PP-5	1	SR	D	H	2.0	3.2	-1.2
PP-6	1	SR	V	V	1.9	3.6	-1.6
PP-7	1, 2	SA	D/S	L	2.8	2.3	0.5
PP-8	1	SA	S	L	2.0	3.8	-1.8
PP-9	1	PE (AS)	D	L	1.7	4.1	-2.4
PP-10	1	SR (AS)	D	L	3.0	5.1	-2.1
PP-11	1, 2	SR	S	L	2.5	4.8	-2.3
PP-12	1, 2	PE	S	L	2.6	4.7	-2.1
PP-13	2	PE (Ca)	S	L	4.9	4.4	0.5
PP-14	2	LR	S	L	5.5	2.6	2.9
PP-15	2	SR	S	R	4.7	3.3	1.3
PP-16	2	SR	V	V	2.7	2.5	0.2
PP-17	2	SA (HCl)	S	L	4.0	3.1	0.9
PP-18	2	None	S	L	4.0	2.6	1.4
PP-19	2	AM	S	L	3.8	4.2	-0.4
STC-1	1	PE	D	L	3.0	2.7	0.3
STC-2	1	SR	D	L	3.1	4.0	-1.0
STC-3	1	SR	V	V	2.9	6.3	-3.5
STC-4	2	PE (Ca)	D	L	3.7	4.7	-1.0
STC-5	2	SR	D	L	3.4	3.8	-0.4
STC-6	2	SR	V	V	3.4	2.7	0.7

Notes:

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

2.3 Macrophyte Communities

Macrophyte invasion in PSTAs is likely to be greatest under antecedent conditions of relatively high available soil P (>5 to 10 mg/kg total labile P) and whenever inflow P concentrations are high (>30 to 50 µg/L). Under those conditions, larger-scale PSTA systems are not likely to remain free of macrophytes without significant intervention. It is less likely that macrophyte invasion and dominance will be a significant issue for PSTA operation and management under low soil P conditions and near the downstream end of a treatment train, where P concentrations have already been reduced to less than 15 to 20 µg/L.

Sparse macrophyte communities are likely to help maintain higher periphyton populations by providing attachment sites and anchoring against wind-induced periphyton movement. Existing periphyton-dominated plant communities in the Everglades invariably have associated macrophytes, typically spikerush (*E. cellulosa*) and bladderwort (*Utricularia* spp.). For these reasons, the PSTA Test Cell treatments were intentionally planted with spikerush and bladderwort. One goal of the PSTA project was to document the growth rate and density of these macrophytes, as well as other volunteer plant species, and to attempt to identify a macrophyte density and control strategy that optimizes periphyton development and overall system P removal performance.

Exhibit 2-11 summarizes the PSTA POR average macrophyte results. Detailed monthly data are provided in Appendices C and D. Cover numbers are visual estimates for comparison purposes and do not provide an exact assessment of total leaf cover. The routine biomass values summarized in Exhibit 2-11 are from plants collected in periphyton core samples. Live stems were visually estimated in the smaller mesocosms.

Average total macrophyte plant cover varied from as little as 0 to 2 percent in the non-soil and Aquashade treatments, to 124 percent in the shellrock Test Cell Treatment (STC-5). Macrophyte cover was typically highest in the peat-based Porta-PSTAs compared to the other soil treatments. Cover was dominated by spikerush because cattail seedlings were routinely pulled from the tank-based mesocosms. Submerged aquatic plants (chara and bladderwort) were typically less than 15 percent cover in the Porta-PSTAs, but were more prevalent in the PSTA Test Cells with average cover values ranging from 18 to 83 percent. In the mesocosms with macrophytes, average biomass varied from 3 to 582 g DW/m^2. Final destructive sampling in selected Porta-PSTAs found macrophyte biomass values of 688 g DW/m^2 for the peat treatment (PP-3), 381 g DW/m^2 for the shellrock treatment (PP-4), and from 225 to 253 g DW/m^2 for the sand treatments (PP-7 and PP-17) (CH2M HILL, August 2001). Above-and belowground macrophyte biomass was estimated in those treatments, with typically 23 to 32 percent of the DW biomass belowground.

Macrophyte cover was typically highest in the peat-based Porta-PSTAs compared to the other soil treatments.

EXHIBIT 2-11

PSTA Macrophyte Average Cover and Biomass Data for Period-of-Record

Treatment	Phase	Substrate	Depth	HLR	Emergent Macrophytes	Submerged Aquatic Plants	Total Macrophyte % Cover	Macrophyte Biomass (g/m^2)	No. Stems/m^2
PP-1	1	PE	D	L	13%	15%	27%	75	79
PP-2	1	SR	D	L	2%	11%	13%	19	7
PP-3	1, 2	PE	S	L	52%	2%	54%	294	299
PP-4	1, 2	SR	S	L	6%	2%	8%	53	55
PP-5	1	SR	D	H	7%	0%	7%	26	27
PP-6	1	SR	V	V	3%	5%	9%	15	18
PP-7	1, 2	SA	D/S	L	2%	0%	3%	130	26
PP-8	1	SA	S	L	1%	1%	2%	3	3
PP-9	1	PE (AS)	D	L	0%	0%	1%	--	0
PP-10	1	SR (AS)	D	L	0%	2%	2%	--	0
PP-11	1, 2	SR	S	L	14%	0%	14%	116	138
PP-12	1, 2	PE	S	L	60%	1%	62%	284	322
PP-13	2	PE (Ca)	S	L	4%	13%	17%	128	48
PP-14	2	LR	S	L	3%	0%	3%	37	19
PP-15	2	SR	S	R	30%	6%	36%	218	243
PP-16	2	SR	V	V	8%	0%	8%	82	142
PP-17	2	SA (HCl)	S	L	3%	0%	3%	30	37
PP-18	2	None	S	L	0%	0%	0%	--	0
PP-19	2	AM	S	L	0%	0%	0%	--	0
STC-1	1	PE	D	L	28%	76%	103%	582	--
STC-2	1	SR	D	L	15%	29%	44%	61	--
STC-3	1	SR	V	V	18%	18%	36%	55	--
STC-4	2	PE (Ca)	D	L	22%	78%	99%	283	--
STC-5	2	SR	D	L	41%	83%	124%	339	--
STC-6	2	SR	V	V	32%	28%	49%	121	--

Notes:

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

Macrophyte percent cover is visually estimated using semi-quantitative method.

Macrophyte biomass is estimated from periphyton core samples.

Stem counts are for live stems only.

Test Cell emergent macrophyte cover averaged between 15 and 41 percent. While spikerush accounted for most of this cover, volunteer cattails were a significant fraction of the total cover. Cattails were not controlled in any of the PSTA Test Cells during Phase 1. Cattails were pulled from the peat-based PSTA test cell between Phase 1 and Phase 2. Some herbicide control of cattails was conducted in all of the PSTA Test Cells during Phase 2.

Submerged aquatic plant cover in the PSTA Test Cells ranged from 18 to 83 percent. This volunteer SAV cover was dominated by hydrilla (*Hydrilla verticillata*), and the macro-algae chara [*Chara* sp.]. Some bladderwort was present in the PSTA Test Cells.

Macrophyte stem densities were also monitored in the Porta-PSTA treatments throughout the project. In the mesocosms with macrophytes, the number of live spikerush stems averaged from 3 to 322 stems/m^2. Peat-based mesocosms had average stem counts between 48 and 322 stems/m^2. Shellrock tanks had averages between 7 and 243 stems/m^2, and sand tanks had between 3 and 37 stems/m^2. Final stem counts in the peat and shellrock treatments (PP-3 and PP-4, respectively) in February 2001 found 158 live stems/m^2 in the peat and 89 stems/m^2 in the shellrock. Standing dead stems were also counted and included 364 stems/m^2 in the peat and 119 stems/m^2 in the shellrock.

Time series plots of live stem densities in the Porta-PSTAs are provided in Exhibit 2-12. It is important to note the differences in the vertical scales on these three exhibits. In shellrock treatments, stem densities typically remained less than 100 stems/m^2 during the first year but then continued to increase during Phase 2. The highest stem densities were approximately 100 to 300 stems/m^2 in the consistent 30-cm treatments, including the recirculation treatment. Stem densities increased more rapidly in the peat treatments with the consistent 30-cm water depths, leveling off at approximately 400 live stems/m^2 within approximately 6 months after startup and continuing through the end of the 18-month operational period. Macrophyte stem densities were not estimated in the PSTA Test Cells.

For the peat and shellrock PSTA Test Cell treatments, emergent macrophyte cover increased more rapidly in the peat treatment than in the shellrock treatment.

Exhibit 2-13 illustrates the time series trends in macrophyte cover for the peat and shellrock PSTA Test Cell treatments with stable water depths. Emergent macrophyte cover increased more rapidly in the peat treatment than in the shellrock treatment and was dominated by cattails. At the beginning of Phase 2, all of the cattail biomass in the peat treatment was removed when the treatment was re-started in March 2000. This allowed the shellrock treatment macrophyte cover to outstrip the peat cell for most of the second year of operation, but by the end of that period the peat cell emergent cover was comparable to the shellrock Test Cell.

EXHIBIT 2-12

Macrophyte Live Stem Counts for the Porta-PSTA Mesocosm Treatments

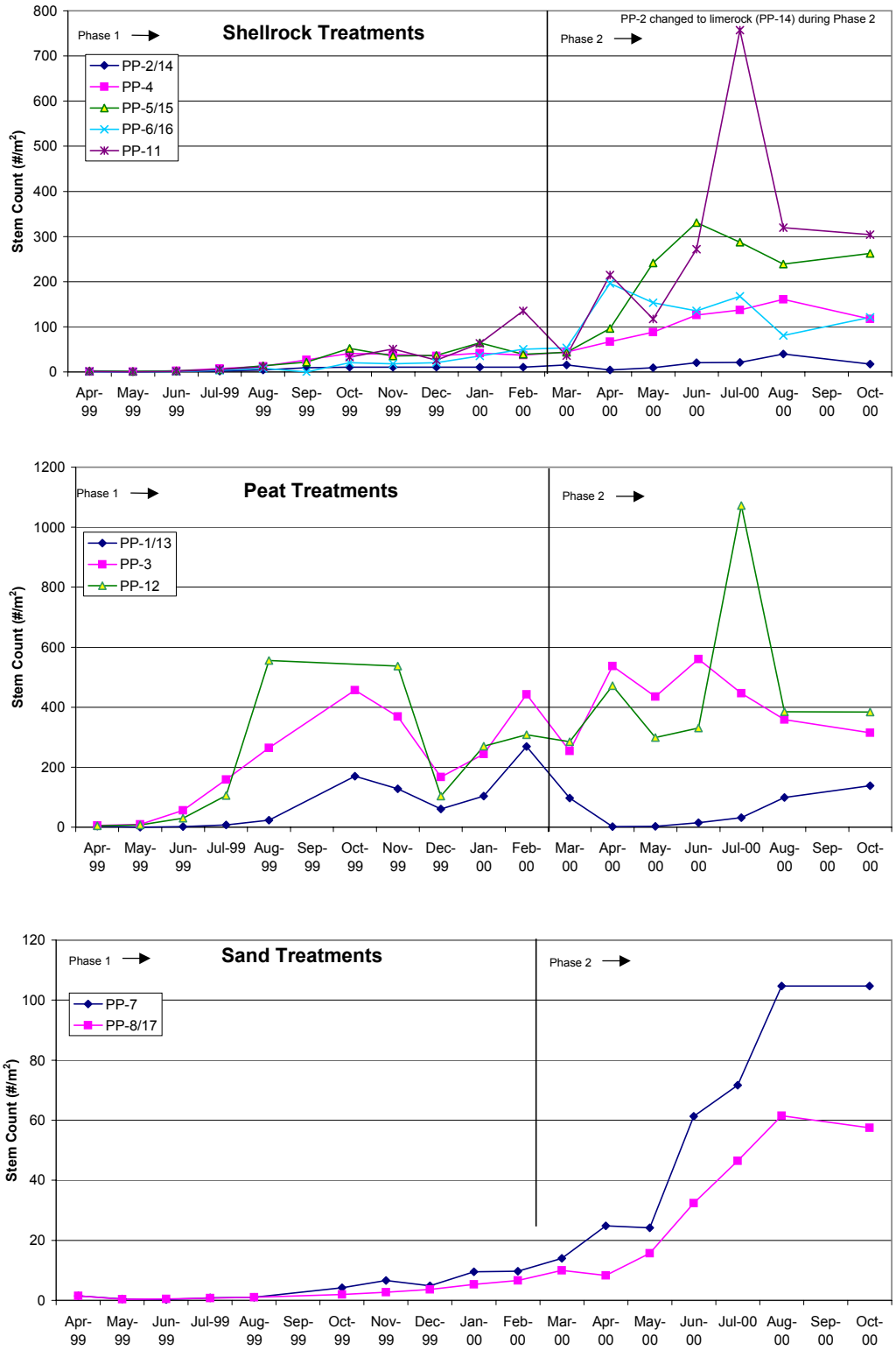
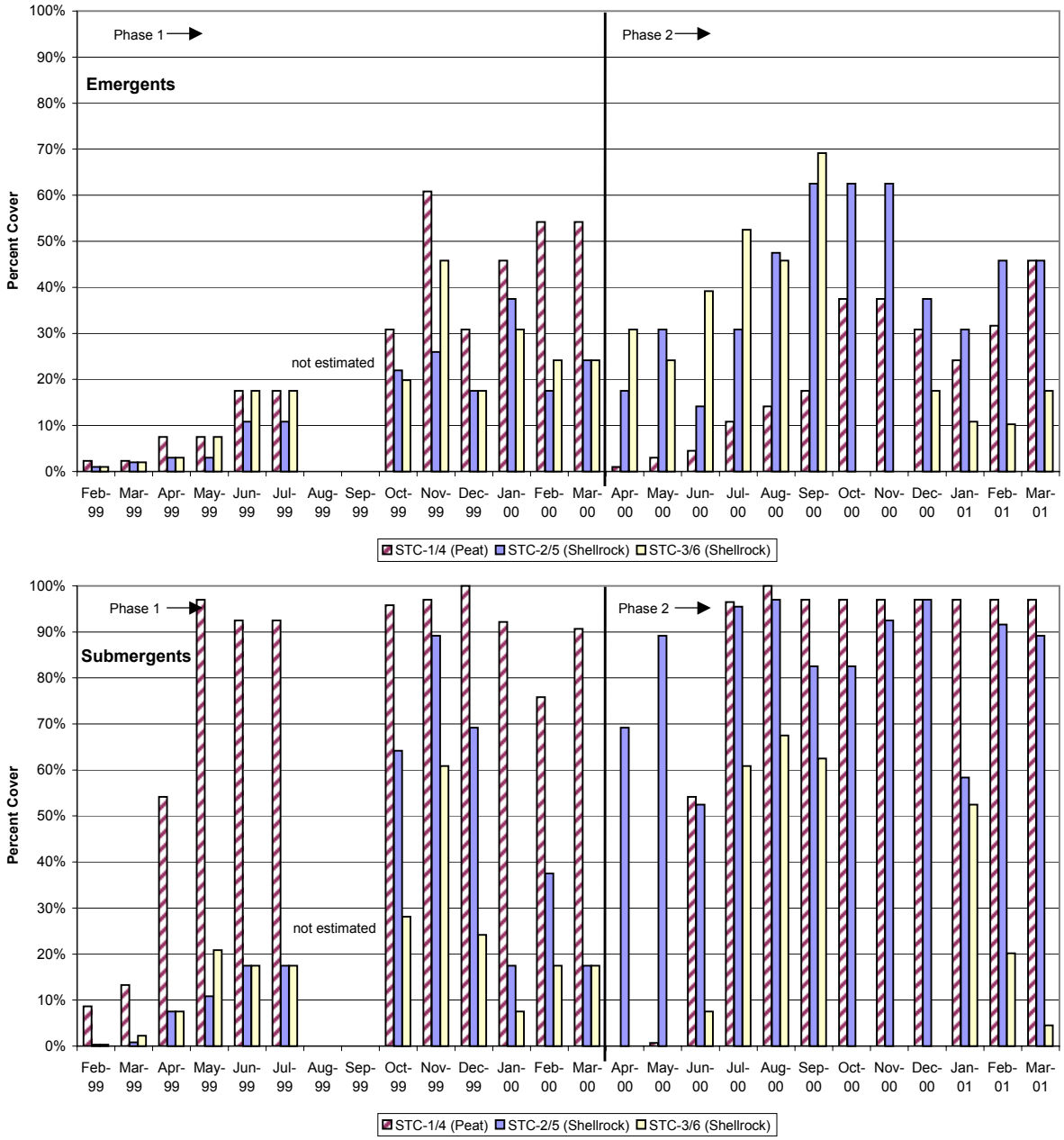


EXHIBIT 2-13

Macrophyte Plant Cover Estimates for the PSTA Test Cells



Submerged macrophyte cover estimates are also summarized for these two PSTA Test Cells in Exhibit 2-13. SAV rapidly invaded the 60-cm PSTA Test Cells during Phase 1, with the fastest growth by hydrilla in the peat-based test cell. It only took approximately 3 to 4 months for SAV to reach 90 percent or higher estimated cover in the peat-based PSTA Test Cells. By the end of the second year, both of these Test Cells were nearly completely colonized by SAV, with hydrilla dominant in the peat-based cell and chara in the shellrock cell.

Former agricultural soils in the peat-based mesocosms were extremely susceptible to rapid colonization by cattails from the seed bank, even under 2 feet of water, and from the spread of submerged aquatic plants introduced from the feed water from STA-1W.

A key finding from Phase 1 is that the former agricultural soils in the peat-based mesocosms were extremely susceptible to rapid colonization by cattails from the seed bank, even under 2 feet of water, and from the spread of submerged aquatic plants introduced from the feed water from STA-1W. Factors that appeared to reduced macrophyte colonization were the soil type (much slower on sand and shellrock than on the peat), water depth (faster emergent growth in shallow water than in deep water; faster SAV colonization in deeper water), and dry-out (significant emergent and SAV macrophyte cover decrease in treatment STC-6 during fall-winter dry-out).

2.4 Faunal Populations

There was minimal focus on the estimation of the faunal components of the PSTA mesocosms. However, many invertebrates and a few vertebrate animal species were observed in the mesocosms. The most visible consumers were two species of snails that attained significant population densities in a limited number of the Porta-PSTAs. In order of relative dominance, the two snail species were *Helisoma* spp. and *Physa* spp. Counts were conducted on five dates to quantify the snail population. Snails were counted and removed.

Exhibit 2-14 summarizes the results of these snail counts. All of the numbers in this exhibit are minimum estimates because of the difficulty of seeing all of the snails. Counts from March 2000 represent the populations of snails harvested from the mesocosms at the end of Phase 1. The highest average snail densities were measured in Porta-PSTA treatments PP-6/16 (variable water regime shellrock), PP-5/15 (high load/re-circulation shellrock), PP-8/17 (sand), and PP-12 (shallow peat). The highest average density was 77 snails/m^2 of bottom area. Average snail weights were determined for the March 2000 samples. The average snail weight was 0.29 g DW per snail. Based on this conversion, the highest snail biomass values averaged approximately 27 g DW/m^2 in PP-8 (60-cm sand) and more than 6 to 15 g DW/m^2 in the other tanks with high snail densities.

EXHIBIT 2-14
Porta-PSTA Snail Counts

						Sample Date												
						Oct-99		Nov-99		Dec-99		Mar-00		Jul-00		Averages		
Treatment #	Substrate	Depth	HLR	Tank #	Snail	Total by Species	Tank Total	Total by Species	Tank Total	Total by Species	Tank Total	Total by Species	Tank Total	Total by Species	Tank Total	By Species	Tank Total	Density #/m^2
1 / 13	PE / PE (Ca)	D / S	L / L	9	H	8	13	11	17	5	10	NS	0	9	9	8.3	9.8	1.63
					P	5		6		5		NS		0		4.0		
				11	H	6	8	3	4	0	7	NS	0	11	11	5.0	6.0	1.00
					P	2		1		7		NS		0		2.5		
				18	H	54	55	11	13	5	7	NS	0	0	0	17.5	15.0	2.50
					P	1		2		2		NS		0		1.3		
2 / 14	SR / LR	D / S	L / L	4	H	24	26	18	18	13	15	NS	0	12	14	16.8	14.6	2.43
					P	2		0		2		NS		2		1.5		
				7	H	4	4	1	1	0	0	NS	0	15	15	5.0	4.0	0.67
					P	0		0		0		NS		0		0.0		
				8	H	20	32	22	22	2	2	NS	0	14	14	14.5	14.0	2.33
					P	12		0		0		NS		0		3.0		
3	PE	S	L	12	H	28	30	3	4	8	8	22	26	20	20	16.2	17.6	2.93
					P	2		1		0		4		0		1.4		
				14	H	9	9	8	8	11	11	17	17	13	17	11.6	12.4	2.07
					P	0		0		0		0		4		0.8		
				17	H	72	75	44	65	15	36	42	49	48	62	44.2	57.4	9.57
					P	3		21		21		7		14		13.2		
4	SR	S	L	3	H	0	1	0	0	0	0	0	0	54	57	10.8	11.6	1.93
					P	1		0		0		0		3		0.8		
				5	H	0	1	0	0	0	0	0	0	63	64	12.6	13.0	2.17
					P	1		0		0		0		1		0.4		
				10	H	0	0	0	0	2	2	81	81	142	142	45.0	45.0	7.50
					P	0		0		0		0		0		0.0		
5 / 15	SR / SR	D / S	H / R	2	H	5	5	7	33	1	2	31	33	11	11	11.0	16.8	2.80
					P	0		26		1		2		0		5.8		
				13	H	152	156	68	76	17	18	248	258	37	40	104.4	109.6	18.27
					P	4		8		1		10		3		5.2		
				16	H	1	3	0	0	0	0	0	0	0	13	0.2	3.2	0.53
					P	2		0		0		0		13		3.0		
6 / 16	SR / SR	V / V	V / V	1	H	0	0	417	454	230	232	201	201	163	193	202.2	216.0	36.00
					P	0		37		2		0		30		13.8		
				6	H	345	382	353	360	207	211	301	301	21	21	245.4	255.0	42.50
					P	37		7		4		0		0		9.6		
				15	H	1	1	0	0	0	0	0	0	17	19	3.6	4.0	0.67
					P	0		0		0		0		2		0.4		
7	SA	D / S	L	19	H	6	7	0	2	0	0	0	0	6	6	2.4	3.0	0.50
					P	1		2		0		0		0		0.6		
8 / 17	SA / SA (HCl)	S / S	L / L	20	H	555	1143	571	594	502	509	NS	0	71	75	424.8	464.2	77.37
					P	588		23		7		NS		4		155.5		
9 / 18	PE (AS) / None	D / S	L / L	21	H	2	8	ND	ND	7	8	NS	0	NS	0	4.5	4.0	0.67
					P	6		ND		1		NS		NS		3.5		
10 / 19	SR (AS) / AM	D / S	L / L	22	H	1	2	ND	ND	0	0	NS	0	NS	0	0.5	0.5	0.08
					P	1		ND		0		NS		NS		0.5		
11	SR	S	L	23	H	7	7	4	4	4	21	106	120	NS	0	30.3	30.4	5.07
					P	0		0		17		14		NS		7.8		
12	PE	S	L	24	H	97	98	97	98	36	36	126	144	NS	0	89.0	75.2	12.53
					P	1		1		0		18		NS		5.0		
						Total	2066	**Total**	1773	**Total**	1135	**Total**	1230	**Total**	803			

Note:
Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade
Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)
HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate
NS = not sampled, dry tank
ND = not determined (not visable)
H = *Helisoma* spp.
P = *Physa* spp.

High snail densities were observed to dramatically modify the periphyton macroscopic structure. Wall and benthic periphyton mats were nearly eliminated in the tanks with high snail counts. No similar snail population increases were observed in the Test Cell PSTA mesocosms. More attention should be paid to this trophic level during continuing PSTA research and development efforts.

These high snail densities were observed to dramatically modify the periphyton macroscopic structure. Wall and benthic periphyton mats were nearly eliminated in the tanks with high snail counts. Coherent periphyton mats were replaced by a flocculent collection of snail castings. The effects of this high snail productivity on P removal are discussed in Section 3.

No similar snail population increases were observed in the Test Cell PSTA mesocosms, and it is currently hypothesized that this phenomenon may be an effect of the relatively small scale of the Porta-PSTAs and the resulting absence of a snail predator population. Optimal snail grazing is thought to maximize primary productivity in adapted spring ecosystems in Florida (Knight, 1983). Higher consumer levels must regulate snail densities to provide this stimulatory effect. The PSTA observation that snail density can significantly affect periphyton viability indicates that more attention should be paid to this trophic level during continuing PSTA research and development efforts.

2.5 Community Metabolism/Productivity

Aquatic ecosystems contain numerous biological processes that consume and produce DO. The oxygen-consuming processes are referred to as community respiration (CR) and include cellular metabolism and decomposition processes. The oxygen-producing processes are referred to as primary productivity and include photosynthetic activities of submerged algae and plants in response to PAR or the input of light that can be used by the plants. These community-level metabolism measurements are indispensable for determining turnover of this ecological community.

Periphyton gross and net production have been routinely measured based on upstream-downstream diurnal DO profiles, corrected for atmospheric diffusion (Odum, 1956; Odum and Hoskins, 1957). These oxygen changes must be corrected for the effects of diffusion of oxygen into or out of the water column. Diffusion rate was not measured in the PSTA mesocosms until Phase 2. A value of 0.1 g $O_2/m^2/hr$ was initially used for correcting observed changes in the Phase 1 report (CH2M HILL, 2000). This is a typical diffusion rate observed under relatively low flow conditions. Floating-dome diffusion studies were conducted in several of the Porta-PSTA and PSTA Test Cell mesocosms during Phase 2 (CH2M HILL, 2001a). Diffusion rates were found to be affected by nominal velocity and mesocosm size. Average diffusion rates used for correction of metabolism data for this final report are:

- Porta-PSTAs = 0.005 g $O_2/m^2/hr$
- Porta-PSTA with re-circulation = 0.011 g $O_2/m^2/hr$
- PSTA Test Cell = 0.009 g $O_2/m^2/hr$

Changes in DO content of the water column during a daily period can be used to estimate the processes of CR and photosynthesis. The combination of respiration and photosynthesis is called community metabolism (CM). This is also equal to gross primary production (GPP), a measure of the total oxygen fixed by the ecosystem. Respiration continues throughout the daylight and nighttime hours and is reported as CR. The difference between CM or GPP and CR is called net primary production (NPP). NPP can be reported for the full 24-hour day or just for the daylight portion (NPP day). The 24-hour NPP is an estimate of the accumulation of fixed organic matter. The approximate conversion between oxygen and carbon is 1:1 (Odum, 1971). The conversion between oxygen and AFDW is approximately 1:2. GPP is sometimes expressed as an efficiency by dividing the GPP converted to kilocalories (kcal) assuming a conversion of approximately 10 kcal/g O_2 (Odum, 1971) and converting PAR to kcal by the assumption that one Einstein (mole of photons) is equal to 52.27 kcal. It is important to note that CM estimates do not include above-water productivity or respiration. However, they include respiration by emergent macrophyte roots and sediment oxygen demand.

Exhibit 2-15 summarizes the ecosystem metabolism estimates for all of the PSTA treatments for the POR. On the basis of these measures of primary productivity, relatively low net production is implied in spite of the visually observed and well-documented biomass production. High sediment oxygen demand is suggested.

On the basis of these measures of primary productivity, relatively low net production is implied in spite of the visually observed and well-documented biomass production. High sediment oxygen demand is suggested.

Long-term average GPP ranged from 1.76 to 2.91 g $O_2/m^2/d$ in the peat-based mesocosms. However, average estimated NPP ranged from -0.18 to 0.02 g $O_2/m^2/d$ in these peat-based mesocosms. This negative to zero net production, in spite of the clear net production of plant biomass in these mesocosms, indicates that the peat soils were resulting in a sediment oxygen demand and root respiration. The P:R ratio, an indication of the autotrophic:heterotrophic nature of the ecosystems in the mesocosms, was typically close to 1.0 in the peat tanks. This is another indication of the heterotrophic dominance in these tanks, possibly from oxidation of peat soils. Ecological efficiencies ranged from approximately 1.0 to 1.7 percent in these peat-based mesocosms.

Long-term average GPP ranged from 1.01 to 3.34 g $O_2/m^2/d$ in the shellrock-based mesocosms. Average NPP ranged from -0.18 to 0.04 g $O_2/m^2/d$. In sharp contrast to Phase 1 when there was a positive net productivity in all of the shellrock treatments, little to no net production was indicated in any of these treatments over the entire POR. The P:R ratio in the shellrock mesocosms ranged from 0.42 to 1.02 in the shellrock mesocosms. Ecological efficiencies ranged

EXHIBIT 2-15

PSTA Community Metabolism Data

Treatment	Phase	Substrate	Depth	HLR	GPP (day) $g/m^2/d$	CR (24) $g/m^2/d$	P/R Ratio	NPP (24hr) $g/m^2/d$	PAR (24hr) $mol/m^2/d$	Efficiency %
PP-1	1	PE	D	L	2.649	2.631	1.01	0.018	34.8	1.5
PP-2	1	SR	D	L	1.010	2.391	0.42	0.002	34.1	0.6
PP-3	1, 2	PE	S	L	1.756	1.804	0.97	-0.048	33.1	1.0
PP-4	1, 2	SR	S	L	3.342	3.368	0.99	-0.027	34.7	1.8
PP-5	1	SR	D	H	2.922	2.897	1.01	0.025	35.3	1.6
PP-6	1	SR	V	V	1.957	1.921	1.02	0.036	32.3	1.2
PP-7	1, 2	SA	D/S	L	2.584	2.536	1.02	0.047	31.4	1.6
PP-8	1	SA	S	L	1.508	1.404	1.07	0.105	25.9	1.1
PP-9	1	PE (AS)	D	L	0.350	0.669	0.52	-0.035	36.5	0.2
PP-10	1	SR (AS)	D	L	0.391	1.124	0.35	0.066	36.4	0.2
PP-11	1, 2	SR	S	L	2.802	2.836	0.99	-0.034	29.4	1.8
PP-12	1, 2	PE	S	L	1.942	2.074	0.94	-0.132	33.9	1.1
PP-13	2	PE (Ca)	S	L	2.156	2.236	0.96	-0.079	33.9	1.2
PP-14	2	LR	S	L	3.387	3.359	1.01	0.028	32.9	2.0
PP-15	2	SR	S	R	1.301	1.363	0.95	-0.062	33.4	0.7
PP-16	2	SR	V	V	2.435	2.464	0.99	-0.029	32.8	1.4
PP-17	2	SA (HCl)	S	L	3.119	3.004	1.04	0.115	35.9	1.7
PP-18	2	None	S	L	1.989	2.015	0.99	-0.026	35.5	1.1
PP-19	2	AM	S	L	1.870	1.830	1.02	0.039	35.5	1.0
STC-1	1	PE	D	L	2.908	3.065	0.95	-0.157	34.3	1.6
STC-2	1	SR	D	L	3.005	3.034	0.99	-0.015	34.9	1.6
STC-3	1	SR	V	V	2.263	2.271	1.00	-0.008	35.5	1.2
STC-4	2	PE (Ca)	D	L	2.418	2.757	0.88	-0.179	27.6	1.7
STC-5	2	SR	D	L	1.955	2.634	0.74	-0.176	29.9	1.3
STC-6	2	SR	V	V	2.943	2.961	0.99	-0.018	30.7	1.8

Notes:

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

from approximately 0.6 to 1.8 percent in these mesocosms. Sediment oxygen demand and decomposition of initial soil organic matter may also be indicated by these data.

The sand-based mesocosms had similar GPP rates to the other treatments and consistently positive NPP rates, probably indicating less sediment or root oxygen demand in these relatively clean (organic-matter-free) soils. The Aquashade control metabolism rates are of special interest. Low GPP rates in these tanks (0.35 to 0.39 g $O_2/m^2/d$) confirm their low levels of algal productivity, but relatively high CR rates (0.67 to 1.12 g $O_2/m^2/d$) indicate the presence of an active microbial community. The P:R ratios in these tanks (0.35 to 0.52) are indicative of a strongly heterotrophic community.

Exhibits 2-16 to 2-18 illustrate the temporal pattern of ecosystem metabolism in selected PSTA treatments. GPP (below water) in the peat soil mesocosms generally declined as macrophyte cover increased. This equated to an increasingly negative NPP in STC-1/4 and PP-3. When the emergent plants were removed from STC-4 at the beginning of Phase 2, the GPP instantly rebounded to high levels. As submerged macrophytes re-colonized this mesocosm (see Exhibit 2-13), the GPP quickly rebounded but again dropped off as emergent percent cover gradually increased. The GPP of the shellrock treatments shown in Exhibit 2-16 followed the annual solar cycle. It is interesting to note that NPP rates and the P:R ratio in the PSTA Test Cells appeared to decline during the last 8 months of the project. This appears to be a result of decreasing GPP during the fall/winter period.

Exhibit 2-17 illustrates that GPP was higher in the limerock treatment than in the non-soil treatments. NPP was not very different between these treatments, and the P:R ratio averaged around 1.0 for limerock and non-soil control tanks. Exhibit 2-18 presents the community metabolism data for the variable water regime PSTA treatments. GPP and NPP appeared to increase following the first dry-out in late spring and declined after the fall/winter dry-out. The P:R ratio was typically near 1.0 for these treatments.

The GPP rates measured in this PSTA research were similar to values measured in WCA-2A (Duke, 1995) and elsewhere in the Everglades (Browder et al., 1994). Duke (1995) reported a range of GPP estimates between 5 and 14 g $O_2/m^2/d$ in WCA-2A. Browder et al. (1994) summarized GPP data for a variety of Everglades periphyton studies that gave ranges between minimum and maximum values approximately 0.4 to 14 g $O_2/m^2/d$. Typical average GPP values measured in the Everglades are approximately 1 to 5 g $O_2/m^2/d$.

2.6 Summary of PSTA Viability

The PSTA mesocosms tested during this research and development effort met all of the criteria of viability. Normal periphyton algal species assemblages typical of low-P Everglades waters became established in the tank and Test Cell mesocosms. Mesocosms displayed understandable community-level responses

EXHIBIT 2-16

Temporal Pattern of Community Metabolism in Peat and Shellrock PSTA Treatments

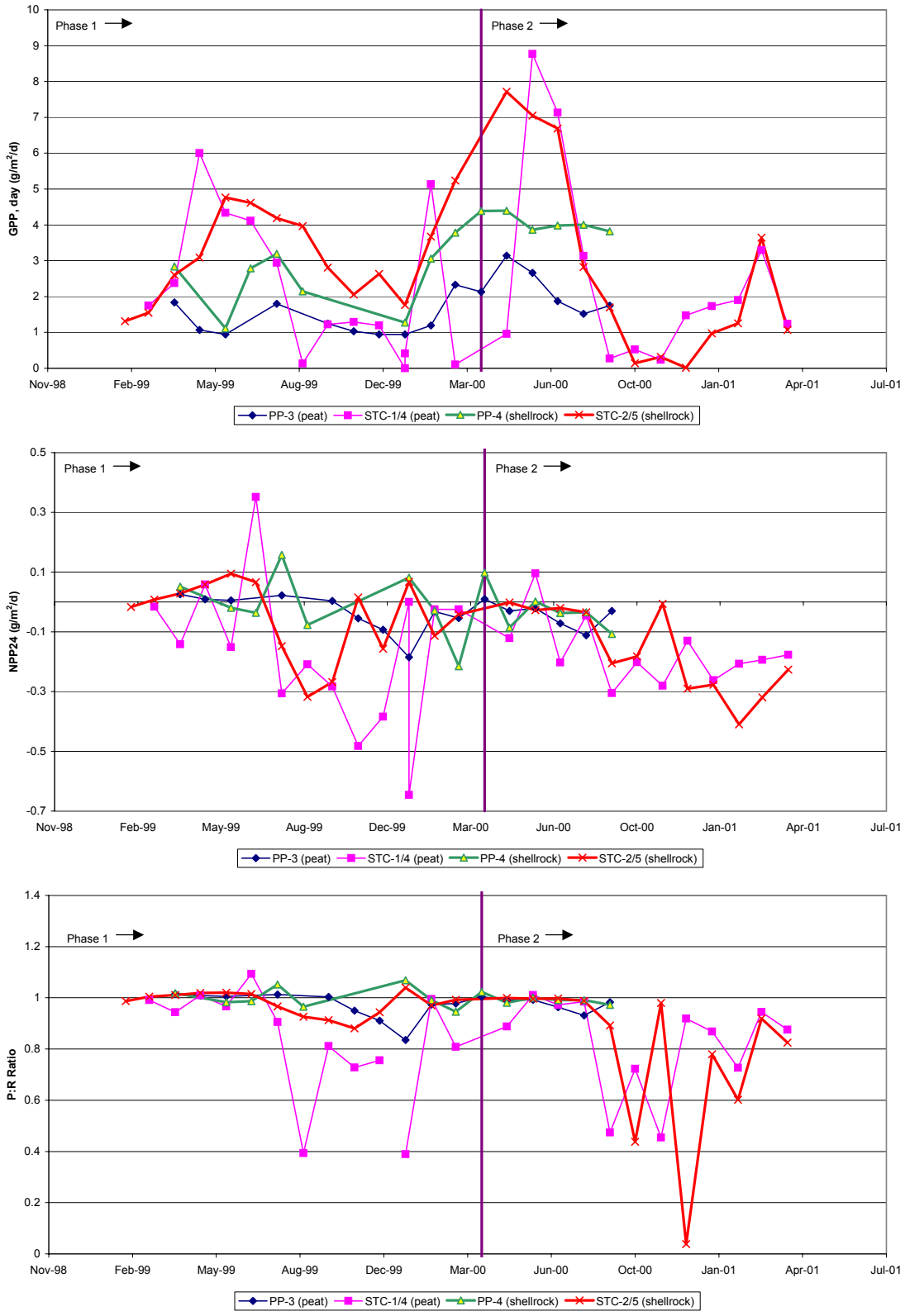
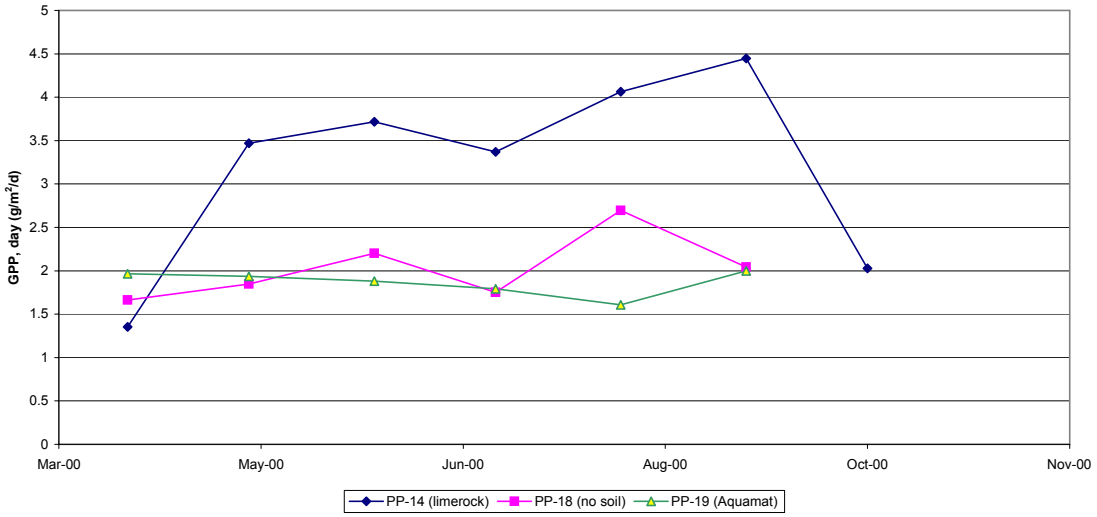
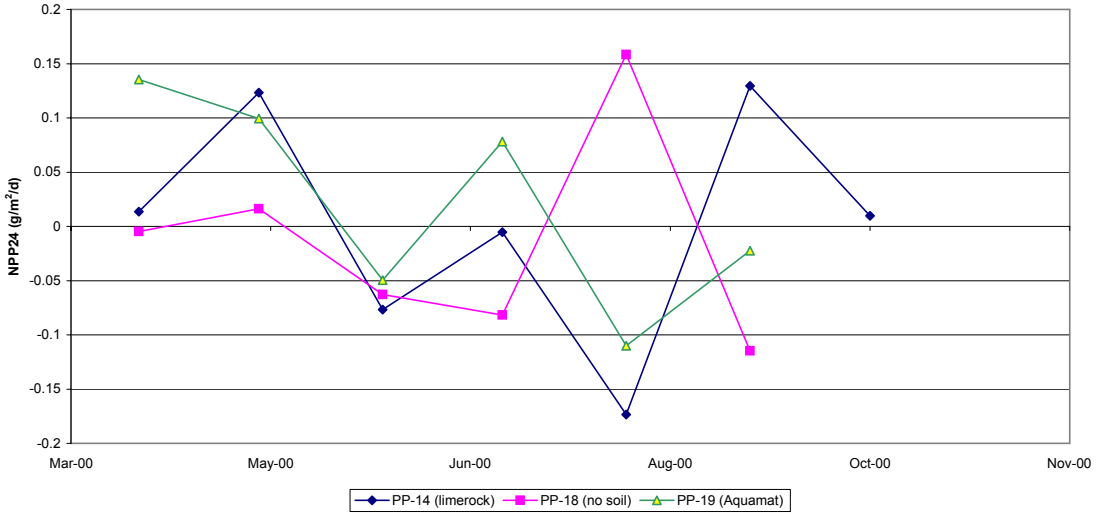


EXHIBIT 2-17

Temporal Pattern of Community Metabolism in Limerock, No Substrate, and Aquamat PSTA Treatments during Phase 2





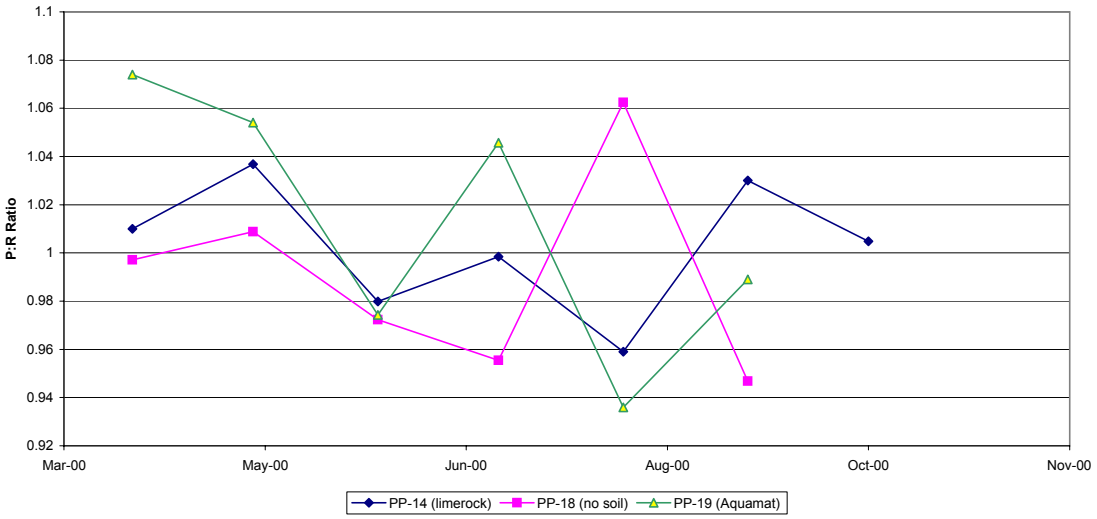
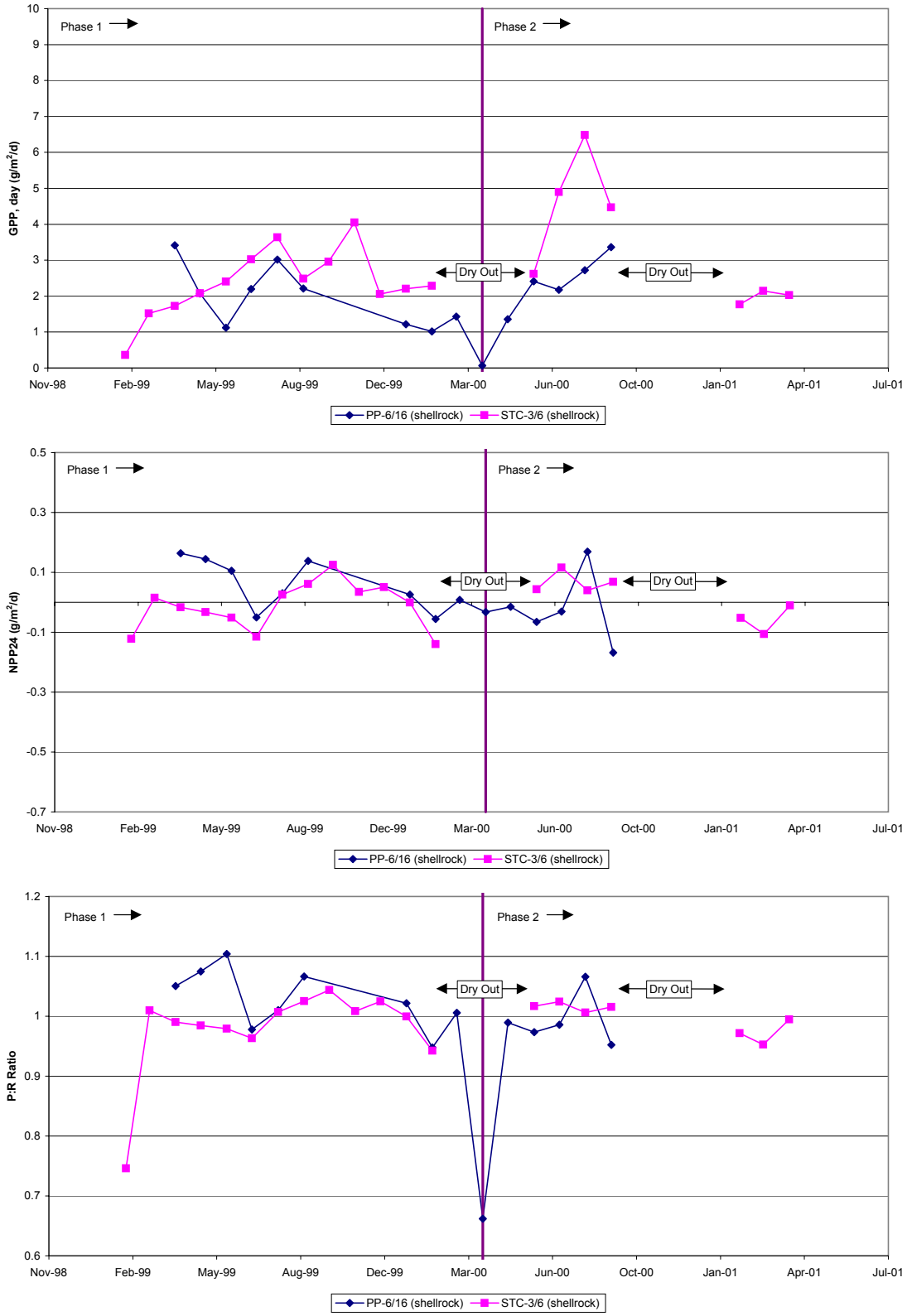


EXHIBIT 2-18

Temporal Pattern of Community Metabolism in Variable Water Depth PSTA Treatments



to environmental forcing functions, such as sunlight and antecedent soil chemistry, interacted with macrophyte plant communities in predictable ways, and contained faunal components that are important in elemental cycling and community structure.

This research effort demonstrated that a periphyton-dominated ecosystem can be established in less than 1 year. Invasion by emergent macrophytes, both desirable and undesirable species, is problematic but not insurmountable. Use of low-P antecedent soils reduced the rate of macrophyte colonization. Water depth control (increased water levels to lower macrophyte growth rates) is another tool that might be useful for decelerating the rate of emergent macrophyte growth. Both emergent and submerged macrophytes are not likely to be favored in PSTAs at the low end of the P concentration gradient. Although a large periphyton biomass quickly developed on peat (organic) soils, it was relatively quickly dominated by volunteer or planted emergent and submerged macrophytes. For this reason, use of un-amended peat soils with high antecedent labile P content will likely require the greatest level of management to support a periphyton-dominated plant community. Soil selection for PSTA development is a cost issue, either initially to avoid unsuitable soils or during operation to control emergent macrophytes that tend to mine P from the soils and inhibit periphyton dominance.

On inorganic soils such as shellrock and sand, the resulting periphyton community was viable after less than 1 year of development, and was similar in composition to natural Everglades periphyton communities. Such inorganic-soil-based communities also maintained an acceptable partial cover of emergent macrophytes with fewer cattails. High periphyton biomass and density was compatible with the spikerush densities measured in the PSTA shellrock-based Test Cells. However, a shellrock mesocosm with dry-out was the most viable-appearing PSTA at the end of Phase 2 because of reduced cover by both emergent and submerged macrophytes.

SECTION 3

Phosphorus Removal Performance and Effectiveness

3.1 Introduction

A primary objective of the PSTA Research and Development Project is to determine the effectiveness of this type of plant community for reduction of P loads to downstream surface waters. For the PSTA concept to be viewed as a useful P advanced treatment technology, it must be able to reduce concentrations and mass of TP in a predictable fashion. This P removal effectiveness must be predictable and repeatable based on specific design criteria, such as wetted area, substrate type, water depth, and flow rate. The main factors that control PSTA performance must be known to allow defensible evaluation of the cost of full-scale implementation.

To be considered optimally effective, PSTAs must be able to:

- Lower average concentrations of TP to levels protective of downstream wetland and aquatic ecosystems. The planning-level target is 10 µg/L TP.
- Reduce P mass load at a high enough rate to allow full-scale implementation within a realistic footprint.
- Perform TP removal in a predictable fashion that allows for successful design and reliable performance.
- Provide treatment under varying input load conditions.
- Recover from drought or flood conditions and return to a high level of performance within a reasonable time frame.
- Continue to perform into the foreseeable future with an affordable level of routine maintenance.

This section summarizes the Phase 1 and 2 project findings related to the effectiveness of PSTA for P reduction in agricultural runoff.

3.2 Phosphorus Inflow Concentrations

Exhibit 3-1 summarizes the average data for various forms of P in the inflows to the PSTA mesocosm test systems for the POR. The average inflow TP at the PSTA Test Cells was 23.0 µg/L, while the average inflow TP at the Porta-PSTAs was 25.7 µg/L. On average, approximately 50 to 62 percent of this TP was in the dissolved form, and the remainder was particulate P. Average dissolved reactive phosphorus (DRP) was 5.3 µg/L at the PSTA Test Cells and 6.1 µg/L at the Porta-PSTAs.

The average inflow TP at the PSTA Test Cells was 23.0 µg/L, while the average inflow TP at the Porta-PSTAs was 25.7 µg/L. On average, approximately 50 to 62 percent of this TP was in the dissolved form, and the remainder was particulate P.

As illustrated in Exhibit 3-2, inlet P concentrations were variable throughout the project period. While mean TP concentrations were similar at both sites, TP reached maximum concentrations at the PSTA Test Cells during the late summer and fall of 1999 and mid-summer of 2000, while maximum TP values were recorded at the Porta-PSTAs in the spring of 1999 and throughout the first half of 2000. These differences in TP inflow concentrations resulted from complex temporal variations in the concentrations of total dissolved phosphorus (TDP) and total particulate phosphorus (TPP) in the two water supplies.

EXHIBIT 3-1

Average Inflow P Concentrations to South Test Cells and Porta-PSTA Mesocosms for the POR

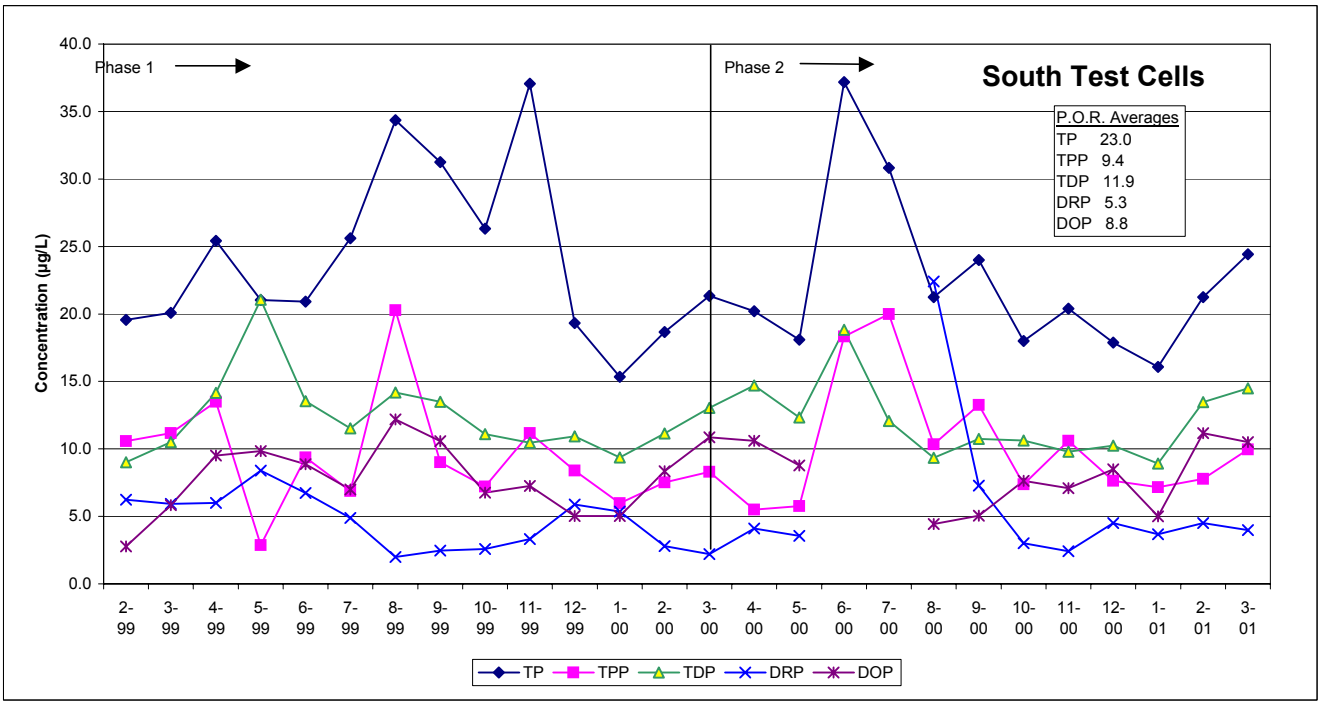
	South Test Cell Inflows					Porta-PSTA Inflows				
Parameter (µg/L)	**Avg.**	**Median**	**Max.**	**Min.**	**Count**	**Avg.**	**Median**	**Max.**	**Min.**	**Count**
Total phosphorus	23.0	20.7	102.0	12.0	103	25.7	20.3	154	11.7	74
Total particulate phosphorus	9.4	8.0	37.0	0.5	78	9.7	5.6	136	0.0	74
Total dissolved phosphorus	11.9	11.3	21.1	1.9	79	16.0	14.6	35.5	6.2	75
Dissolved reactive phosphorus	5.3	3.7	75.0	1.5	85	6.1	5.0	16.5	0.2	50
Dissolved organic phosphorus	8.8	7.7	25.9	1.2	49	7.4	7.6	13.4	0.0	29

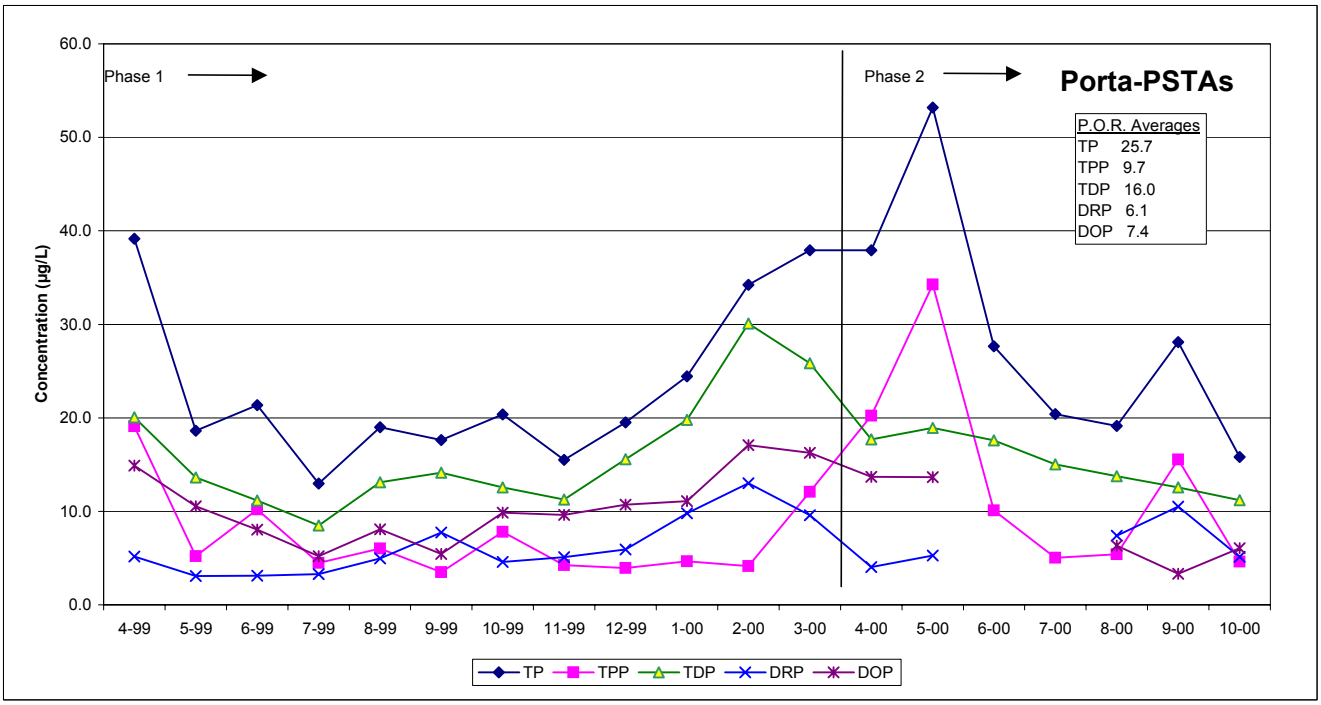
Notes:
South Test Cells: February 23, 1999 - March 3, 2001
Porta-PSTAs: April 13, 1999 - October 2, 2000
In some cases, individual P species do not add to TP because of differing sample sizes in averages.

Exhibit 3-3 illustrates the net change in concentrations of various P forms between the raw water supply and the mesocosm inflow sampling locations. These data indicate that concentrations of TP were slightly reduced in the PSTA Test Cell inlet manifolds (average reduction of 1.6 µg/L) and in the Porta-PSTA manifolds (average reduction of 2.2 µg/L). The median reduction in TP concentration was approximately 1 µg/L at both sites. TPP showed the greatest

EXHIBIT 3-2

Time Series of Input Concentrations of TP, TDP, TPP, DOP, and DRP in Source Water at the PSTA Test Sites





Notes:
TP = total phosphorus
TDP = total dissolved phosphorus
DOP = dissolved organic phosphorus
TPP = total particulate phosphorus
DRP = dissolved reactive phosphorus

EXHIBIT 3-3

Difference Between Water Samples Collected from the Head Cell and Head Tank Stations and PSTA Cell Inflow Stations

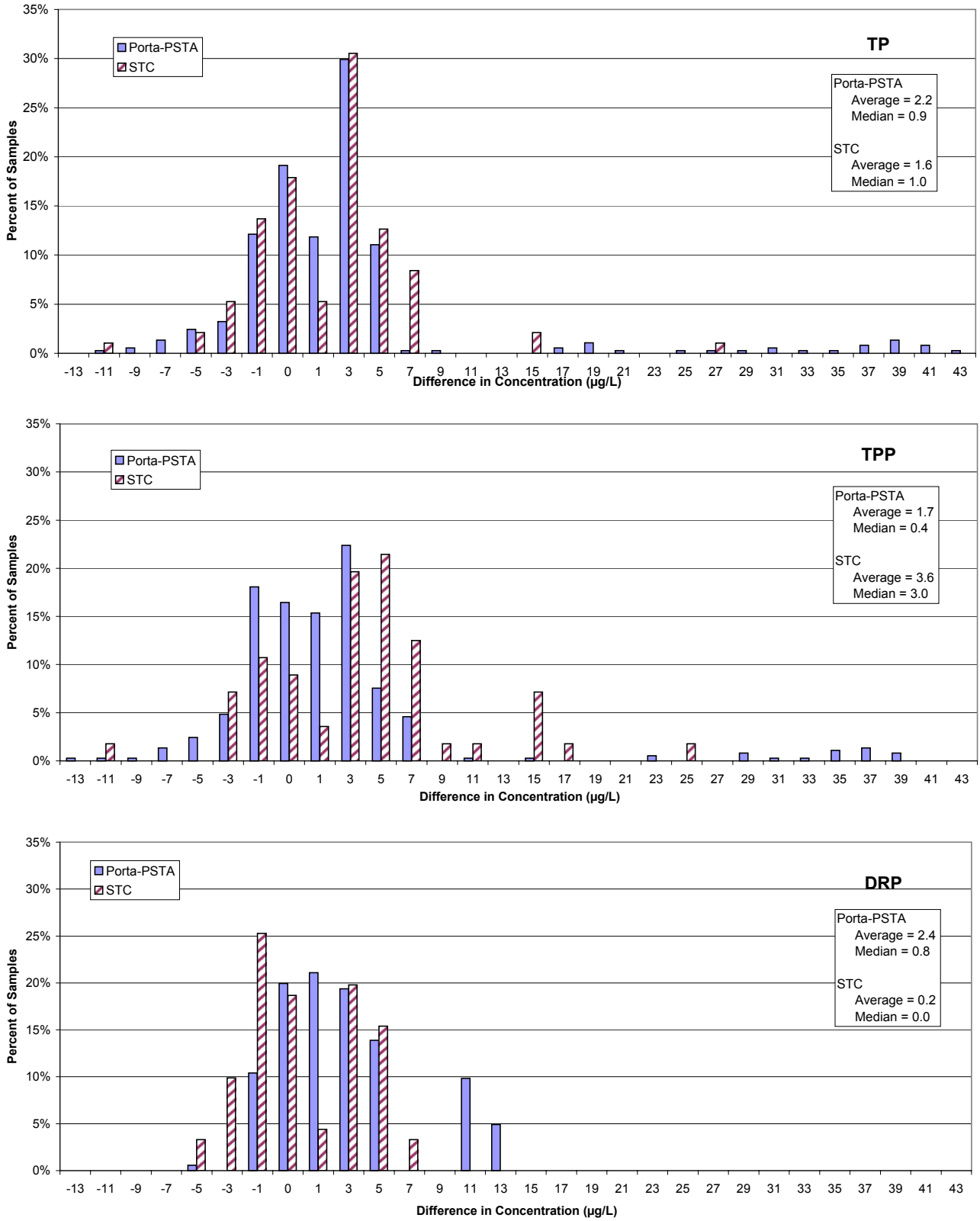
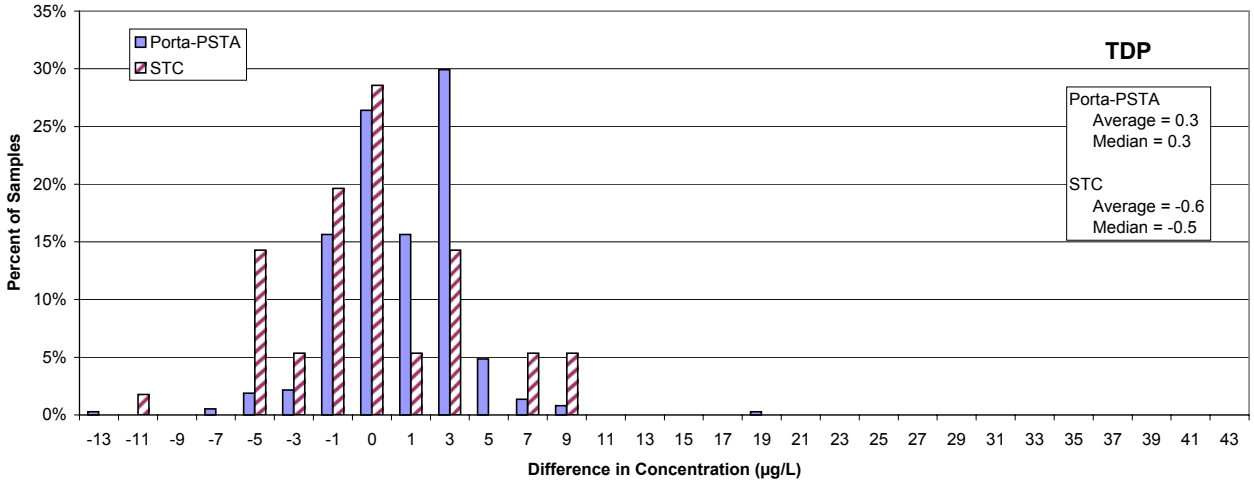
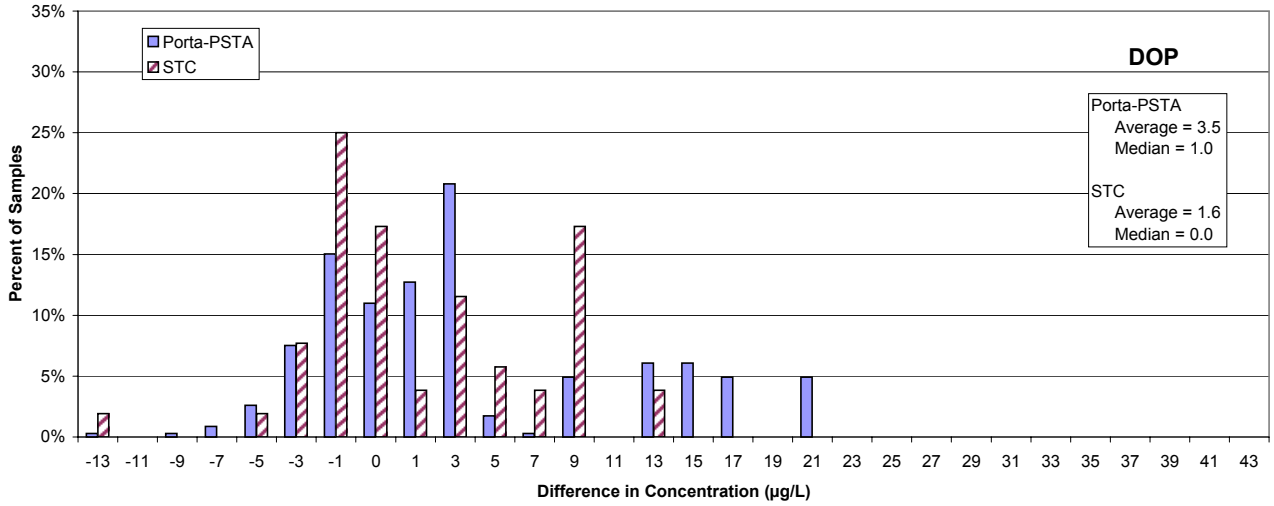


EXHIBIT 3-3

Difference Between Water Samples Collected from the Head Cell and Head Tank Stations and PSTA Cell Inflow Stations





reduction between the feed water and the mesocosm inlets, and dissolved organic phosphorus (DOP) increased by a similar amount. The increase in TDP was less than DOP because of a slight decrease in the concentration of DRP. These types of subtle water quality changes are likely to occur in any full-scale raw water delivery system. Because Head Cell and Head Tank TP concentrations were frequently used to estimate PSTA mesocosm inflow concentrations, the mass reductions described in this section incorporate these changes into the performance estimates for the mesocosms.

3.3 Phosphorus Removal Performance

3.3.1 Performance Periods

P outflow concentrations from the PSTA mesocosms were variable over the study period. Inlet and outlet P time-series plots for each mesocosm are provided in Appendices C and D. PSTA mesocosm performance data are summarized in this report for two operational periods, as described in Exhibit 3-4. The POR includes data for the entire testing period for each PSTA treatment. PSTA mesocosm performance estimates for the POR offer a very conservative view of P removal capability. This dataset includes the end of soil and plant growth startup phenomena.

The startup period prior to the OPP was typically approximately 5 to 6 months. Performance estimates during the OPP represent an estimate of the long-term or steady-state P removal after completion of short-term startup phenomena.

The "Optimal Performance Period" (OPP) includes a subset of the PSTA data for the non-startup portion of the POR. Minimum and maximum dates for each PSTA treatment for the OPP are also summarized in Exhibit 3-4. The OPP includes a shorter time interval than the POR after net P removals were consistently positive through the remainder of the study period. The startup period prior to the OPP was typically approximately 5 to 6 months. Performance estimates during the OPP are typically better than for the POR and represent an estimate of the long-term or steady-state P removal after completion of short-term startup phenomena.

3.3.2 Concentration Changes

Exhibit 3-5 summarizes the mean, median, maximum, and minimum concentrations for each P form during the POR. Exhibit 3-6 provides a similar summary for the OPP. The lowest POR average outflow TP concentrations are 11.7 µg/L for STC-5 (Phase 2 data only, which do not include any start-up effects), 14.2 µg/L for PP-17 (the sand-based Porta-PSTA with HCl rinse), 15.2 µg/L for PP-19 (the Aquamat [no soil] treatment), and 15.8 µg/L for PP-10 (shellrock-based Aquashade treatment) and PP-14 (limerock treatment). Median TP outflow concentrations were typically approximately 1 to 3 µg/L lower than average values. The POR median outflow TP concentration for STC-5 (shellrock

Exhibit 3-4

PSTA Phase 1 and 2 Period-of-Record and Optimal Performance Periods

Treatment	Phase	Cell	Substrate	Depth	HLR	Period of Record	# Days	Optimal Performance Period	# Days
PP-1	1	9,11,18	PE	D	L	4/13/99 - 3/13/00	335	10/4/99 - 1/10/00	98
PP-2	1	4,7,8	SR	D	L	4/13/99 - 3/13/00	335	10/4/99 - 1/10/00	98
PP-3	1, 2	12,14,17	PE	S	L	4/13/99 - 2/12/01	671	10/4/99 - 10/2/00	364
PP-4	1, 2	3,5,10	SR	S	L	4/13/99 - 2/12/01	671	10/4/99 - 10/2/00	364
PP-5	1	2,13,16	SR	D	H	4/13/99 - 3/27/00	349	10/4/99 - 3/27/00	175
PP-6	1	1,6,15	SR	V	V	4/13/99 - 3/13/00	335	10/4/99 - 3/13/00	161
PP-7	1, 2	19	SA	S	L	4/13/99 - 2/12/01	671	10/4/99 - 10/2/00	364
PP-8	1	20	SA	D	L	4/13/99 - 3/13/00	335	10/4/99 - 1/10/00	98
PP-9	1	21	PE (AS)	D	L	4/13/99 - 3/13/00	335	10/4/99 - 3/13/00	161
PP-10	1	22	SR (AS)	D	L	4/13/99 - 3/13/00	335	10/4/99 - 3/13/00	161
PP-11	1, 2	23	SR	S	L	4/13/99 - 2/12/01	671	10/4/99 - 10/2/00	364
PP-12	1, 2	24	PE	S	L	4/13/99 - 2/12/01	671	10/4/99 - 10/2/00	364
PP-13	2	9,11,18	PE (Ca)	S	L	4/17/00 - 2/12/01	301	6/5/00 - 10/2/00	119
PP-14	2	4,7,8	LR	S	L	4/17/00 - 2/12/01	301	6/5/00 - 10/2/00	119
PP-15	2	2,13,16	SR	S	R	4/3/00 - 2/12/01	315	6/5/00 - 10/2/00	119
PP-16	2	1,6,15	SR	V	V	5/1/00 - 2/12/01	287	6/5/00 - 10/2/00	119
PP-17	2	20	SA (HCl)	S	L	4/17/00 - 2/12/01	301	6/5/00 - 10/2/00	119
PP-18	2	21	None	S	L	4/17/00 - 2/12/01	301	6/5/00 - 10/2/00	119
PP-19	2	22	AM	S	L	4/17/00 - 2/12/01	301	6/5/00 - 10/2/00	119
STC-1	1	13	PE	D	L	2/23/99 - 3/6/00	377	7/6/99 - 1/31/00	209
STC-2	1	8	SR	D	L	2/23/99 - 3/27/00	398	7/6/99 - 3/27/00	265
STC-3	1	3	SR	V	V	2/23/99 - 3/6/00	377	7/6/99 - 3/6/00	244
STC-4	2	13	PE (Ca)	S	L	4/24/00 - 4/3/01	344	7/5/00 - 4/3/01	272
STC-5	2	8	SR	S	L	4/3/00 - 4/3/01	365	4/3/00 - 4/3/01	365
STC-6	2	3	SR	V	V	5/22/00 - 4/3/01	316	5/22/00 - 4/3/01	316

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

EXHIBIT 3-5

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Period-of-Record

								TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
Treatment	**Cell**	**Phase**	**Substrate**	**Depth**	**HLR**	**Statistics**	**Key Dates**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
PP-1	9,11,18	1	PE	D	L	Mean		22.3	17.7	6.4	8.6	16.1	9.3	6.4	2.4	10.9	7.8
						Median		19.0	15.7	4.6	7.6	14.5	8.7	5.0	2.1	10.0	7.4
						Max	3/13/00	45.0	66.0	22.0	53.0	35.5	16.5	16.5	6.3	22.5	13.5
						Min	4/13/99	11.7	10.3	0.0	0.3	6.2	5.5	1.8	1.2	0.0	3.7
						N		45	39	45	39	45	39	30	22	30	22
						StdDev		9.0	9.1	5.1	8.1	7.2	2.6	3.8	1.1	5.4	2.6
PP-2	4,7,8	1	SR	D	L	Mean		23.2	17.3	7.5	8.2	15.7	9.2	5.7	2.6	11.1	7.3
						Median		19.0	14.4	4.9	5.6	13.6	8.6	4.3	2.3	10.3	7.2
						Max	3/13/00	49.5	45.7	31.0	32.0	35.5	14.5	16.5	8.0	22.5	12.0
						Min	4/13/99	11.7	10.5	0.0	1.4	6.2	6.3	1.8	0.7	3.8	4.2
						N		41	36	41	36	41	36	27	22	27	22
						StdDev		10.1	8.9	7.0	7.6	7.1	2.3	3.6	1.7	5.2	2.2
PP-3	12,14,17	1, 2	PE	S	L	Mean		26.4	18.1	9.7	8.0	16.7	10.1	6.5	2.4	11.1	7.4
						Median		21.3	17.3	5.5	7.3	15.3	9.7	5.3	2.3	10.6	7.2
						Max	2/12/01	153.7	41.6	136.0	30.1	35.5	18.0	16.5	4.8	23.6	14.7
						Min	4/13/99	11.7	11.3	0.0	2.1	6.2	5.9	0.2	0.3	0.3	4.3
						N		76	77	76	77	77	77	53	27	53	27
						StdDev		17.4	5.2	15.9	4.4	6.7	2.7	3.8	0.9	5.4	2.6
PP-4	3,5,10	1, 2	SR	S	L	Mean		25.7	16.4	9.8	7.4	15.9	9.0	6.1	2.0	10.5	7.0
						Median		20.3	15.2	5.6	6.3	14.6	8.8	5.0	2.0	10.3	6.8
						Max	2/12/01	153.7	50.7	136.0	37.7	35.5	14.3	16.5	4.7	23.6	11.8
						Min	4/13/99	11.7	9.7	0.0	1.5	6.2	4.7	0.2	0.6	0.3	2.7
						N		75	75	75	75	76	75	51	26	51	26
						StdDev		17.4	6.1	16.1	5.1	5.7	2.3	3.6	1.0	4.9	2.7
PP-5	2,13,16	1	SR	D	H	Mean		23.1	18.2	6.8	8.0	16.3	10.1	6.3	2.1	11.0	8.1
						Median		19.3	16.3	4.6	6.5	14.1	9.3	4.8	1.9	9.8	7.7
						Max	3/27/00	45.0	35.7	22.0	22.7	35.5	17.7	16.5	5.3	22.5	15.3
						Min	4/13/99	11.7	11.1	0.0	1.9	6.2	6.2	1.8	1.1	3.8	4.3
						N		47	46	47	46	47	46	32	21	32	21
						StdDev		9.0	5.7	5.3	4.5	6.9	2.9	3.8	0.9	4.9	3.0
PP-6	1,6,15	1	SR	V	V	Mean		22.4	17.5	6.5	8.6	15.9	8.9	6.2	2.5	10.7	7.0
						Median		19.0	14.8	4.5	6.5	13.7	8.9	4.6	2.1	9.6	7.2
						Max	3/13/00	45.0	46.7	22.0	35.7	35.5	13.3	16.5	7.7	22.5	11.5
						Min	4/13/99	11.7	11.8	0.0	2.8	6.2	5.0	1.8	0.8	3.0	3.8
						N		46	45	46	45	46	45	31	21	31	21
						StdDev		8.6	7.6	5.1	6.6	6.7	2.2	3.8	1.5	4.8	2.2
PP-7	19	1, 2	SA	S	L	Mean		25.6	17.3	9.7	7.9	15.9	9.4	6.2	2.1	10.4	7.5
						Median		20.0	14.8	5.6	5.5	14.4	8.9	5.0	2.0	9.8	7.4
						Max	2/12/01	153.7	130.0	136.0	109.0	35.5	21.0	16.5	6.0	23.6	15.0
						Min	4/13/99	11.7	9.5	0.0	0.0	6.2	4.0	1.8	0.8	0.3	2.3
						N		74	73	74	73	75	73	50	23	50	23
						StdDev		17.4	14.3	16.1	12.9	6.0	3.1	3.5	1.3	5.1	3.3
PP-8	20	1	SA	D	L	Mean		22.4	20.0	6.5	10.5	15.9	9.5	6.3	2.2	10.5	7.7
						Median		19.0	16.1	4.7	7.3	13.4	9.2	5.1	2.0	9.0	7.2

EXHIBIT 3-5

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Period-of-Record

								TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
Treatment	**Cell**	**Phase**	**Substrate**	**Depth**	**HLR**	**Statistics**	**Key Dates**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
						Max	3/13/00	45.0	88.0	22.0	70.0	35.5	18.0	16.5	5.0	22.5	17.0
						Min	4/13/99	11.7	12.5	0.0	2.6	6.2	5.9	1.8	1.0	0.7	3.1
						N		45	38	45	38	45	38	30	21	30	21
						StdDev		8.9	12.5	5.1	11.1	7.2	2.6	3.8	0.9	5.4	3.3
PP-9	21	1	PE	D	L	Mean		22.5	18.5	6.6	7.6	16.0	11.0	6.3	2.7	10.7	7.9
			(Aquashade)			Median		19.0	16.1	5.0	6.5	13.6	9.5	5.0	2.2	9.1	7.5
						Max	3/13/00	45.0	38.1	22.0	31.1	35.5	27.0	16.5	8.4	22.5	15.0
						Min	4/13/99	11.0	10.3	0.0	0.0	6.2	5.0	1.8	0.9	3.8	3.7
						N		45	44	45	44	45	44	30	21	30	21
						StdDev		9.0	6.6	5.4	5.7	6.9	4.6	3.8	1.8	4.9	3.3
PP-10	22	1	SR	D	L	Mean		22.4	15.8	6.6	6.3	15.8	9.6	6.3	2.8	10.4	6.8
			(Aquashade)			Median		19.0	15.0	5.0	5.4	13.4	9.0	5.0	2.2	9.1	6.9
						Max	3/13/00	45.0	34.0	22.0	22.0	35.5	18.0	16.5	10.9	22.5	13.0
						Min	4/13/99	11.7	9.8	0.0	0.0	6.2	5.0	1.8	0.8	3.0	0.0
						N		46	44	46	44	46	45	31	22	31	22
						StdDev		8.6	5.0	5.0	4.2	6.8	2.8	3.7	2.4	4.9	2.9
PP-11	23	1, 2	SR	S	L	Mean		25.9	19.9	9.7	9.9	16.2	10.3	6.2	2.1	10.7	9.3
						Median		21.0	17.9	5.6	8.0	15.3	9.1	5.0	2.0	10.6	6.9
						Max	2/12/01	153.7	62.5	136.0	46.0	35.5	51.4	16.5	5.0	23.6	49.9
						Min	4/13/99	11.7	10.7	0.0	0.0	6.2	4.0	0.2	0.2	0.3	2.4
						N		74	72	74	72	75	74	50	25	50	25
						StdDev		17.5	10.0	16.1	8.5	6.1	5.8	3.6	1.0	5.2	9.0
PP-12	24	1, 2	PE	S	L	Mean		25.5	19.7	9.5	9.2	15.9	10.5	6.1	2.3	10.6	7.7
						Median		20.7	17.8	5.6	8.4	14.5	10.0	5.0	2.2	10.5	7.4
						Max	2/12/01	153.7	45.0	136.0	29.0	35.5	22.5	16.5	5.0	23.6	13.0
						Min	4/13/99	11.5	11.6	0.0	0.0	6.2	5.0	0.2	1.0	0.3	2.0
						N		74	72	74	72	75	74	50	24	50	24
						StdDev		17.4	6.4	16.1	5.4	6.2	2.9	3.6	0.9	5.2	2.6
PP-13	9,11,18	2	PE	S	L	Mean		31.0	18.9	15.4	8.5	15.5	10.6	6.4	1.9	9.1	4.3
			(Ca)			Median		23.2	19.3	9.2	7.3	14.3	9.7	5.2	1.8	7.8	4.4
						Max	2/12/01	153.7	40.3	136.0	24.7	30.3	19.7	14.0	2.5	23.6	5.0
						Min	4/17/00	15.8	8.7	2.0	2.7	9.3	4.7	3.7	1.3	0.3	3.3
						N		24	25	24	25	25	25	15	4	15	4
						StdDev		27.5	7.4	26.7	4.6	4.3	4.2	3.2	0.5	5.8	0.7
PP-14	4,7,8	2	LR	S	L	Mean		30.4	15.8	14.8	7.4	15.5	8.5	6.3	1.6	9.2	4.6
						Median		22.3	15.7	8.7	7.0	14.3	7.7	5.0	1.3	7.8	3.7
						Max	2/12/01	153.7	24.7	136.0	12.7	30.3	15.3	14.0	2.7	23.6	8.0
						Min	4/17/00	15.3	10.0	2.0	3.0	9.3	4.3	3.7	1.0	0.3	3.0
						N		24	25	24	25	25	25	15	4	15	4
						StdDev		27.4	4.5	26.6	2.6	4.4	3.2	3.3	0.8	5.9	2.3
PP-15	2,13,16	2	SR	S	R	Mean		30.8	17.9	15.1	8.1	15.6	9.9	6.2	2.4	9.5	3.8
						Median		24.1	16.7	9.3	7.7	14.3	9.0	5.3	2.5	9.3	3.7
						Max	2/12/01	153.7	31.7	136.0	16.3	30.3	17.3	14.0	3.0	23.6	5.0
						Min	4/3/00	15.7	9.3	2.0	4.0	9.3	5.0	3.7	1.7	0.3	3.0

EXHIBIT 3-5

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Period-of-Record

								TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
Treatment	**Cell**	**Phase**	**Substrate**	**Depth**	**HLR**	**Statistics**	**Key Dates**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
						N		26	27	26	27	27	27	17	4	17	4
						StdDev		26.3	5.8	25.5	3.1	4.2	3.5	3.1	0.7	5.6	0.9
PP-16	1,6,15	2	SR	V	V	Mean		29.9	17.2	14.7	7.8	15.1	9.6	7.1	2.6	7.7	6.8
						Median		21.3	16.8	8.0	7.0	13.7	9.3	5.7	2.3	7.2	6.3
						Max	2/12/01	153.7	27.2	136.0	20.5	30.3	15.7	14.0	5.1	23.6	10.5
						Min	5/1/00	15.3	11.2	2.0	4.2	9.3	6.3	4.2	1.2	0.3	4.0
						N		20	20	20	20	21	21	11	5	11	5
						StdDev		30.0	4.4	29.1	3.6	4.6	2.5	3.5	1.5	6.4	2.4
PP-17	20	2	SA	S	L	Mean		30.4	14.2	14.7	5.3	15.7	8.9	6.2	2.0	9.4	6.3
			(HCl)			Median		22.3	13.0	8.7	4.0	14.3	9.0	5.0	2.0	7.8	5.0
						Max	2/12/01	153.7	30.0	136.0	19.0	30.3	16.0	14.0	3.0	23.6	11.0
						Min	4/17/00	15.0	7.0	2.0	0.0	9.3	4.0	3.7	1.0	0.3	3.0
						N		24	24	24	24	25	25	15	3	15	3
						StdDev		27.6	6.6	26.8	4.6	4.4	3.3	3.3	1.0	5.9	4.2
PP-18	21	2	None	S	L	Mean		30.5	16.5	14.9	6.6	15.5	10.4	6.4	2.0	9.2	5.0
						Median		22.3	15.0	9.0	5.0	14.3	9.0	5.0	2.0	7.8	5.0
						Max	2/12/01	153.7	32.0	136.0	20.0	30.3	28.0	14.0	3.0	23.6	6.0
						Min	4/17/00	16.0	8.0	2.0	0.0	9.3	5.0	3.7	1.0	0.3	4.0
						N		24	25	24	25	25	25	15	3	15	3
						StdDev		27.4	6.4	26.6	5.4	4.2	4.6	3.3	1.0	5.8	1.0
PP-19	22	2	None	S	L	Mean		30.3	15.2	14.6	5.4	15.6	10.0	6.2	1.2	9.4	4.5
			(Aquamat)			Median		23.2	14.0	8.7	4.0	14.3	9.0	5.0	1.0	7.8	5.0
						Max	2/12/01	153.7	35.0	136.0	23.0	30.3	20.0	14.0	1.5	23.6	6.0
						Min	4/17/00	15.0	7.0	2.0	0.0	9.3	4.0	3.7	1.0	0.3	2.5
						N		24	25	24	25	25	25	15	3	15	3
						StdDev		27.4	7.0	26.6	5.2	4.4	3.9	3.3	0.3	6.0	1.8
STC-1	13	1	PE	D	L	Mean		24.6	22.2	10.2	11.1	11.0	11.3	4.8	3.4	6.5	8.8
						Median		22.0	19.1	10.3	8.1	10.9	10.3	4.6	2.9	6.9	7.8
						Max	3/6/00	102.0	86.0	24.9	70.0	18.6	22.8	12.5	17.0	14.0	18.1
						Min	2/23/99	14.6	10.7	1.0	0.0	1.9	5.2	1.5	0.2	0.0	3.4
						N		50	52	27	52	27	52	50	30	27	30
						StdDev		13.1	12.9	5.6	11.8	3.3	4.0	2.8	3.1	3.4	3.8
STC-2	8	1	SR	D	L	Mean		24.0	17.3	8.0	7.1	12.5	10.3	4.7	3.2	8.3	9.0
						Median		21.0	14.9	6.5	6.0	12.1	8.2	4.2	2.3	7.8	8.0
						Max	3/27/00	102.0	57.0	21.1	46.0	27.8	22.4	13.0	16.6	17.6	19.0
						Min	2/23/99	12.5	8.5	0.0	0.0	1.9	5.2	1.5	0.7	0.0	0.2
						N		53	55	30	55	30	55	53	30	30	30
						StdDev		12.9	8.4	5.4	6.8	4.2	4.4	2.7	3.7	4.0	4.6
STC-3	3	1	SR	V	V	Mean		24.0	22.4	8.1	11.9	11.6	10.5	4.7	3.1	7.4	8.8
						Median		21.3	18.1	7.5	8.9	11.4	9.4	3.8	2.4	7.6	7.8
						Max	3/6/00	102.0	78.0	18.6	69.0	21.0	25.0	11.0	23.1	18.0	20.0
						Min	2/23/99	12.5	10.8	2.0	0.0	1.9	6.1	1.5	0.5	0.0	0.0
						N		50	52	27	52	27	52	50	30	27	30
						StdDev		13.2	12.1	4.4	10.9	3.2	4.0	2.7	3.9	3.7	4.2

EXHIBIT 3-5

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Period-of-Record

								TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
Treatment	**Cell**	**Phase**	**Substrate**	**Depth**	**HLR**	**Statistics**	**Key Dates**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
STC-4	13	2	PE	S	L	Mean		22.1	29.1	10.3	13.1	11.7	15.8	6.7	2.0	7.6	10.8
			(Ca)			Median		20.0	21.5	9.0	9.0	11.0	11.0	3.7	1.9	7.8	10.1
						Max	4/3/01	64.0	186.0	43.0	83.0	21.0	103.0	75.0	5.1	13.0	25.9
						Min	4/24/00	12.0	9.0	2.0	0.0	7.0	5.0	1.9	1.0	0.0	5.7
						N		47	48	45	47	46	48	29	18	28	18
						StdDev		8.7	30.3	7.8	15.6	3.1	15.4	13.5	1.1	2.9	5.0
STC-5	8	2	SR	S	L	Mean		22.1	11.7	10.1	4.3	12.0	7.3	6.3	2.0	8.2	5.0
						Median		20.5	11.0	8.9	4.0	11.0	7.0	3.3	1.8	8.0	4.7
						Max	4/3/01	64.0	29.0	43.0	14.0	21.0	15.0	75.0	4.0	13.4	7.2
						Min	4/3/00	12.0	7.0	0.5	0.0	7.0	4.0	1.9	1.0	0.0	2.0
						N		50	51	48	50	49	51	32	17	31	17
						StdDev		8.5	3.7	7.7	2.5	3.2	2.2	12.9	0.9	3.0	1.5
STC-6	3	2	SR	V	V	Mean		23.7	18.8	11.4	8.1	12.2	10.7	9.0	1.8	7.7	9.1
						Median		23.0	18.5	10.4	7.0	11.3	10.0	3.4	1.0	8.0	10.0
						Max	4/3/01	47.0	56.7	37.0	40.7	22.0	16.0	75.0	4.0	14.0	12.0
						Min	5/22/00	15.0	9.0	2.0	2.0	7.0	4.5	2.0	1.0	0.0	5.5
						N		28	28	26	27	27	28	16	5	15	5
						StdDev		6.9	9.1	6.9	7.3	3.6	3.4	18.0	1.3	4.0	2.7

Notes:
Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells
Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate
Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)
HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

EXHIBIT 3-6

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Optimal Performance Period (Excluding Startup)

Treatment	Cell	Phase	Substrate	Depth	HLR	Statistics	Key Dates	TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
								Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
PP-1	9,11,18	1	PE	D	L	Mean		18.8	14.1	4.9	6.1	13.9	8.1	5.3	1.7	10.0	7.5
						Median		17.3	13.6	3.6	5.4	13.6	8.2	4.9	1.7	10.0	7.4
						Max	1/10/00	27.4	17.7	16.4	10.0	24.5	10.6	6.1	2.0	10.4	8.4
						Min	10/4/99	14.3	10.3	1.1	2.3	7.4	5.5	4.8	1.3	9.6	6.6
						N		15	15	15	15	15	15	3	3	3	3
						StdDev		4.2	2.4	3.7	2.3	3.9	1.6	0.7	0.4	0.4	0.9
PP-2	4,7,8	1	SR	D	L	Mean		19.1	13.0	5.0	4.7	14.1	8.2	5.1	1.3	10.8	7.6
						Median		18.0	11.9	4.3	4.9	13.6	8.2	5.0	1.6	10.9	7.4
						Max	1/10/00	27.4	16.7	16.4	6.8	24.5	10.9	5.9	1.7	11.2	8.4
						Min	10/4/99	14.3	10.7	1.7	1.4	7.4	6.3	4.4	0.7	10.3	7.0
						N		15	15	15	15	15	15	3	3	3	3
						StdDev		4.2	2.0	3.6	1.5	3.9	1.4	0.7	0.5	0.5	0.7
PP-3	12,14,17	1, 2	PE	S	L	Mean		28.3	17.0	10.8	7.3	17.4	9.8	7.7	2.4	11.9	6.4
						Median		23.8	17.2	5.7	7.3	16.0	9.5	6.1	2.4	12.1	6.8
						Max	9/25/00	153.7	29.3	136.0	16.0	35.5	18.0	16.5	3.0	23.6	8.0
						Min	10/4/99	14.3	11.6	1.8	2.1	7.4	5.7	2.7	1.7	0.3	4.3
						N		50	51	50	51	51	51	28	5	28	5
						StdDev		20.0	3.6	19.1	3.2	6.2	2.5	3.8	0.6	5.5	1.6
PP-4	3,5,10	1, 2	SR	S	L	Mean		28.8	14.6	11.2	5.8	17.5	8.9	7.7	1.5	11.9	5.4
						Median		25.2	14.3	6.2	5.3	16.2	8.9	5.9	1.4	12.3	6.1
						Max	10/2/00	153.7	23.0	136.0	12.7	35.5	14.3	16.5	2.0	23.6	7.6
						Min	10/26/99	14.3	9.7	0.6	1.5	7.4	4.7	2.7	0.6	0.3	2.7
						N		48	49	48	49	49	49	28	5	28	5
						StdDev		20.4	3.2	19.6	2.2	6.1	2.2	3.9	0.6	5.2	2.4
PP-5	2,13,16	1	SR	D	H	Mean		25.0	16.4	6.1	6.2	18.9	10.1	9.5	1.8	14.3	7.9
						Median		22.8	15.6	4.5	6.1	16.1	9.7	9.8	1.7	12.7	7.9
						Max	3/27/00	45.0	23.7	18.5	11.5	35.5	16.0	16.5	2.3	22.5	7.9
						Min	10/4/99	14.3	11.1	1.8	1.9	7.4	6.7	2.7	1.4	8.9	7.8
						N		26	26	26	26	26	26	13	3	13	3
						StdDev		9.0	3.5	4.4	2.1	7.8	2.5	3.8	0.4	4.5	0.1
PP-6	1,6,15	1	SR	V	V	Mean		24.1	14.5	5.6	6.1	18.5	8.4	9.9	1.0	14.0	7.3
						Median		22.2	14.1	4.5	5.8	15.9	8.4	10.5	1.0	13.3	6.8
						Max	3/13/00	45.0	20.6	16.4	12.5	35.5	13.1	16.5	1.3	22.5	8.5
						Min	10/4/99	14.3	11.8	1.3	2.8	7.4	5.0	4.6	0.8	8.7	6.4
						N		24	24	24	24	24	24	11	3	11	3
						StdDev		8.6	2.2	3.8	2.1	7.7	2.0	3.7	0.3	4.6	1.1
PP-7	19	1, 2	SA	S	L	Mean		27.8	15.2	10.5	6.0	17.3	9.1	7.5	1.2	12.0	5.9
						Median		24.0	14.2	5.7	5.0	16.0	8.9	5.6	1.0	12.0	6.0
						Max	10/2/00	153.7	28.5	136.0	20.0	35.5	17.5	16.5	2.0	23.6	8.7
						Min	10/4/99	14.3	9.5	0.8	0.0	7.4	4.0	2.7	0.8	0.3	3.0
						N		51	52	51	52	52	52	29	5	29	5
						StdDev		19.8	4.4	18.9	4.1	6.2	2.8	3.9	0.5	5.3	2.4
PP-8	20	1	SA	D	L	Mean		19.3	16.1	5.3	7.1	14.0	9.0	6.1	1.8	9.4	8.1
						Median		19.0	14.3	4.6	5.4	13.6	9.1	6.4	1.8	9.4	7.7
						Max	1/10/00	27.4	25.3	16.4	18.3	24.5	12.5	6.7	1.9	10.1	9.3
						Min	10/4/99	14.3	12.5	1.8	2.6	7.4	5.9	5.1	1.6	8.6	7.2
						N		15	15	15	15	15	15	3	3	3	3
						StdDev		4.2	4.1	3.5	4.7	3.9	1.7	0.9	0.2	0.8	1.1

EXHIBIT 3-6

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Optimal Performance Period (Excluding Startup)

Treatment	Cell	Phase	Substrate	Depth	HLR	Statistics	Key Dates	TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
								Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
PP-9	21	1	PE	D	L	Mean		24.0	19.5	5.4	8.4	18.7	11.3	10.0	1.7	14.4	7.6
			(Aquashade)			Median		22.1	17.4	4.6	6.6	16.1	9.7	10.5	1.6	15.6	7.5
						Max	3/13/00	45.0	38.1	16.4	31.1	35.5	27.0	16.5	2.1	22.5	7.8
						Min	10/4/99	14.3	13.6	0.8	0.0	7.4	5.0	4.9	1.3	7.5	7.4
						N		24	24	24	24	24	24	11	3	11	3
						StdDev		8.8	6.3	3.8	6.6	7.8	5.1	3.6	0.4	4.7	0.2
PP-10	22	1	SR	D	L	Mean		24.2	14.6	5.6	5.0	18.6	9.7	9.8	3.9	14.4	5.1
			(Aquashade)			Median		21.2	14.0	4.6	4.9	16.1	9.4	10.5	1.9	14.0	6.4
						Max	3/13/00	45.0	24.0	16.4	11.9	35.5	15.0	16.5	10.9	22.5	7.6
						Min	10/4/99	14.3	9.8	0.9	0.9	7.4	5.0	3.4	0.8	9.1	0.0
						N		24	24	24	24	24	24	11	4	11	4
						StdDev		8.8	3.3	3.8	2.6	7.7	2.7	3.9	4.7	4.3	3.5
PP-11	23	1, 2	SR	S	L	Mean		28.1	17.8	10.5	8.0	17.5	9.6	7.7	1.7	12.2	6.1
						Median		24.0	17.8	5.7	7.7	16.2	9.4	6.0	1.8	12.6	6.9
						Max	10/2/00	153.7	27.0	136.0	20.0	35.5	25.0	16.5	3.0	23.6	9.4
						Min	10/4/99	14.0	10.7	0.0	0.9	7.4	4.0	2.7	0.6	0.3	3.0
						N		51	50	51	50	52	52	29	5	29	5
						StdDev		19.9	4.7	18.9	3.9	6.4	3.2	3.8	0.9	5.6	2.6
PP-12	24	1, 2	PE	S	L	Mean		27.8	18.6	10.3	8.1	17.5	10.6	7.6	2.3	12.1	6.3
						Median		24.0	17.2	5.3	7.6	16.1	10.2	6.0	1.6	12.2	6.8
						Max	10/2/00	153.7	37.0	136.0	23.0	35.5	22.5	16.5	5.0	23.6	9.9
						Min	10/4/99	14.0	11.6	0.0	0.0	7.4	5.0	2.7	1.0	0.3	2.0
						N		51	50	51	50	52	52	29	5	29	5
						StdDev		19.9	5.2	19.0	4.3	6.4	3.1	3.8	1.7	5.6	3.3
PP-13	9,11,18	2	PE	S	L	Mean		23.1	16.2	8.4	7.3	14.7	9.0	8.0	1.8	5.5	4.1
			(Ca)			Median		21.0	17.0	6.2	7.0	13.7	9.0	5.7	1.7	6.3	4.3
						Max	10/2/00	42.3	23.7	28.0	12.0	19.7	15.0	14.0	2.5	9.3	4.5
						Min	6/5/00	15.8	8.7	2.0	2.7	10.0	4.7	5.0	1.3	0.3	3.3
						N		16	17	16	17	17	17	7	3	7	3
						StdDev		7.2	4.9	6.5	2.8	2.9	3.1	4.2	0.6	3.3	0.6
PP-14	4,7,8	2	LR	S	L	Mean		23.1	14.5	8.4	7.3	14.6	7.3	7.8	1.2	5.5	4.8
						Median		21.0	13.7	6.8	7.0	13.7	7.3	5.0	1.0	6.3	3.3
						Max	10/2/00	42.3	22.3	28.0	11.7	19.7	12.0	14.0	1.7	9.3	8.0
						Min	6/5/00	15.3	10.0	2.0	3.0	10.0	4.3	4.3	1.0	0.3	3.0
						N		16	17	16	17	17	17	7	3	7	3
						StdDev		7.4	3.9	6.5	2.4	3.1	2.4	4.3	0.4	3.3	2.8
PP-15	2,13,16	2	SR	S	R	Mean		23.1	14.6	8.4	6.6	14.6	8.1	8.1	2.2	5.3	3.4
						Median		21.0	15.0	6.7	6.7	13.7	7.7	6.0	2.0	6.3	3.3
						Max	10/2/00	42.3	19.2	28.0	11.3	19.7	12.3	14.0	3.0	9.3	4.0
						Min	6/5/00	15.7	9.3	2.0	4.0	10.0	5.0	5.0	1.7	0.3	3.0
						N		16	17	16	17	17	17	7	3	7	3
						StdDev		7.3	2.9	6.5	1.9	2.9	2.4	4.1	0.7	3.2	0.5
PP-16	1,6,15	2	SR	V	V	Mean		23.1	17.0	8.4	7.7	14.6	9.3	8.2	2.1	5.2	5.8
						Median		21.0	16.0	6.7	7.0	13.7	9.3	6.7	2.3	6.3	5.8
						Max	10/2/00	42.3	27.2	28.0	20.5	19.7	14.0	14.0	2.8	9.3	7.5
						Min	6/5/00	15.3	11.2	2.0	4.2	10.0	6.3	5.0	1.2	0.3	4.0
						N		16	17	16	17	17	17	7	3	7	3
						StdDev		7.4	4.5	6.5	3.9	3.0	2.3	4.1	0.8	3.3	1.8

EXHIBIT 3-6

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Optimal Performance Period (Excluding Startup)

Treatment	Cell	Phase	Substrate	Depth	HLR	Statistics	Key Dates	TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
								Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
PP-17	20	2	SA	S	L	Mean		22.9	11.4	8.0	4.0	14.7	7.4	7.7	1.5	5.6	4.0
			(HCl)			Median		21.0	10.0	5.5	3.0	13.7	7.0	5.0	1.5	7.0	4.0
						Max	10/2/00	42.3	22.0	28.0	13.0	21.0	13.0	14.0	2.0	9.3	5.0
						Min	6/5/00	15.0	7.0	2.0	1.0	10.0	4.0	4.0	1.0	0.3	3.0
						N		16	17	16	17	17	17	7	2	7	2
						StdDev		7.4	3.8	6.7	2.8	3.2	2.5	4.4	0.7	3.3	1.4
PP-18	21	2	None	S	L	Mean		23.2	14.0	8.5	5.1	14.6	8.9	8.0	1.5	5.5	4.5
						Median		21.2	13.0	7.5	4.5	13.7	8.0	7.0	1.5	6.3	4.5
						Max	10/2/00	42.3	25.0	28.0	17.0	19.7	14.0	14.0	2.0	9.3	5.0
						Min	6/5/00	16.0	8.0	2.0	1.0	10.0	5.0	4.0	1.0	0.3	4.0
						N		16	17	16	17	17	17	7	2	7	2
						StdDev		7.1	4.4	6.5	3.7	2.9	2.8	4.2	0.7	3.3	0.7
PP-19	22	2	None	S	L	Mean		23.0	13.8	8.4	5.2	14.6	8.6	7.7	1.3	5.5	3.8
			(Aquamat)			Median		21.0	12.0	6.3	4.5	13.7	7.0	5.0	1.3	6.3	3.8
						Max	10/2/00	42.3	35.0	28.0	23.0	19.7	14.0	14.0	1.5	9.3	5.0
						Min	6/5/00	15.0	7.0	2.0	0.8	10.0	4.0	4.0	1.0	0.3	2.5
						N		16	17	16	17	17	17	7	2	7	2
						StdDev		7.4	7.5	6.5	5.3	3.0	3.3	4.4	0.4	3.3	1.8
STC-1	13	1	PE	D	L	Mean		27.1	16.3	9.7	7.0	10.5	9.5	4.0	2.2	6.2	7.1
						Median		22.8	14.3	10.3	5.5	11.5	9.4	2.6	2.2	6.5	6.4
						Max	1/31/00	102.0	31.7	24.9	21.1	13.6	20.4	9.0	4.3	11.0	11.6
						Min	7/6/99	14.6	10.7	1.0	0.0	1.9	5.2	1.9	0.9	0.0	5.1
						N		28	29	16	29	16	29	28	12	16	12
						StdDev		16.9	5.0	6.0	4.4	3.1	2.8	2.4	1.2	3.4	2.1
STC-2	8	1	SR	D	L	Mean		25.1	13.3	7.7	5.0	11.9	8.5	3.7	1.8	8.1	7.9
						Median		20.6	13.1	6.3	4.9	12.1	7.9	2.6	1.5	7.5	6.9
						Max	3/27/00	102.0	19.7	21.1	9.1	19.0	22.4	9.0	4.4	14.3	19.0
						Min	7/6/99	12.5	8.5	1.0	0.0	1.9	5.2	1.5	1.0	0.0	3.6
						N		36	37	24	37	24	37	36	13	24	13
						StdDev		15.4	2.6	5.4	2.3	3.2	2.9	2.3	1.1	3.7	4.2
STC-3	3	1	SR	V	V	Mean		25.1	17.1	7.7	8.4	11.0	8.8	3.7	1.9	7.2	7.0
						Median		21.0	15.5	7.2	7.5	11.4	8.2	2.7	1.9	7.6	6.5
						Max	3/6/00	102.0	30.7	18.6	19.4	14.3	14.0	9.0	2.8	12.3	12.5
						Min	7/6/99	12.5	10.8	2.0	3.6	1.9	6.1	1.5	1.0	0.0	4.0
						N		33	34	21	34	21	34	33	12	21	12
						StdDev		16.0	5.1	4.5	3.8	2.6	2.0	2.3	0.6	3.2	2.4
STC-4	13	2	PE	S	L	Mean		21.8	20.0	10.5	8.4	11.2	11.3	7.4	1.8	7.4	9.9
			(Ca)			Median		22.0	18.0	9.0	7.0	11.0	10.5	3.5	1.8	7.5	9.5
						Max	4/3/01	47.0	38.0	37.0	22.3	20.0	20.0	75.0	3.0	13.0	15.7
						Min	7/5/00	12.0	9.0	4.0	0.0	7.0	5.0	2.0	1.0	0.0	5.7
						N		39	39	37	38	38	39	23	17	22	17
						StdDev		6.5	8.4	6.2	5.2	2.8	3.8	15.1	0.8	3.2	3.3
STC-5	8	2	SR	S	L	Mean		22.1	11.7	10.1	4.3	12.0	7.3	6.3	2.0	8.2	5.0
						Median		20.5	11.0	8.9	4.0	11.0	7.0	3.3	1.8	8.0	4.7
						Max	4/3/01	64.0	29.0	43.0	14.0	21.0	15.0	75.0	4.0	13.4	7.2
						Min	4/3/00	12.0	7.0	0.5	0.0	7.0	4.0	1.9	1.0	0.0	2.0
						N		50	51	48	50	49	51	32	17	31	17
						StdDev		8.5	3.7	7.7	2.5	3.2	2.2	12.9	0.9	3.0	1.5

EXHIBIT 3-6

Summary Statistics for Weekly Values of Phosphorus Concentrations During the Optimal Performance Period (Excluding Startup)

Treatment	Cell	Phase	Substrate	Depth	HLR	Statistics	Key Dates	TP (µg/L)		TPP (µg/L)		TDP (µg/L)		DRP (µg/L)		DOP (µg/L)	
								Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
STC-6	3	2	SR	V	V	Mean		23.7	18.8	11.4	8.1	12.2	10.7	9.0	1.8	7.7	9.1
						Median		23.0	18.5	10.4	7.0	11.3	10.0	3.4	1.0	8.0	10.0
						Max	4/3/01	47.0	56.7	37.0	40.7	22.0	16.0	75.0	4.0	14.0	12.0
						Min	5/22/00	15.0	9.0	2.0	2.0	7.0	4.5	2.0	1.0	0.0	5.5
						N		28	28	26	27	27	28	16	5	15	5
						StdDev		6.9	9.1	6.9	7.3	3.6	3.4	18.0	1.3	4.0	2.7

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

Lowest mean outflow TP concentrations during the OPP were 11.4 µg/L for PP-17 (HCl-rinsed sand), 11.7 µg/L for STC-5 (shellrock), 13 µg/L for PP-2 (shellrock 60 cm), and 13.8 µg/L for PP-19 (Aquamat). Approximately 4 to 10 µg/L of this P was in the DOP form, and 4 to 8 µg/L was in the TPP form.

Test Cell) was 11 µg/L. Minimum weekly TP values less than 10 µg/L were observed in 13 of the 25 PSTA treatments. POR average DRP values were less than 3.5 µg/L in all of the PSTA treatments.

Mean TP outflow concentrations for the OPP ranged from approximately 11.4 to 20.0 µg/L. Lowest mean outflow TP concentrations during the OPP were 11.4 µg/L for PP-17 (HCl-rinsed sand), 11.7 µg/L for STC-5 (shellrock), 13 µg/L for PP-2 (shellrock 60 cm), and 13.8 µg/L for PP-19 (Aquamat). Approximately 4 to 10 µg/L of this P was in the DOP form, and 4 to 8 µg/L was in the TPP form. All mean DRP outflow concentrations in vegetated treatments were 2.2 µg/L or less.

3.3.3 Mass Removals

P mass loadings are a function of both inflow concentration and HLR. Exhibit 3-7 summarizes the average TP mass loading and removal data from the PSTA mesocosms based on the OPP described above. OPP TP mass loadings averaged between 0.38 and 1.55 g/m^2/yr. Removal rates for the OPP averaged between 0.063 and 0.57 g/m^2/yr. Average TP mass removal efficiencies ranged from approximately 16 to 52 percent. The highest TP mass removal rate was observed in treatment PP-5 (deep shellrock with high HLR), which also received the highest loading rate. The highest TP mass removal efficiencies were observed in treatment STC-2 (deep shellrock), PP-7 (unrinsed sand treatment), PP-17 (HCl-rinsed sand treatment), and PP-4 (shallow shellrock constant flow). The lowest mass removal rate was measured in STC-4, the peat-based Test Cell with calcium amendment. This cell also had the lowest mass removal efficiency.

Average TP mass removal efficiencies ranged from approximately 16 to 52 percent.

These estimated mass removal rates do not account for atmospheric TP loadings. Detailed wet and dry TP atmospheric deposition values are not available during the period of this research. The average rainfall TP was 18 µg/L between August 1998 and March 2000. Based on an annualized rainfall rate of 124 cm during the project period, this wet deposition from atmospheric sources is approximately 0.022 g/m^2/yr. This is equivalent to approximately 6 percent or less of the pumped TP loading rate. Dry atmospheric TP deposition may be greater than the amount delivered by rain alone. The estimated total atmospheric deposition of TP delivered by rain and particulate fallout is approximately 0.0464 g/m^2/yr (Burns & McDonnell, 1999). Even this amount is only approximately 3 to 12 percent of the TP delivered in the pumped inflows, and therefore atmospheric TP inputs were not considered in these mass balances.

EXHIBIT 3-7

PSTA Mesocosm TP Mass Balances for the Optimal Performance Period

Treatment	Cell	Phase	Substrate	Depth	HLR	TP (µg/L) Inflow	TP (µg/L) Outflow	Inflow (m^3/d)	Outflow (m^3/d)	Avg_flow (m^3/d)	q_avg (cm/d)	TP (g/m^2/yr) Inflow	TP (g/m^2/yr) Outflow	Removal (g/m^2/yr)	Removal (%)	Calc k_1 (m/yr)
PP-1	9,11,18	1	PE	D	L	18.8	14.1	0.577	0.545	0.561	9.62	0.645	0.466	0.178	27.6	10.11
PP-2	4,7,8	1	SR	D	L	19.1	13.0	0.550	0.541	0.546	9.17	0.611	0.424	0.187	30.6	12.92
PP-3	12,14,17	1, 2	PE	S	L	28.1	17.0	0.488	0.467	0.477	8.14	0.792	0.466	0.327	41.2	14.91
PP-4	3,5,10	1, 2	SR	S	L	28.2	14.6	0.499	0.506	0.503	8.31	0.812	0.449	0.363	44.7	19.91
PP-5	2,13,16	1	SR	D	H	25.0	16.4	1.039	1.003	1.021	17.32	1.547	0.979	0.568	36.7	26.74
PP-6	1,6,15	1	SR	V	V	24.1	14.5	0.271	0.285	0.278	4.51	0.406	0.258	0.147	36.3	8.35
PP-7	19	1, 2	SA	S	L	27.8	15.2	0.491	0.468	0.480	8.19	0.803	0.426	0.377	46.9	18.14
PP-8	20	1	SA	D	L	19.3	16.1	0.559	0.517	0.538	9.32	0.640	0.501	0.139	21.7	6.23
PP-9	21	1	PE (AS)	D	L	24.0	19.5	0.563	0.588	0.575	9.38	0.837	0.697	0.139	16.7	7.18
PP-10	22	1	SR (AS)	D	L	24.2	14.6	0.536	0.524	0.530	8.93	0.781	0.462	0.318	40.8	16.48
PP-11	23	1, 2	SR	S	L	28.1	17.8	1.546	1.525	1.535	8.59	0.831	0.531	0.300	36.1	14.42
PP-12	24	1, 2	PE	S	L	27.8	18.6	1.528	1.511	1.520	8.49	0.819	0.556	0.263	32.2	12.50
PP-13	9,11,18	2	PE (Ca)	S	L	23.1	16.2	0.518	0.505	0.511	8.64	0.715	0.495	0.220	30.7	11.28
PP-14	4,7,8	2	LR	S	L	23.1	14.5	0.518	0.570	0.544	8.63	0.726	0.520	0.205	28.3	14.53
PP-15	2,13,16	2	SR	S	R	23.1	14.6	0.481	0.448	0.464	8.01	0.668	0.394	0.274	41.1	13.39
PP-16	1,6,15	2	SR	V	V	23.1	17.0	1.062	1.113	1.087	17.70	1.471	1.144	0.326	22.2	19.63
PP-17	20	2	SA (HCl)	S	L	22.9	11.4	0.463	0.502	0.482	7.71	0.651	0.348	0.303	46.5	19.48
PP-18	21	2	None	S	L	23.2	14.0	0.470	0.588	0.529	7.84	0.654	0.521	0.133	20.3	14.47
PP-19	22	2	AM	S	L	23.0	13.8	0.515	0.542	0.528	8.58	0.700	0.450	0.249	35.6	15.92
STC-1	13	1	PE	D	L	27.1	16.3	108.8	117.2	106.8	4.03	0.424	0.240	0.184	43.4	7.44
STC-2	8	1	SR	D	L	25.1	13.3	119.9	108.8	114.4	4.44	0.429	0.204	0.225	52.4	10.38
STC-3	3	1	SR	V	V	25.1	17.1	108.4	86.2	97.3	3.69	0.384	0.219	0.165	43.0	5.15
STC-4	13	2	PE (Ca)	S	L	21.8	20.0	121.9	116.7	119.4	4.95	0.399	0.336	0.063	15.8	1.56
STC-5	8	2	SR	S	L	22.1	11.7	123.1	118.5	120.9	5.06	0.414	0.211	0.203	49.1	11.78
STC-6	3	2	SR	V	V	23.7	18.8	153.2	144.2	152.6	6.01	0.516	0.348	0.168	32.5	5.00

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

3.3.4 k-C* Model Parameter Estimates

Pollutant removal rates can be summarized as a simple logarithmic decay (first-order process) using inflow/outflow concentrations and hydraulic loading data. Wetland performance is tied more closely to surface area than to water volume (Kadlec and Knight 1996), so an area-based model is typically more appropriate than a volumetric first-order model. A plug-flow hydraulic assumption was used for preliminary PSTA TP performance calibrations (CH2M HILL, 2000). In this report, intrinsic TP removal rate constants are also presented based on the tanks-in-series model and on measured tracer residence time distributions in selected PSTA treatments.

The simplest expression of the first-order, area-based plug flow wetland performance model, assuming no net rainfall or seepage, is:

$$\ln (C_1/C_2) = k_1/q \qquad \text{[Equation 3-1]}$$

where:

C_1 = average inlet concentration, mg/L
C_2 = average outlet concentration, mg/L
k_1 = first-order, area-based rate constant, m/yr
q = average hydraulic loading rate, m/yr

This is the general form of the wetland model and can be referred to as the one-parameter or k_1 plug-flow model. Exhibit 3-7 includes the average treatment TP k_1 values estimated for the OPP. During this period, average treatment estimated k_1 values ranged from 1.6 to 27 m/yr. The highest k_1 value was estimated for PP-5, the high HLR shellrock Porta-PSTA treatment. The lowest was estimated for STC-4, the peat-based Test Cell with calcium amendment. Most of the average estimated k_1 values were between 5 and 20 m/yr. It is well known that k_1 is highly correlated with inlet loading of both TP and water (Kadlec, 2001) and therefore it is not surprising that higher k_1 values were measured for higher inlet loadings.

In general, wetland data indicate that internal and external loading of TP may result in non-zero, irreducible wetland water column constituent concentrations. For some purposes these concentrations may be so low as to be indistinguishable from zero. In other cases, effluent discharge goals approach the lowest constituent concentrations measured in natural wetlands. In these situations, the plug flow model can be corrected by introducing a second parameter that represents the lowest achievable or irreducible concentration that will occur in a treatment wetland, C*.

The two-parameter first-order, area-based plug flow model, or k-C* model, is:

$$\ln[(C_1-C^*)/(C_2-C^*)] = k/q \qquad \text{[Equation 3-2]}$$

where:

k = two-parameter model first-order, area-based removal rate constant, m/yr

Inlet and outlet concentration data can be combined with average HLR, q, to estimate k and C* for a given treatment wetland dataset. Average data for a period of time greater than the average HRT in the wetland should be used when making these parameter estimates. These parameters are most often calculated based on at least monthly, quarterly, or annual average datasets.

For some constituents, the value of k is dependent upon temperature. The modified Arrhenius equation that describes this dependency is:

$$k_T = k_{20}(\text{theta}^{[T-20]}) \qquad \text{[Equation 3-3]}$$

where:

theta = temperature correction factor
T = the average water temperature, deg C
k_T = k at T deg C, m/yr
k_{20} = k at 20 deg C, m/yr

Tracer studies in the PSTA mesocosms indicated that they do not behave as pure plug flow reactors (see Appendix F for a complete description of the tracer test results). The tanks-in-series model has been used to describe the observed deviation of these systems from plug flow (Kadlec and Knight, 1996). This model assumes that flow through the PSTA is similar to a number of completely mixed stirred reactors in series. The number of reactors is estimated by the model to describe the observed distribution of tracer residence times. The tanks-in-series model can be written as:

$$(C_2-C^*)/(C_1-C^*) = (1+k_{TIS}/nq)^{-n} \qquad \text{[Equation 3-4]}$$

where:

k_{TIS} = the 2-parameter tanks-in-series, area-based removal rate constant (m/yr)

n = number of tanks-in-series

The plug flow reactor rate constant is now renamed as k_{PFR} and is related to k_{TIS} by the following equations:

$$k_{TIS} = nq[(e^{(-kPFR/q)})^{-1/n} - 1] \qquad \text{[Equation 3-5]}$$

$$k_{PFR} = nq[\ln(1+k_{TIS}/nq)] \qquad \text{[Equation 3-6]}$$

In all cases, $k_{TIS} \geq k_{PFR}$. If the number of tanks-in-series is more than approximately 7, then the two forms of the removal rate constant are nearly identical. It is important to note that because this is a two-parameter model, values for k_{PFR} and k_{TIS} cannot be compared between treatments except in light of the C* estimate. A high C* results in a higher value for the rate constant for a given amount of P removal.

The PSTA OPP data were used to calibrate the k-C* model. All data collected during the OPP were utilized, and the Excel Solver routine was employed to provide the best-fit calibration to these datasets. The value for k_{PFR} was estimated with Solver and then k_{TIS} was calculated based on an assumed number of tanks-in-series using the typical values from the PSTA tracer studies. Solver

tests with identical datasets returned equivalent parameters for both forms of the k-C* model.

Some of the individual PSTA treatment datasets were not robust enough to allow simultaneous calibration of k, C*, and the temperature correction factor (theta). Therefore, in some cases where Solver could not find a solution, it was assumed that C* was approximately equal to the lowest monthly average for a given dataset. In some cases, it was also assumed that theta was equal to 1.0, indicating no effect of temperature on k. When the model would provide an estimate of theta, it was found that it varied from 0.82 to 1.03. A value of theta less than 1.0 indicates that the TP removal rate constant increases at water temperatures less 20 degrees Celsius (°C). A theta greater than 1.0 indicates that the actual TP removal rate constant was higher than the k_{20} value because the mean operational temperature was approximately 24.5°C.

For values of C actually estimated by the model, these low C* estimates may indicate that a large PSTA constructed on soils with very low concentrations of available TP may be able to achieve TP concentrations consistently less than 10 µg/L.*

Exhibit 3-8 summarizes the estimated average PSTA k-C* values for the OPP. Estimated C^*_{TP} values ranged from 5 to 16 µg/L. It is of interest to note that for those values of C* actually estimated by the model, the lowest were the Porta-PSTA treatments with either shellrock (6 µg/L) or acid-rinsed sand (5 µg/L) and the PSTA Test Cell with shellrock and constant water depth (7 µg/L). These low C* estimates may indicate that a large PSTA constructed on soils with very low concentrations of available TP may be able to achieve TP concentrations consistently less than 10 µg/L.

Estimated k_{PFR} values in the PSTA Test Cell treatments ranged from 5.5 to 42.5 m/yr. The estimated k_{PFR} values in the Porta-PSTA treatments were generally higher, ranging from 20.4 to 89 m/yr during the OPP. Estimated k_{TIS} values in the Porta-PSTAs ranged from 24 to 185 m/yr and from 5.8 to 76 m/yr in the Test Cells. Little effect of temperature was found on any of these k-C* model parameters.

When similar treatments were combined in this analysis, the Porta-PSTA peat and shellrock treatments returned very similar values for k_{PFR} and k_{TIS}, although the shellrock treatments were approximately 15 percent higher. The removal rate constants for the other Porta-PSTA treatments were lower as was the C* estimate, except for the Aquashade treatments that returned a high C* and higher values of k_{PFR} and k_{TIS}.

The startup effects on TP out and k_1 were clearly greater in the peat Test Cell than in the shellrock Test Cell. The k_1 value for the shellrock cell remained relatively steady throughout the 2-year study.

3.3.5 Time Series for Key Treatments

Temporal trends in TP inflow and outflow concentrations and monthly average k_1 values are presented for the stable water regime peat and shellrock PSTA Test Cell treatments in Exhibits 3-9 and 3-10, respectively. The startup effects on TP out and k_1 were clearly

EXHIBIT 3-8

Model Parameters for the PSTA Treatments for the Optimal Performance Period

Treatment	Phase	Substrate	Depth	HLR	TP (mg/L) C1	TP (mg/L) C2	HLR (m/yr)	Wtr Temp (C)	k_{20PFR} (m/yr)	k_{20TIS} (m/yr)	# TIS	C*	Theta
Porta-PSTAs													
PP-1	1	PE	D	L	0.020	0.014	34.9	22.7	61.9	99.6	***2.0***	0.015	0.87
PP-2	1	SR	D	L	0.020	0.013	33.4	22.0	46.5	67.2	***2.0***	0.011	0.98
PP-3	1, 2	PE	S	L	0.027	0.017	29.2	24.6	54.0	88.7	***2.0***	0.016	***1.00***
PP-4	1, 2	SR	S	L	0.027	0.014	30.5	24.7	43.2	62.9	***2.0***	0.011	1.02
PP-5	1	SR	D	H	0.025	0.017	62.8	21.7	68.1	90.4	***2.0***	0.011	0.90
PP-6	1	SR	V	V	0.026	0.015	16.5	21.1	39.6	76.5	***2.0***	0.013	0.95
PP-7	1, 2	SA	S	L	0.027	0.015	29.6	24.4	31.1	40.8	***2.0***	0.010	1.03
PP-8	1	SA	D	L	0.020	0.016	33.9	22.9	89.3	185.2	***2.0***	***0.015***	***1.00***
PP-9	1	PE (AS)	D	L	0.026	0.020	34.9	21.4	35.5	46.3	***2.0***	***0.016***	***1.00***
PP-10	1	SR (AS)	D	L	0.026	0.015	32.4	19.8	35.8	47.7	***2.0***	0.010	1.02
PP-11	1, 2	SR	S	L	0.027	0.017	32.3	24.4	39.6	54.6	***2.0***	0.013	0.96
PP-12	1, 2	PE	S	L	0.027	0.018	31.1	24.2	44.9	65.8	***2.0***	0.015	0.96
PP-13	2	PE (Ca)	S	L	0.022	0.015	31.8	28.1	20.4	24.1	***2.0***	***0.007***	***1.00***
PP-14	2	LR	S	L	0.022	0.014	32.0	28.3	27.6	34.6	***2.0***	***0.008***	***1.00***
PP-15	2	SR	S	R	0.022	0.014	29.4	31.0	26.4	33.3	***2.0***	***0.008***	***1.00***
PP-16	2	SR	V	V	0.022	0.016	64.1	28.7	45.0	53.9	***2.0***	0.006	0.96
PP-17	2	SA (HCl)	S	L	0.022	0.011	28.4	28.2	42.4	63.0	***2.0***	0.005	0.94
PP-18	2	None	S	L	0.023	0.013	29.5	28.0	32.8	43.9	***2.0***	***0.008***	***1.00***
PP-19	2	AM	S	L	0.022	0.013	31.6	28.1	28.6	36.2	***2.0***	***0.007***	***1.00***
South Test Cells													
STC-1	1	PE	D	L	0.027	0.016	16.2	24.6	34.9	51.1	***3.0***	0.013	0.92
STC-2	1	SR	D	L	0.025	0.013	16.3	25.2	31.7	44.6	***3.0***	0.010	0.96
STC-3	1	SR	V	V	0.025	0.018	13.2	23.8	42.5	76.2	***3.0***	0.016	0.93
STC-4	2	PE (Ca)	S	L	0.022	0.019	18.1	23.3	8.5	9.2	***3.0***	***0.013***	***1.00***
STC-5	2	SR	S	L	0.023	0.012	18.4	23.7	20.7	25.2	***3.0***	0.007	1.00
STC-6	2	SR	V	V	0.023	0.019	20.9	26.1	5.5	5.8	***3.0***	***0.010***	***1.00***
Porta-PSTA Summary													
		PE			0.025	0.016	30.9	24.9	48.0	72.6	***2.0***	0.014	0.97
		SR			0.024	0.015	40.1	24.7	56.7	82.5	***2.0***	0.013	0.97
		SA			0.025	0.015	30.6	24.1	33.0	43.8	***2.0***	0.011	1.03
		LR			0.022	0.014	32.0	28.3	27.6	34.6	***2.0***	***0.008***	***1.00***
		AS			0.026	0.018	33.7	20.6	95.5	210.8	***2.0***	0.016	0.82
		None			0.023	0.013	29.5	28.0	32.8	43.9	***2.0***	***0.008***	***1.00***
		AM			0.022	0.013	31.6	28.1	28.6	36.2	***2.0***	***0.007***	***1.00***
South Test Cells Summary													
		PE			0.024	0.018	17.3	23.9	58.5	108.5	***3.0***	0.018	1.03
		SR			0.024	0.015	17.2	24.6	136.3	671.4	***3.0***	0.015	0.90

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

TIS = tanks-in-series

bold and italics = values fixed in model

greater in the peat Test Cell than in the shellrock Test Cell. The peat cell went through this startup a second time following a batch-mode study in January and February 2000 and subsequent plant removal and soil liming. While outflow TP concentrations were generally lower in the shellrock treatment than in the peat treatment, the difference was not great except during startup conditions, during the batch test with no inflow to the peat cell, and during the last 3 months of the project. After the longer startup, the k_1 values for both treatments were similar during Phase 1. During Phase 2, the k_1 value for the peat cell never matched the k_1 for the shellrock cell and declined throughout the last 8 months of the test. The reasons for these changes in the peat PSTA Test Cell during Phase 2 are not clear. The k_1 value for the shellrock cell remained relatively steady throughout the 2-year study.

The same type of time-series graphs for the variable water regime PSTA Test Cell are presented in Exhibits 3-11 and 3-12 for TP inflow/outflow and k_1 values, respectively. The startup period for this cell also took approximately 5 months as was seen for the shellrock Test Cell with stable water flows and levels. The outflow TP level stayed fairly low in this cell, except for temporary increases following dry-out periods. The response during the first dryout—conducted in the spring—was an increasing and high k_1 value. The response to the second dryout—conducted during the fall and winter months—was a reduction in TP removal performance.

Porta-PSTA treatments PP-3 (peat) and PP-4 (shellrock) were both operated for 18 months with 30 cm of water depth (Exhibits 3-13 and 3-14). Treatments PP-11 (shellrock) and PP-12 (peat) were identical in terms of water depth and their POR, but were larger at 3 x 6 m (Exhibits 3-15 and 3-16). The time series TP data for these four treatments are of interest because the only treatment variable in each pair is the soil type. For both pairs, the shellrock treatment was slightly better than the peat treatment during the first operational phase. The higher performance of the 1 x 6 m shellrock mesocosms increased during Phase 2, but there was not much difference between the larger mesocosms.

3.3.6 Analytical Considerations for Low Phosphorus Concentrations

The results of the P monitoring of all PSTA experiments must be interpreted in light of the very low concentrations measured and the variability in those measurements introduced by natural causes and normal and acceptable analytical error. Appendix A includes detailed descriptions of the P detection methods employed by the University of Florida Institute of Food and Agricultural Sciences (IFAS) labs, as well as the quality assurance/quality control (QA/QC) record of results from duplicate samples and equipment blanks collected over the course of the project. The University of Florida IFAS facilities have an approved quality assurance project plan (QAPP) filed with FDEP and consistently meet QA expectations in P measurement as a routine participant in the state's round-robin laboratory analysis.

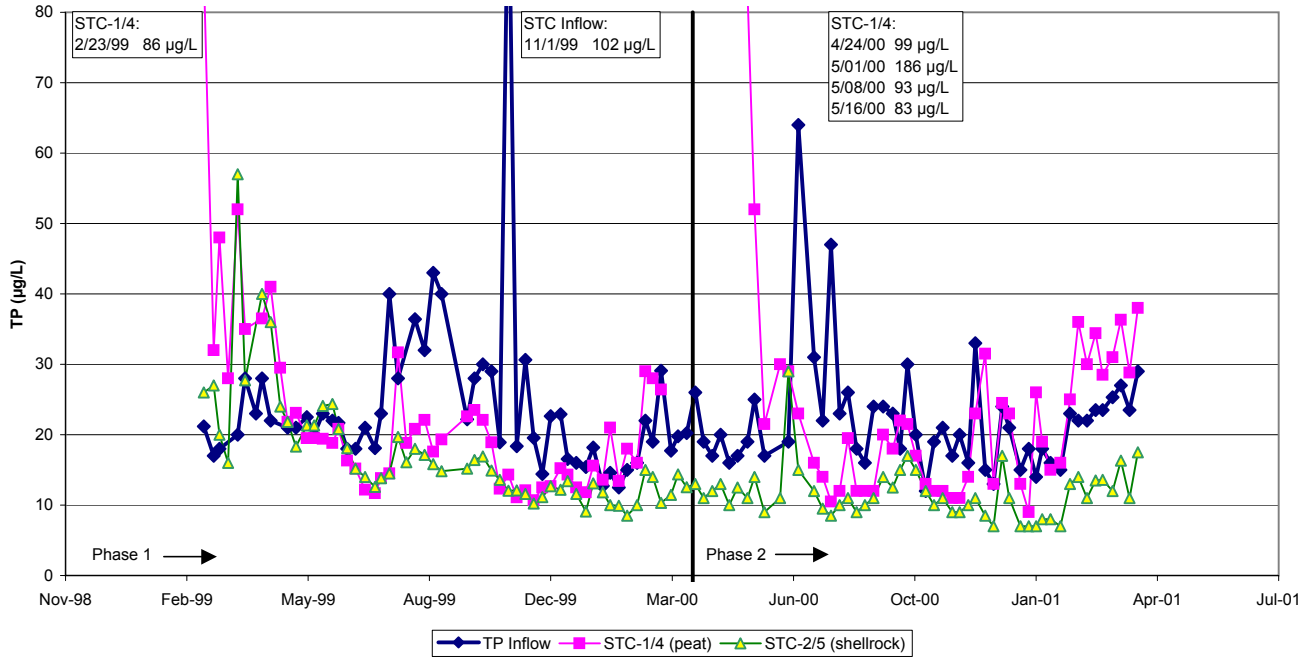


EXHIBIT 3-9

PSTA Test Cell TP Inflow and Outflow Concentrations in Treatments STC-1/4 (Peat) and STC-2/5 (Shellrock)

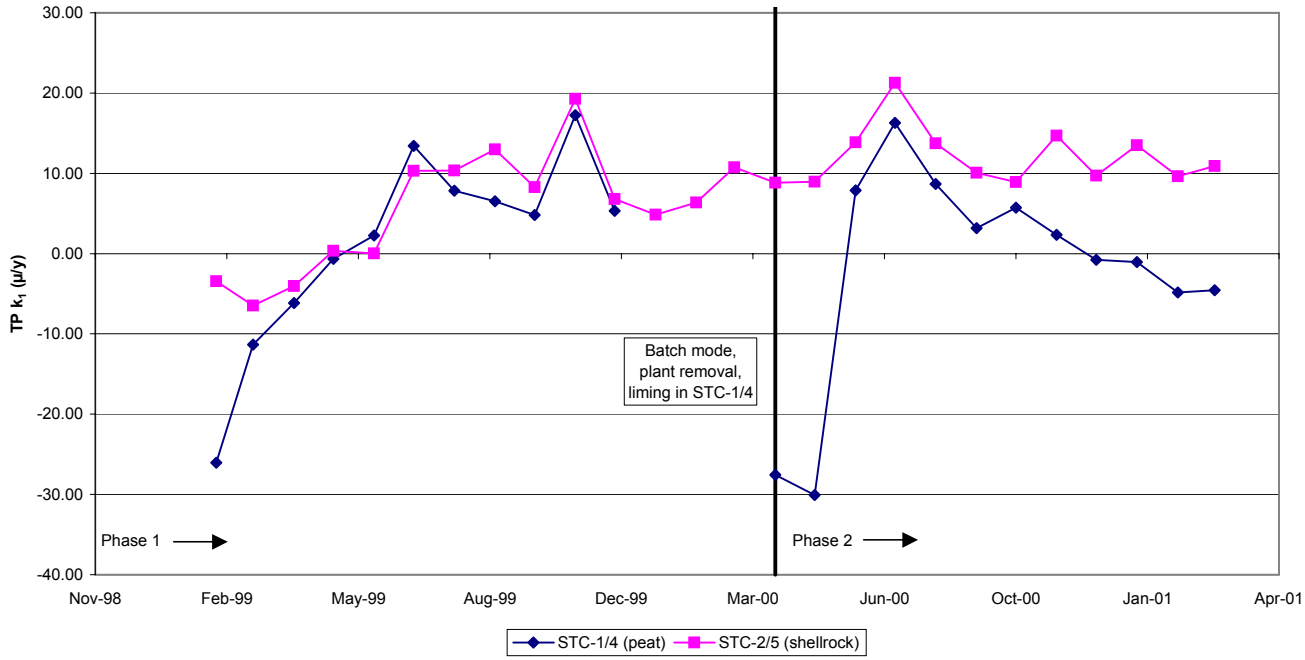


EXHIBIT 3-10

PSTA Test Cell k_{1TP} Values in Treatments STC-1/4 (Peat) and STC-2/5 (Shellrock)

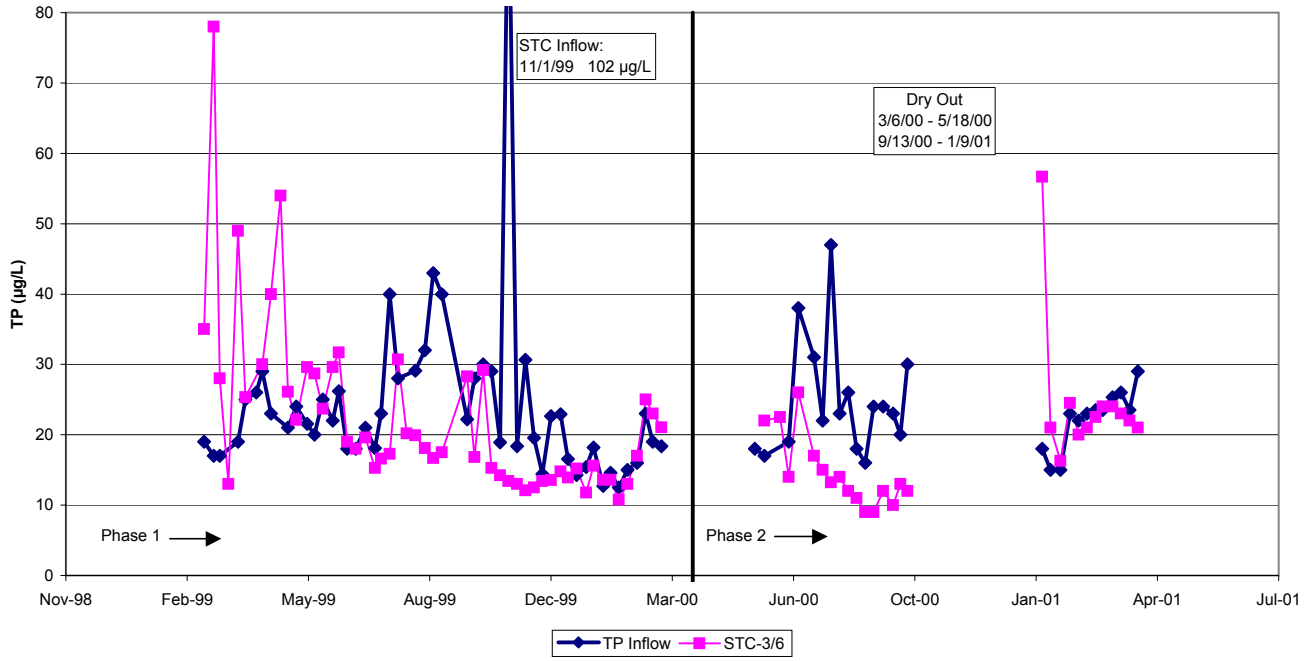


EXHIBIT 3-11

PSTA Test Cell TP Inflow and Outflow Concentrations in Treatments STC-3/6 (Shellrock with Dry-Down)

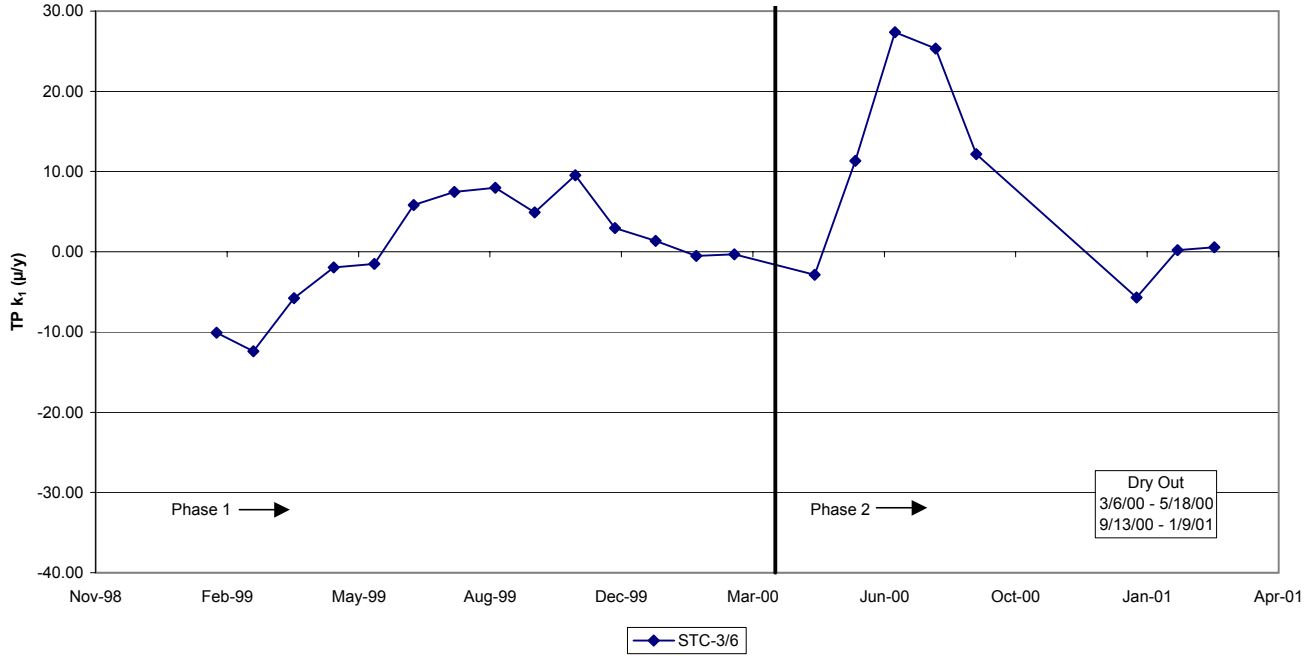


EXHIBIT 3-12

PSTA Test Cell k_{1TP} Values in Treatments STC-3/6 (Shellrock with Dry-Down)

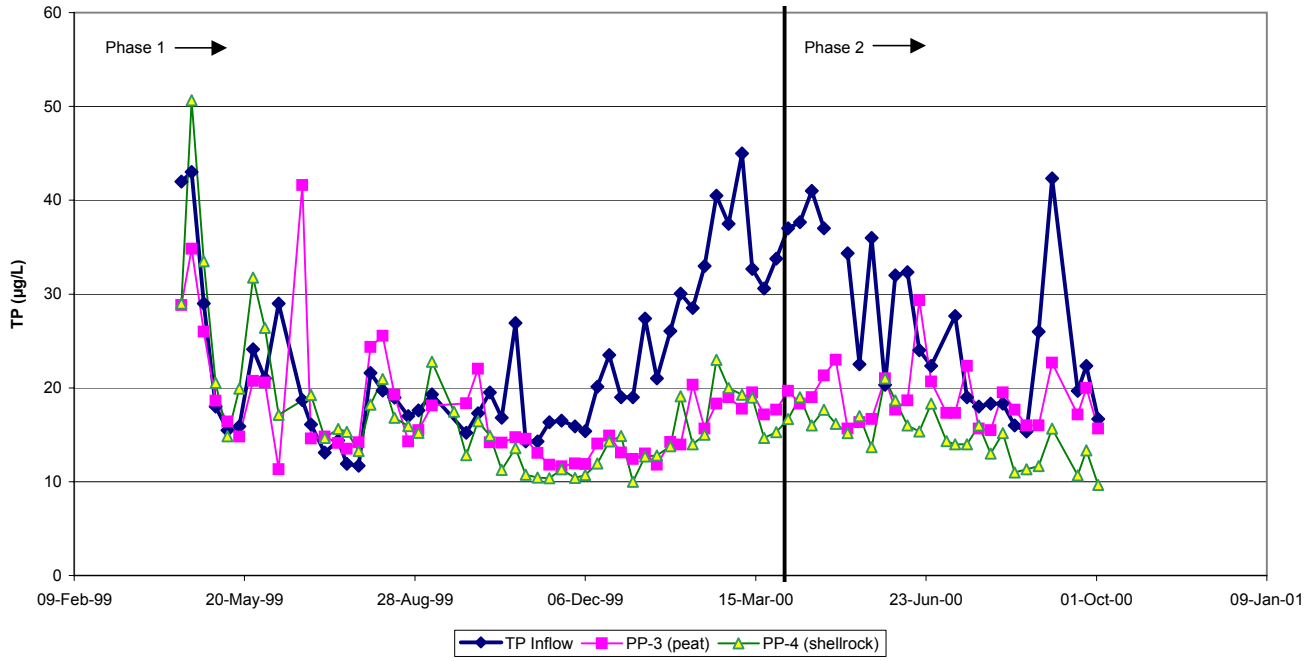


EXHIBIT 3-13

Porta-PSTA TP Inflow and Outflow Concentrations in Treatments PP-3 (1x6 m Peat) and PP-4 (1x6 m Shellrock) for the POR

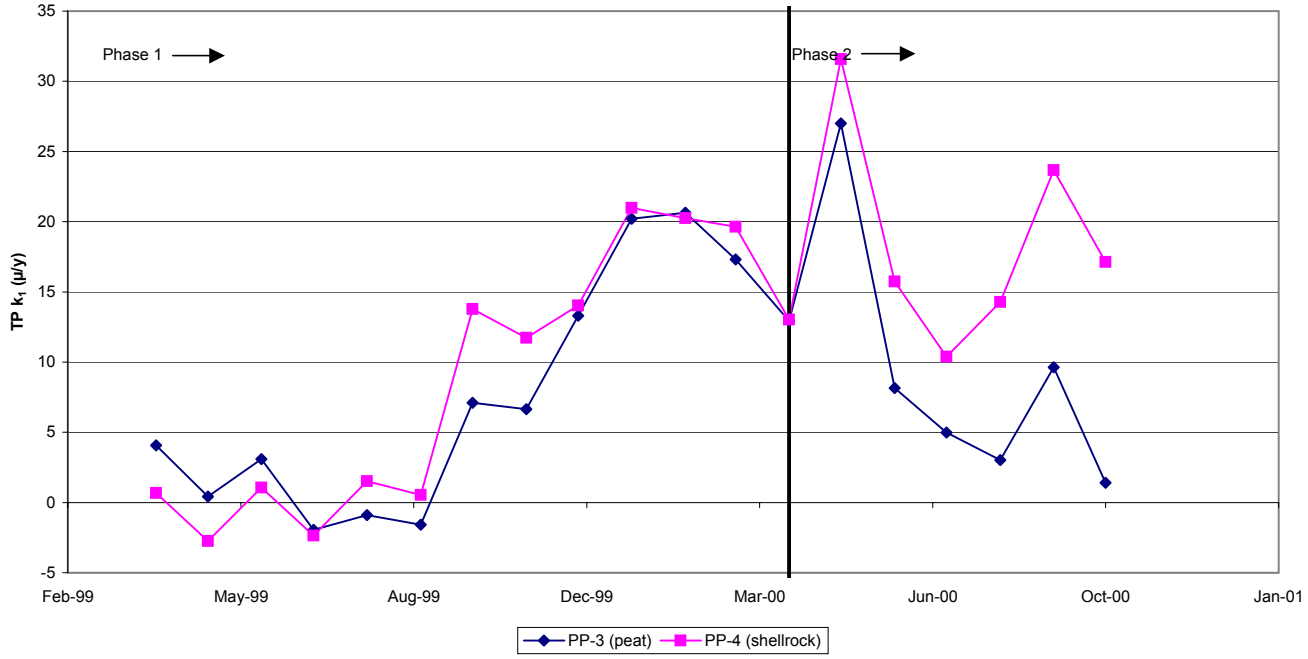


EXHIBIT 3-14

Porta-PSTA Test Cell k_{1TP} Values in Treatments PP-3 (Peat) and PP-4 (Shellrock) for the POR

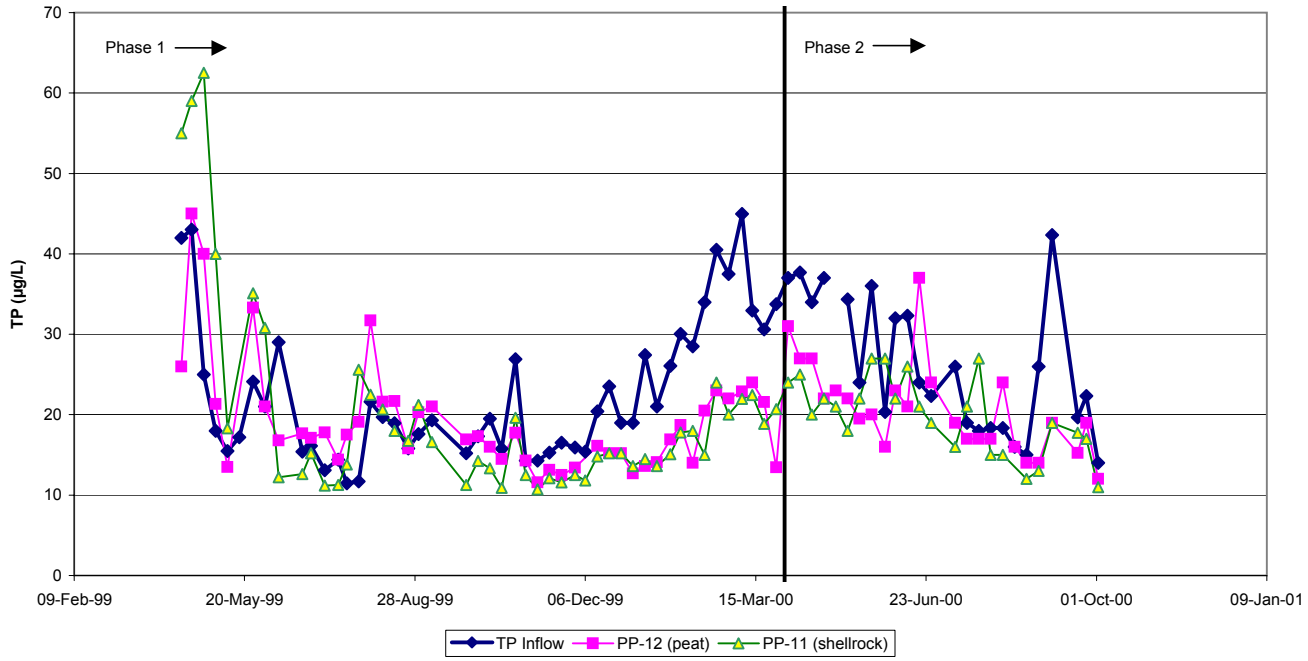


EXHIBIT 3-15

Porta-PSTA TP Inflow and Outflow Concentrations in Treatments PP-11 (3x6 m Shellrock) and PP-12 (3x6 m Peat) for the POR

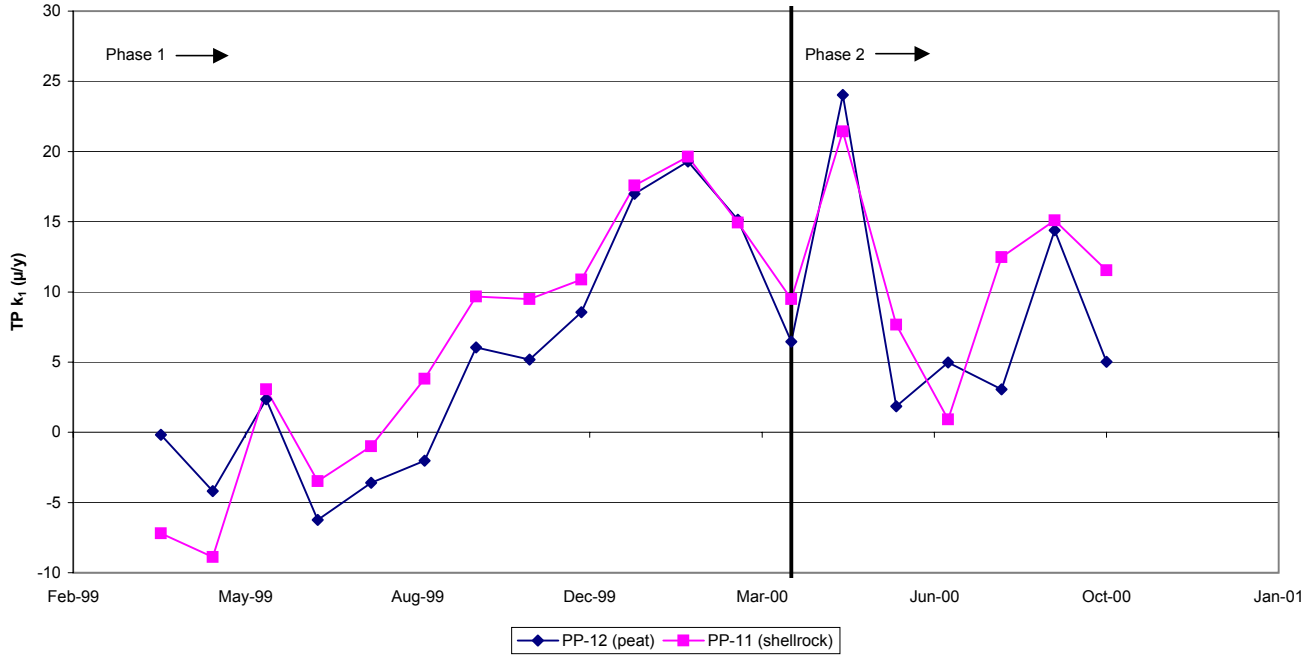


EXHIBIT 3-16

Porta-PSTA Test Cell k_{1TP} Values in Treatments PP-3 (Peat) and PP-4 (Shellrock) for the POR

Equipment blanks collected during the sampling of the Porta-PSTAs yielded respective median DRP, TDP, and TP values of 0.001, 0.003, and 0.002 mg/L, respectively. Similar equipment blanks collected during the Test Cell sampling yield median DRP, TDP, and TP values of 0.001, 0.002, and 0.002 mg/L, respectively.

Field duplicates collected during the sampling of the Porta-PSTAs yielded median DRP, TDP, and TP values of 0.001, 0.001, and 0.002 mg/L, respectively. Similar field duplicate samples collected during the Test Cell sampling yielded median DRP, TDP, and TP values of 0.0005, 0.001, and 0.001 mg/L, respectively.

Collectively, these data indicate a high level of quality control and consistency in the analyses employed during the PSTA project, but they also illustrate why experimental treatment differences on the order of 0.001 to 0.003 mg/L TP are at the nominal detection levels of the experimental methods approved and implemented during this study. Also, average PSTA outflow TP measurements of 0.011 and 0.012 mg/L may not necessarily be statistically different from the 0.010 mg/L target, given the analytical error in the methods and QA procedures selected for this project. However, the convention employed for this study is that this analytical variation is uniform across all experimental treatments, and that results are reported as received from the laboratory and after QA/QC review.

3.4 Treatment Effects

A large number of treatments were investigated in the PSTA Test Cells and in the fiberglass Porta-PSTA mesocosms because of the many unanswered questions about PSTA effectiveness prior to this research and demonstration project. This section provides a summary of the observed effects of each key treatment variable on PSTA outflow TP concentration and TP removal performance.

3.4.1 Water Depth and Dry-Out

Water depth was one of the key treatment variables for the PSTA research. Three different water depth regimes were tested:

- Stable water levels at 60 cm
- Stable water levels at 30 cm
- Varying water depths between 0 and 60 cm

The effects of water depth on TP removal performance can be examined by comparison of treatment averages for outflow TP and k_1 for the OPP in Exhibit 3-17, by examination of the standard errors in the exhibit, and by a review of statistical analyses presented in Appendix G. Standard errors were calculated based on all individual weekly values for TP out and for monthly values for k_1. Detailed statistical analyses are presented in Appendix G.

EXHIBIT 3-17
Depth Effects for the Optimal Performance Period

						TP Out (µg/L)		k_1 (m/y)		k-C* Model		
Treatment	**Cell**	**Phase**	**Substrate**	**Depth**	**HLR**	**Average**	**SE**	**Average**	**SE**	k_{PFR}	k_{TIS}	**C***
PP-1	9,11,18	1	PE	D	L	14.1	0.71	10.6	1.71	61.9	99.6	15.2
PP-3	12,14,17	1, 2	PE	S	L	17.0	0.46	12.7	0.97	54.0	88.7	15.5
STC-1	13	1	PE	D	L	16.3	0.92	8.3	1.60	34.9	51.1	12.9
STC-4	13	2	PE (Ca)	S	L	20.0	1.35	2.8	1.30	8.5	9.2	***13.0***
PP-2	4,7,8	1	SR	D	L	13.0	0.39	11.7	1.15	46.5	67.2	10.7
PP-4	3,5,10	1, 2	SR	S	L	14.6	0.32	16.8	0.80	43.2	62.9	11.4
PP-6	1,6,15	1	SR	V	V	14.5	0.41	7.9	0.79	39.6	76.5	13.4
STC-2	8	1	SR	D	L	13.3	0.43	9.1	1.03	31.7	44.6	10.0
STC-5	8	2	SR	S	L	11.7	0.52	11.5	0.83	20.7	25.2	6.6
STC-3/6	3	1, 2	SR	V	V	17.9	0.91	6.9	1.41	11.1	12.4	***10.0***

Notes:
Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells
Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade
Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)
HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate
Weekly data used in calculations
bold and italics = values fixed in model

Average water depths between 30 and 60 cm in peat-based mesocosms did not have a statistically significant effect on PSTA performance. Shallow depth slightly increased the outflow TP concentration and had variable effects on the removal rate constant in the peat Porta-PSTA treatments. A decline in k_1 at the shallow depth was only observed in the peat-based PSTA Test Cell; however, this difference is potentially confounded by the soil treatment that occurred in this cell between Phase 1 and Phase 2.

Average water depths between 30 and 60 cm in peat-based mesocosms did not have a clear effect on PSTA performance. Average water depths between 30 and 60 cm in shellrock mesocosms did not have a clear effect on performance for TP removal. Variable water depth accompanied by varying hydraulic loads did reduce TP removal performance in the shellrock mesocosms.

Depth effects on the performance of shellrock-based PSTA treatments were not clear. Based on data from the OPP, the shallow Porta-PSTA shellrock treatment did not show a significant difference in average TP outflow concentration than the deep treatment, but the TP removal rate constant, k_1, was significantly higher in the 30-cm treatment. In the depth test in the shellrock Test Cells, the shallow treatment performed better than the deep treatment, both for outflow TP and for the TP removal rate constant and C*. The shellrock treatments with variable water regime generally had higher TP outflow concentrations and lower values for k_1. In conclusion,

average water depths between 30 and 60 cm in shellrock mesocosms did not have a clear effect on performance for TP removal. Variable water depth accompanied by varying hydraulic loads reduced TP removal performance in the shellrock mesocosms.

3.4.2 Soil Type and Amendments

Three types of soils and two non-soil controls were employed in the PSTA mesocosms:

- Peat (high organic content) agricultural soils
- Shellrock
- Sand (beach)
- No soil
- Aquamat (synthetic substrate)

Also, there were two soil amendments tested:

- Application of lime to the peat soils
- Rinsing the sand soils with dilute HCl

The effects of these soil treatments on PSTA TP removal performance can be examined by comparing treatment combinations for the OPP (see Exhibit 3-18). At both water depths in the Porta-PSTA mesocosms, shellrock out-performed peat and sand. In the PSTA Test Cells, shellrock also outperformed peat. Sand treatments were not consistently better or worse than the peat treatments. The shallow sand treatment (PP-7) performed nearly as well as the comparable shellrock treatment.

At both water depths in the Porta-PSTA mesocosms, shellrock outperformed peat and sand. In the PSTA Test Cells, shellrock also outperformed peat.

Exhibit 3-18 also compares the performance of the Phase 2 Porta-PSTA treatments with limerock, HCl-rinsed sand, Aquamat, and no soil with the replicated peat and shellrock treatments. These data averages for the OPP indicate that the limerock and two non-soil treatments performed about as well as the shellrock treatment and better than the peat treatment, and the acid-rinsed sand treatment out-performed all of the other treatments, both in terms of achievable outflow TP concentration and k_1. This result was especially notable because the k-C* model returned an estimated C* for this treatment of 4.5 µg/L. This concentration is lower than any other known measured C*, except for natural areas of the Everglades and cannot be lowered further because of natural inputs of TP from rainfall.

Limerock and two non-soil treatments performed about as well as the shellrock treatment, and the acid-rinsed sand treatment out-performed all of the other treatments, both in terms of achievable outflow TP concentration and k_1. This result was especially notable because the k-C model returned an estimated C* for this treatment of 4.5 µg/L.*

It was observed during Phase 1 that peat soils released labile P to the water column at a higher rate and for a longer period than the calcium-based shellrock soils (CH2M HILL, August 2000). Phase 2 PSTA research in these mesocosms

EXHIBIT 3-18
Soil Effects for the Optimal Performance Period

						TP Out (µg/L)		k_1 (m/y)		k-C* Model		
Treatment	**Cell**	**Phase**	**Substrate**	**Depth**	**HLR**	**Average**	**SE**	**Average**	**SE**	**kPFR**	**kTIS**	**C***
PP-1	9,11,18	1	PE	D	L	14.1	0.71	10.6	1.71	61.9	99.6	15.2
PP-2	4,7,8	1	SR	D	L	13.0	0.39	11.7	1.15	46.5	67.2	10.7
PP-8	20	1	SA	D	L	16.1	1.06	6.4	3.21	89.3	185.2	***15.0***
PP-3	12,14,17	1, 2	PE	S	L	17.0	0.46	12.7	0.97	54.0	88.7	15.5
PP-4	3,5,10	1, 2	SR	S	L	14.6	0.32	16.8	0.80	43.2	62.9	11.4
PP-7	19	1, 2	SA	S	L	15.2	0.61	15.3	1.30	31.1	40.8	10.3
PP-11	23	1, 2	SR	S	L	17.8	0.67	11.7	1.24	39.6	54.6	12.9
PP-12	24	1, 2	PE	S	L	18.6	0.73	9.9	1.30	44.9	65.8	15.2
STC-1/4	13	1, 2	PE / PE (Ca)	D/S	L	18.4	0.89	5.0	1.06	58.5	108.5	18.0
STC-2/5	8	1, 2	SR	D/S	L	12.4	0.36	10.5	0.66	47.2	76.4	10.2
PP-3	12,14,17	1, 2	PE	S	L	17.0	0.46	12.7	0.97	54.0	88.7	15.5
PP-4	3,5,10	1, 2	SR	S	L	14.6	0.32	16.8	0.80	43.2	62.9	11.4
PP-14	4,7,8	2	LR	S	L	14.5	0.79	14.8	1.79	27.6	34.6	***8.0***
PP-17	20	2	SA (HCl)	S	L	11.4	0.93	20.1	2.44	42.4	63.0	4.5
PP-18	21	2	None	S	L	14.0	1.06	15.5	2.27	32.8	43.9	***8.2***
PP-19	22	2	AM	S	L	13.8	1.83	17.4	3.15	28.6	36.2	***7.0***

Notes:
Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells
Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade
Depth = S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)
HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate
Weekly data used in calculations
bold and italics = values fixed in model

was expanded to look at the effects of amending some of the peat (organic) soils with calcium minerals recommended by Ann et al. (2000).

PSTA South Test Cell Treatment 1 (STC-1 or Test Cell 13) was converted to South Test Cell Treatment 4 (STC-4) by the addition of approximately 1,580 kg of hydrated lime [$Ca(OH)_2$], providing an effective application rate of 7 metric tonnes per hectare (mt/ha). Porta-PSTA treatment PP-3 was converted to PP-13 using the same amount of lime addition. All emergent macrophytes in these mesocosms were removed as part of this process. Spikerush was replanted once the soil amendment was finished. The other notable difference between the conversion from STC-1 to STC-4 and from PP-3 and PP-13 was that the water depth was lowered in the PSTA Test Cell but not in the Porta-PSTA.

Exhibit 3-19 provides a comparison of the results from each of these four treatments. Results are summarized for the POR, the OPP, and for the last 60 days of each treatment. Comparison of outflow TP concentrations, TP mass removals, and k_1 indicate that there was no observed benefit of liming in the PSTA peat-based Test Cell. However, in the Porta-PSTA treatments, there was a significant benefit. The difference between these two mesocosm scales probably results from the method of lime addition. Lime was added to the PSTA Test Cell by hand broadcasting in the partially drained cell. This disturbed the peat sediments because of the foot traffic involved. Lime addition in the Porta-PSTA tanks was from outside the tank with minimal internal disturbance. It appears that to be effective for controlling internal releases of TP, lime addition on a large scale would need to avoid or minimize soil disturbance.

EXHIBIT 3-19

PSTA Amended Peat Soils Data Summary

Treatment	Period	q_in (cm/d)	Wtr Depth (m)	TP (µg/L) Inflow	TP (µg/L) Outflow	TP ($g/m^2/yr$) Inflow	TP ($g/m^2/yr$) Outflow	Removal ($g/m^2/yr$)	Calc_k (m/yr)
STC-1	POR	4.6	0.64	25	27	0.43	0.50	-0.07	-1.2
(Peat)	OPP	4.6	0.65	29	17	0.50	0.28	0.22	9.3
	Last 60 d	4.7	0.66	28	13	0.48	0.17	0.31	13.3
STC-4	POR	5.1	0.28	23	32	0.42	0.54	-0.12	-6.6
(Peat - Ca)	OPP	5.1	0.29	22	19	0.40	0.33	0.07	2.0
	Last 60 d	5.1	0.28	23	30	0.42	0.46	-0.04	-5.1
PP-3	POR	7.4	0.30	29	19	0.75	0.47	0.28	12.1
(Peat)	OPP	8.0	0.31	27	17	0.77	0.46	0.30	13.7
	Last 60 d	7.0	0.30	22	18	0.58	0.42	0.16	5.5
PP-13	POR	8.1	0.33	30	18	0.84	0.50	0.34	14.8
(Peat - Ca)	OPP	8.8	0.34	21	13	0.66	0.40	0.26	14.6
	Last 60 d	8.9	0.34	22	11	0.71	0.35	0.37	21.3

Notes:
POR = period of record
OPP = optimal performance period

3.4.3 Hydraulic and Phosphorus Loading Rate

HLR was a treatment variable at the Porta-PSTA mesocosm scale. The only design difference between shellrock treatments PP-2 and PP-5 was hydraulic loading, with a two-fold difference between the two treatments. Data for the OPP indicate that increasing the hydraulic loading to an average rate of approximately 17 cm/d from 9 cm/d increased the average outflow TP concentration (from 13 to 16 µg/L), increased k_1 (from 13 to 27 m/yr), increased k_{PFR} and k_{TIS} (from 46 to 68 m/yr and from 67 to 90 m/yr, respectively), and had no effect on C* (11 µg/L for both treatments) (Exhibits 3-7 and 3-8).

The removal rate constants in both the one- and two-parameter TP removal models are a function of loading rate. TP removal rate constants for differing technologies can only be accurately compared when they are presented on the basis of TP loading.

It is clear from this comparison and from earlier regressions between HLR and TP mass removal (CH2M HILL, May 2001) that the removal rate constants in both

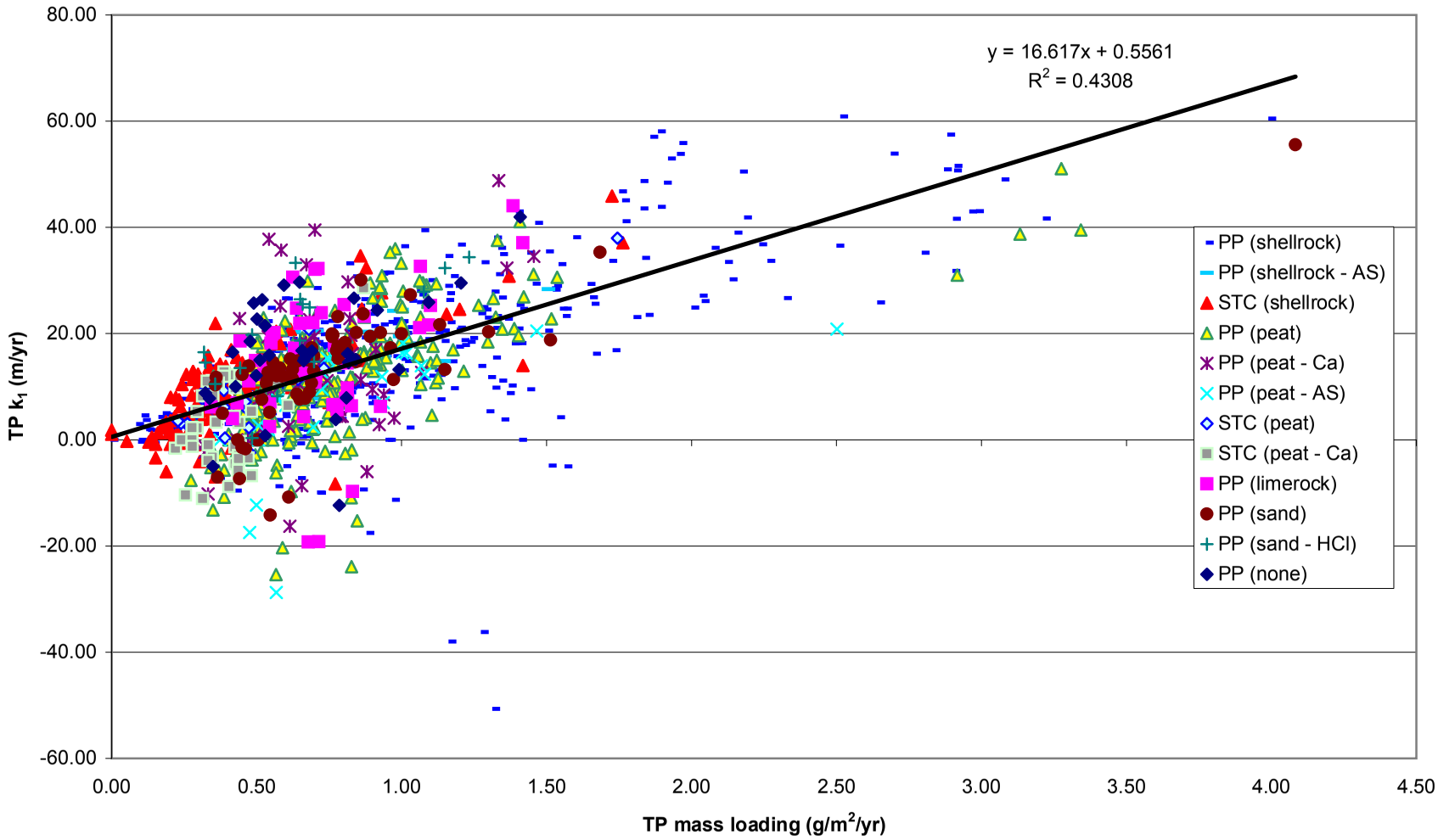


EXHIBIT 3-20

Relationship Between Inflow TP Mass Loading Rate and k_{1TP} for the PSTA Mesocosms for the Optimal Performance Period

the one- and two-sizing parameter TP removal models described above are a function of loading rate (see, for example, Exhibit 3-20). This relationship indicates that these models have limited utility for treatment area because the removal rate constant chosen for a given flow and inlet load varies with the selected treatment footprint. It also indicates that TP removal rate constants for differing technologies can only be accurately compared when they are presented on the basis of TP loading.

One impact of this finding is that it may be possible to remove a significantly greater mass of TP in a PSTA operated at a higher hydraulic loading, as long as the lowest possible outflow TP concentration is not desired downstream. This finding affects the potential trade off between maximizing TP mass removed and minimizing effects of downstream TP concentrations.

3.4.4 Batch Operation

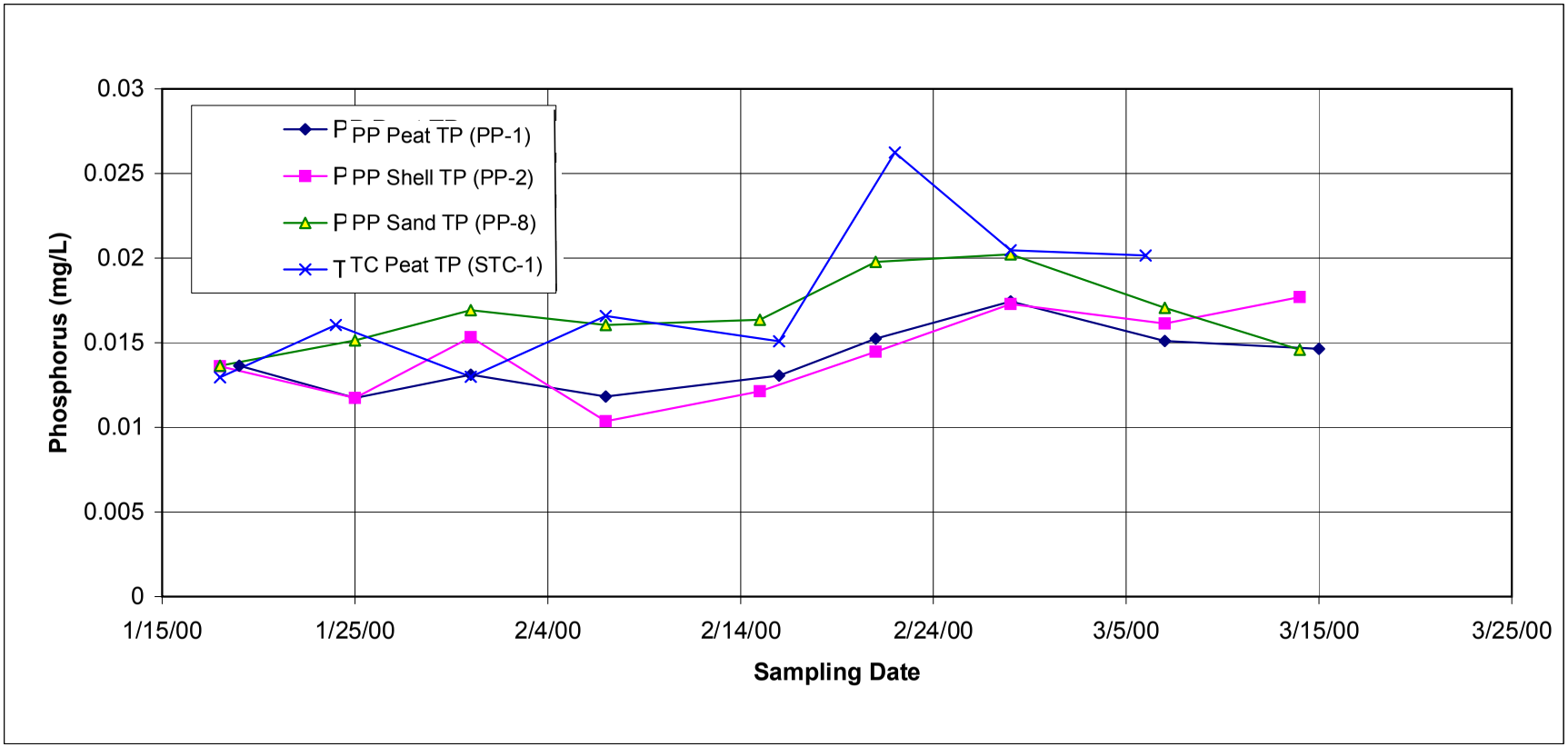
A batch-mode study was conducted in selected PSTA treatments between January 18 and March 14, 2000. The purpose of this study was to determine whether TP concentration in the PSTA water columns would increase or decrease following cessation of inflows and whether these concentrations would level off to some stable value without pumped inflows. A decline could be interpreted to indicate the dominance of an external loading effect on TP outflow concentration. When loading of external TP is stopped, water column concentrations could be expected to decline to a new lower equilibrium concentration in response to a balance between internal loading and removal processes. A rise in TP concentration to a higher stable concentration is an indication that internal P loading from soils is greater than the gross biological removal rate of the periphyton community. Stable concentrations during the batch study would indicate a balance between internal loads and removals.

Exhibit 3-21 illustrates the results of the batch-mode study. TP water column concentrations increased or remained relatively constant in each of the mesocosms tested. None of the TP concentrations decreased during the 2-month period. Increases were generally in the range of 15 to 50 percent in the Porta-PSTAs that were tested. The STC-1 (peat) average water column TP concentration increased by approximately 54 percent. These results provide a convincing demonstration of the importance of internal P loading on the achievable C* in these PSTA mesocosms. Under the conditions of this study (first year, peat, shellrock, and sand soils, etc.), batch mesocosms did not attain TP concentrations less than 10 ppb and typically had values between 10 and 20 ppb. Rising TP water column concentrations in some treatments during the period of this batch study resulted from continuing soil releases of labile TP nearly 1 year after startup. This internal loading appeared to be highest in the peat-based PSTA Test Cell. A detailed description of the batch treatments is provided in Appendix D.

These results provide a convincing demonstration of the importance of internal P loading on the achievable C in these PSTA mesocosms. Rising TP water column concentrations resulted from continuing soil releases of labile TP nearly 1 year after startup.*

EXHIBIT 3-21

TP Water Column Concentrations During the Batch-Mode Study in Selected PSTA Mesocosms During Phase 1



3.4.5 Velocity (Recirculation)

During Phase 2, PP-15 (shallow shellrock with recirculation) tested the effects of higher flow velocity on TP removal performance against a comparable treatment, PP-4, with low HLR. Both treatments were replicated. PP-15 had re-circulation pumps installed to provide approximately 20 gallons per minute (gpm) of pumping from the downstream end of the tank back to the inflow baffle. This re-circulation pumping resulted in a velocity increase with no increase in influent TP loading. The nominal velocity in PP-4 was 0.0014 cm/s; in PP-15, nominal velocity was approximately 0.5 cm/s. Actual average velocities during these Phase 2 investigations for the three replicates ranged from 0.18 to 0.34 cm/s because of variable pumping rates in the replicate mesocosms.

An initial increase in average TP outflow concentration was observed in PP-15 as a result of running the re-circulation pumps (Exhibit 3-22). This resulted in a higher average of 18 µg/L in the re-circulation treatment, compared to 17 µg/L in PP-4. However, no detectable difference in performance between the two treatments during the last 4 months of the test was observed. The OPP averages for these two treatments were nearly identical at approximately 15 µg/L. Exhibit 3-23 illustrates the time series for k_{1TP} values for these two treatments. Phase 2 OPP averages for PP-4 and PP-15 were 16 and 13 m/yr, respectively. In summary, installation of re-circulation and resulting higher velocities (190x increase) in the shellrock Porta-PSTAs did not provide any observed enhancement of TP outflow concentration or TP mass removal rate.

Installation of re-circulation and resulting higher velocities (190x increase) in the shellrock Porta-PSTAs did not provide any observed enhancement of TP outflow concentration or TP mass removal rate.

3.4.6 Mesocosm Scale

All mesocosm research systems have certain limitations for scale-up to full-scale design (Bowling et al., 1980; Beyers and Odum, 1993). Reduced-size systems may have unrealistic surface-area-to-volume ratios and flow velocity regimes. Scale-up effects are likely when extrapolating from small test systems to larger, full-scale systems. The PSTA research included specific treatment combinations that provide some quantification of the effect of mesocosm scale on treatment performance. Two Porta-PSTA scales were tested: 1-m and 3-m-wide fiberglass tanks. Both sets of tanks were 6 m long, so the scale difference between these tanks was quantified as the depth: width ratio. The 1-m-wide Porta-PSTA tanks had a nominal depth: width ratio of either 0.6 or 0.3 depending on water depth. The 3-m-wide tanks had a nominal depth: width ratio of approximately 0.1. The PSTA Test Cells had the least effect of scale, with a nominal depth: width ratio of approximately 0.02.

Exhibit 3-24 summarizes the effect of mesocosm scale on the key P performance indicators: average outflow concentration and k_1 for the OPP. For the peat-based PSTA mesocosms, increasing scale (reduced edge or wall effects) resulted in increasing outflow TP concentrations. The effect of scale on the TP one-

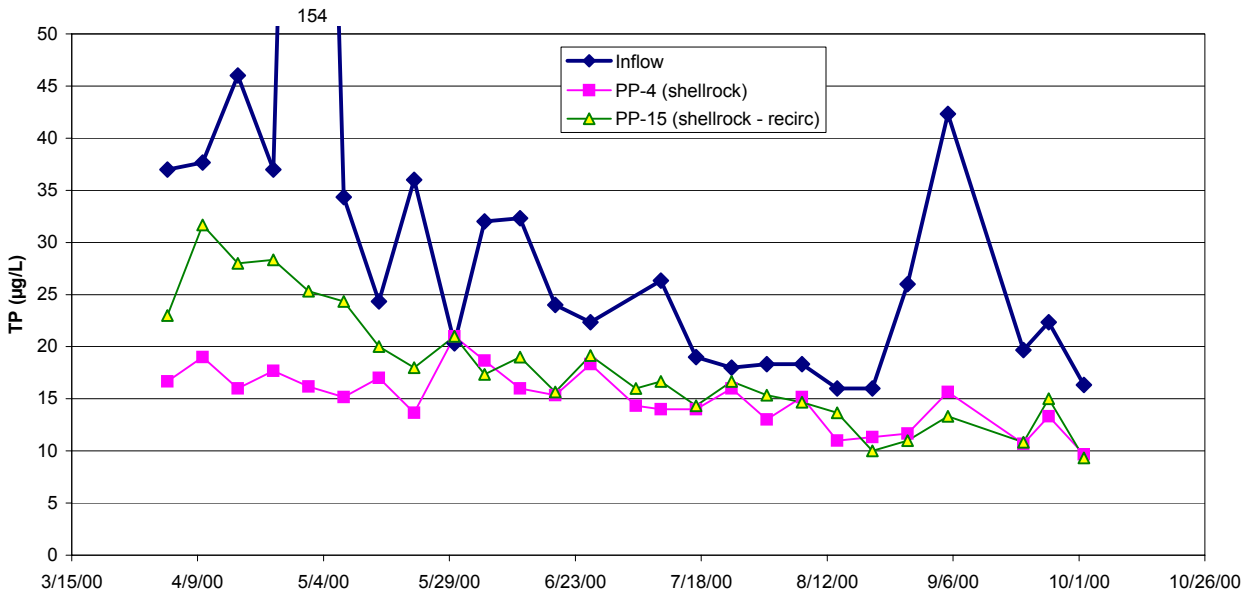


EXHIBIT 3-22
Porta-PSTA TP Inflow and Outflow Concentrations in Treatments PP-4 (Shellrock) and PP-15 (Shellrock with Recirculation) for Phase 2

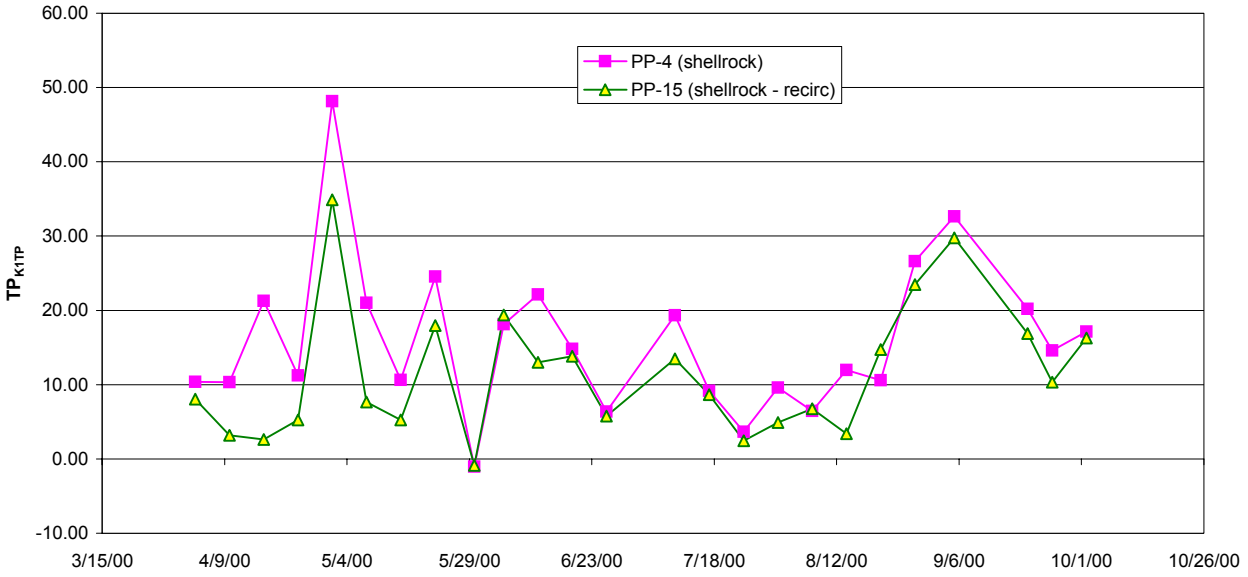


EXHIBIT 3-23
Porta-PSTA k_{1TP} Values in Treatments PP-4 (Shellrock) and PP-15 (Shellrock with Recirculation) for Phase 2

EXHIBIT 3-24

Mesocosm Scale Effects for the OPP

							TP Out (µg/L)		k_1 (m/yr)		k-C* Model		
Treatment	**Cell**	**Phase**	**Substrate**	**Depth:Width**	**Depth**	**HLR**	**Average**	**SE**	**Average**	**SE**	k_{PFR}	k_{TIS}	**C***
PP-1	9,11,18	1	PE	0.600	D	L	14.1	0.71	10.6	1.71	61.9	99.6	15.2
PP-3	12,14,17	1, 2	PE	0.300	S	L	17.0	0.46	12.7	0.97	54.0	88.7	15.5
PP-12	24	1, 2	PE	0.100	S	L	18.6	0.73	9.9	1.30	44.9	65.8	15.2
STC-1	13	1	PE	0.021	D	L	16.3	0.92	8.3	1.60	34.9	51.1	12.9
STC-4	13	2	PE (Ca)	0.021	S	L	20.0	1.35	2.8	1.30	8.5	9.2	***13.0***
PP-2	4,7,8	1	SR	0.600	D	L	13.0	0.39	11.7	1.15	46.5	67.2	10.7
PP-4	3,5,10	1, 2	SR	0.300	S	L	14.6	0.32	16.8	0.80	43.2	62.9	11.4
PP-11	23	1, 2	SR	0.100	S	L	17.8	0.67	11.7	1.24	39.6	54.6	12.9
STC-2	8	1	SR	0.021	D	L	13.3	0.43	9.1	1.03	31.7	44.6	10.0
STC-5	8	2	SR	0.021	S	L	11.7	0.52	11.5	0.83	20.7	25.2	6.6

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

Weekly data used in calculations

bold = values fixed in model

parameter removal rate constant k_1 was not consistent but generally resulted in lower rate constants. For the shellrock treatments, increasing the scale had no consistent effect on either the TP outflow concentration or the value of k_1.

If there is a scale effect, it appears to be one of over-estimation of TP removal performance in the smallest test systems.

As a result, a consistent effect of mesocosm scale was not detected under this project, either because no relationship exists or because of limited replication and measurement sensitivity. If there is a scale effect, it appears to be one of over-estimation of TP removal performance in the smallest test systems. This line of reasoning indicates that conclusions from the Porta-PSTAs may be overly optimistic and that the data from the PSTA Test Cells may be more reliable for extrapolation to full-scale design.

3.4.7 Periphyton and Macrophytes

Two Porta-PSTA control tanks were operated with Aquashade for comparison to the vegetated Porta-PSTA treatments to obtain an indication of the importance of periphyton and macrophytes to the observed P removal rates. These treatments, PP-9 (peat) and PP-10 (shellrock), were unreplicated and operated only during Phase I. For both soil types, the outflow TP concentration (OPP) from the Aquashade control was higher than the corresponding vegetated tank (Exhibit 3-25). This difference was significant for the peat-based mesocosms but not for shellrock.

EXHIBIT 3-25
Aquashade Treatment Results with Respect to Plant/Periphyton Effects for the OPP

							TP Out (µg/L)		k_1 (m/y)		k-C* Model		
Treatment	Cell	Phase	Plants/ Periphyton	Substrate	Depth	HLR	Average	SE	Average	SE	k_{PFR}	k_{TIS}	C*
PP-1	9,11,18	1	yes	PE	D	L	14.1	0.71	10.6	1.71	61.9	99.6	15.2
PP-9	21	1	no	PE (AS)	D	L	19.5	1.30	7.0	2.50	35.5	46.3	***16.0***
PP-2	4,7,8	1	yes	SR	D	L	13.0	0.39	11.7	1.15	46.5	67.2	10.7
PP-10	22	1	no	SR (AS)	D	L	14.6	0.68	15.3	1.36	35.8	47.7	9.8

Notes:
Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells
Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade
Depth = S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)
HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate
Weekly data used in calculations
bold and italics = values fixed in model

Aquashade effects on the average k_1 and k-C* model parameters (Phase 1 OPP) were not consistent. The Aquashade k_1 value was lower by 34 percent for the peat soils and was higher by 23 percent for shellrock soils. C* estimates were similar for each treatment pair.

The Aquashade peat tank had a higher TP outflow concentration (than the shellrock tank), a greater estimated C*, and a lower estimated value for k_1 than the

shellrock tank, providing additional evidence of greater internal loading from the peat soils than from shellrock. In addition, Aquashade treatments were nearly as effective for TP removal as treatments with fairly dense periphyton and macrophyte communities. Based on chlorophyll and biomass sampling, the Aquashade treatments were colonized by low levels of algae but also contained significant populations of heterotrophic microbes. These results may indicate that the net difference between TP removal and recycling effects of the periphyton and macrophytes is relatively minor and these processes offset each other to the point of having little consistent influence on the TP mass removal rate. However, the presence of periphyton and plants resulted in lower achievable TP outflow concentrations. A larger number of controls would have been beneficial to detect effects of periphyton and macrophytes. These data indicate that results from mesocosms must be interpreted with caution.

3.5 Phosphorus Dynamics and Fate

The PSTA research data offer insight into the processes important in evaluating the potential of a periphyton-based concept for full-scale use. While the research design focused on assessing the "green box" parameters important in sizing a full-scale PSTA, insight has been gained into understanding the processes of TP cycling and the fate of the TP that is removed within the mesocosms. Specific processes discussed below include the fate of P in the mesocosm soils, the observed changes in non-reactive organic P forms, gross P accretion rates in new sediments, and the effects of snail grazing on the net P removal.

3.5.1 Soil P Interactions

Exhibit 3-26 summarizes PSTA soil data by treatment for the POR. Appendices C and D provide detailed soil P data for the ENR Test Cells and the Porta-PSTAs, respectively. Shellrock soils had the highest TP concentrations, with average values in the routine soil cores ranging from 752 to 1,044 mg/kg. The average concentration was 919 mg/kg for shellrock. Peat treatment averages ranged from 111 to 319 mg/kg, with an overall average TP of 223 mg/kg. Sand treatments averaged between 20 and 28 mg/kg with an overall average of 26 mg/kg. TIP made up approximately 68 percent of the TP in the peat soils, 99 percent in the shellrock soils, and 46 percent in the sand soils. Total organic phosphorus (TOP) accounts for the rest of the TP in these soils.

The majority of the TP in the shellrock soils is calcium-bound and approximately half of the TP in the peat soils is associated with calcium. These measurements indicate that the peat and sand soils can release P to the water column at higher water concentrations than the shellrock soils.

Detailed P fractionation in the soils indicated that approximately four times as much labile TP existed in peat soils than in the shellrock soils, and that the sand soils had only approximately half as much as the shellrock soils (POR). The majority of the TP in the shellrock soils is calcium-bound and approximately half of the TP in the peat soils is associated with calcium. Soil sorption studies before startup and 1 year later are summarized in Exhibit 3-27. The equilibrium P

EXHIBIT 3-26

Average Soil (upper 10 cm) Phosphorus Fractions (mg/kg) in the PSTA Mesocosms

						Routine Soil Cores (Monthly)			Detailed Phosphorus Fractionation (Quarterly)					
										Inorganic Phosphorus Fractions		Organic Phosphorus Fractions		
Treatment	Phase	Cell	Substrate	Depth	HLR	TP	TIP	TOP	TP	Labile	Calcium-Bound	Labile	Moderately Labile	Residual
PP-1	1	9,11,18	PE	D	L	208	117	91	190	4	75	10	7	43
PP-2	1	4,7,8	SR	D	L	1,044	950	94	840	3	887	2	-18	41
PP-3	1, 2	12,14,17	PE	S	L	177	108	69	222	4	90	10	5	49
PP-4	1, 2	3,5,10	SR	S	L	983	952	31	873	3	953	1	-21	42
PP-5	1	2,13,16	SR	D	H	985	932	53	1020	2	998	2	-24	36
PP-6	1	1,6,15	SR	V	V	975	966	9	839	2	914	2	-16	50
PP-7	1, 2	19	SA	S	L	28	12	16	30	1	5	0	1	12
PP-8	1	20	SA	D	L	24	13	11	24	1	3	2	2	5
PP-9	1	21	PE (AS)	D	L	206	116	90	223	6	85	8	6	53
PP-10	1	22	SR (AS)	D	L	941	932	9	975	4	967	1	-16	43
PP-11	1, 2	23	SR	S	L	925	916	10	977	3	947	1	-23	39
PP-12	1, 2	24	PE	S	L	207	144	64	187	4	120	9	4	49
PP-13	2	9,11,18	PE (Ca)	S	L	111	90	21	119	2	70	7	10	31
PP-15	2	2,13,16	SR	S	R	933	982	-49	981	3	975	0	-29	41
PP-16	2	1,6,15	SR	V	V	880	939	-59	1011	3	988	-1	-30	41
PP-17	2	20	SA (HCl)	S	L	20	9	11	30	2	16	-1	2	8
STC-1	1	13	PE	D	L	319	273	46	346	25	189	4	-15	53
STC-2	1	8	SR	D	L	831	793	38	837	3	781	1	-17	61
STC-3	1	3	SR	V	V	886	864	23	816	4	807	1	-10	52
STC-4	2	13	PE (Ca)	S	L	248	212	36	247	23	165	6	-10	52
STC-5	2	8	SR	S	L	752	767	-15	789	4	731	1	-21	48
STC-6	2	3	SR	V	V	899	878	20	927	3	986	1	-31	46
			PE			223	151	72	229	8	113	8	2	49
			PE (Ca)			180	151	29	196	15	127	6	-2	44
			SR			919	906	14	902	3	906	1	-21	45
			SA			26	12	14	27	1	4	1	2	9
			SA (HCl)			20	9	11	30	2	16	-1	2	8
			ALL			572	544	28	568	5	534	3	-11	41

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

EXHIBIT 3-27

Average Soil Phosphorus Sorption Characteristics During Phase 1

	EPCo (mg/L)		Kd (L/kg)		So (mg/kg)		TP (mg/kg)		DRP-water (mg/kg)		DRP-$NaHCO_3$ (mg/kg)		DRP-HCl (mg/kg)	
Substrate	**Jan-99**	**Mar-00**	**Jan-99**	**Mar-00**	**Jan-99**	**Mar-00**	**Jan-99**	**Mar-00**	**Jan-99**	**Mar-00**	**Jan-99**	**Mar-00**	**Jan-99**	**Mar-00**
Peat	0.013	0.051	47.1	33	-0.6	-1.7	185	201	4.67	1.03	26.23	7.88	131	124
Shellrock	0.002	0.003	812	1349	-1.8	-4.6	1071	1003.5	1.27	0.03	8.70	3.34	855	940
Sand	0.014	ND	4.79	ND	-0.07	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes: Kd = linear adsorption coefficient; So = initial adsorbed P at C=0 (negative sign indicates desorbable P); EPCo = equilibrium P concentration; ND = not determined

concentration at zero DRP concentration was much lower in the shellrock soils (2 to 3 µg/L) than in the peat and sand soils (13 to 51 µg/L). These measurements indicate that the peat and sand soils can release P to the water column at higher water concentrations than the shellrock soils. The linear adsorption coefficient is much higher for the shellrock soils than for the peat and sand soils. This coefficient is measured with DRP and is not indicative of potential for P sorption actually observed in the PSTA mesocosms.

Exhibits 3-28 to 3-30 provide time series plots of TP, TIP, and TOP for selected peat, shellrock, and sand PSTA treatments, respectively. An average measurement for each parameter is indicated by the bold line on the trend charts. A clear declining trend in the TP and TIP soil concentrations in the peat-based PSTAs (Exhibit 3-28) was evident. This downward trend was significant during the first 2 to 3 months of operation and was most pronounced in the peat-based Test Cell (STC-1/4). A slight downward trend in soil TP appears to continue throughout the POR, although measured changes are slight. TOP in these soils was relatively constant throughout the study period.

Initial soil TP concentration in PP-3 (peat) was 188 mg/kg at a bulk density of 0.33 grams per cubic centimeter (g/cm^3). The final TP content of these soils during the destructive sampling event in February 2001 was 130 mg/kg at an average bulk density of 0.36 g/cm^3. TIP declined from approximately 112 to 94 mg/kg in this treatment. Based on a 20-cm soil depth, this loss of TP from the substrate is equivalent to an estimated internal areal load of 2.9 g/m^2 for the study period.

No consistent trend in soil TP concentrations was evident for shellrock and sand (Exhibits 3-29 and 3-30). An apparent seasonal decline in TOP in the shellrock soils during the winter and spring of the first year of operation was observed, with an increasing trend in the summer and fall of the second year and a possible increase in TOP in the sand soils during the POR.

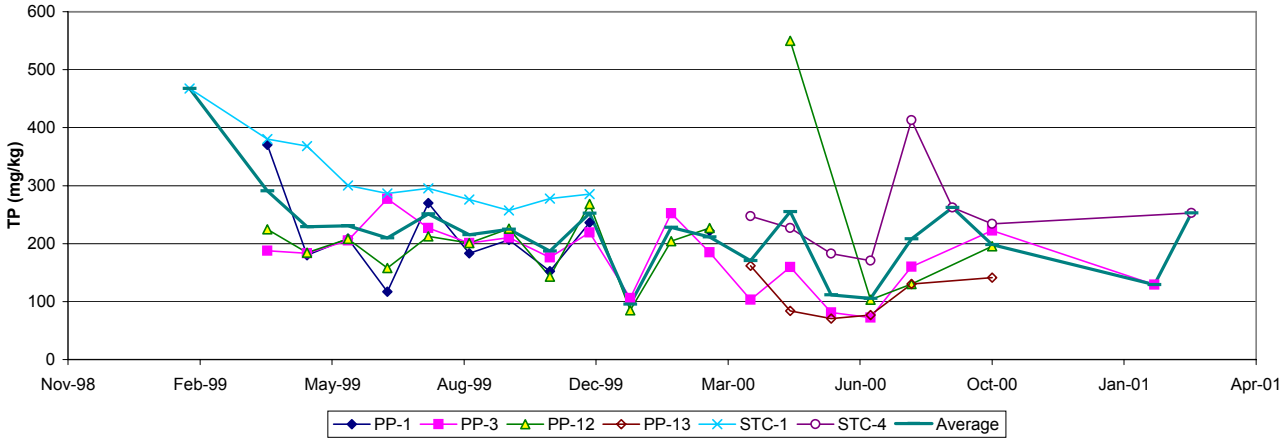
The initial soil TP concentration in PP-4 (shellrock) was 903 mg/kg at a bulk density of 1.31 g/cm^3. The final TP content of these soils during the destructive sampling event in February 2001 was 961 mg/kg at an average bulk density of 1.41 g/cm^3. TIP also increased slightly from approximately 912 to 938 mg/kg in this treatment. Based on a 20-cm soil depth, this increase of TP in the substrate is equivalent to an estimated 34 g/m^2 for the study period.

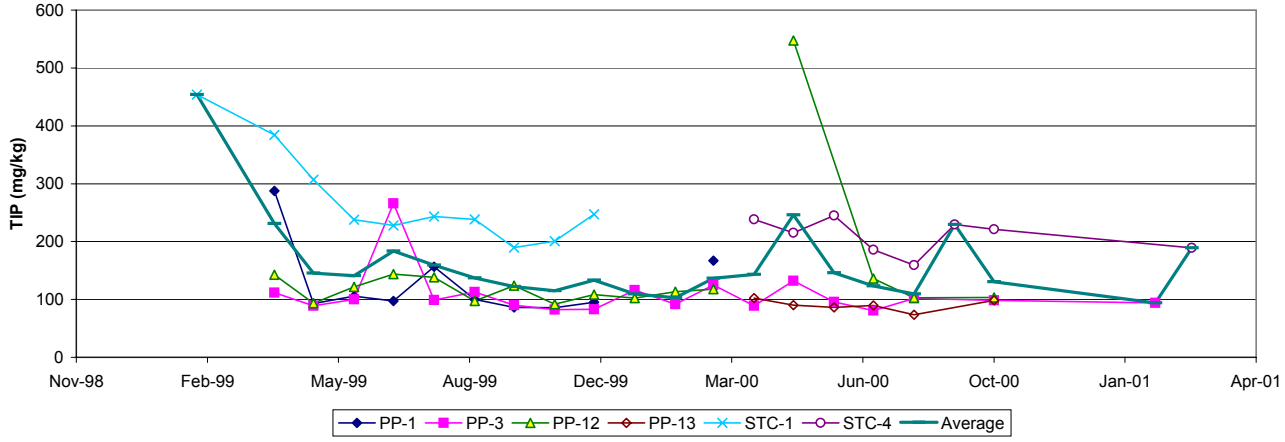
The initial soil TP concentration in PP-7 (untreated sand) was 16.6 mg/kg at a bulk density of 1.43 g/cm^3. The final TP content of these soils during the destructive sampling event in February 2001 was 20.0 mg/kg at an average bulk density of 1.42 g/cm^3. TIP declined from approximately 13.1 to 9.8 mg/kg in this treatment. Based on a 20-cm soil depth, the estimated increase of TP in these soils is equivalent to an estimated 0.88 g/m^2 for the study period.

The initial soil TP concentration measured in the HCl-rinsed sand Porta-PSTA treatment PP-17 was 25.0 mg/kg at a bulk density of 1.16 g/cm^3. The final TP content of these soils during the destructive sampling event in February 2001 was 19.4 mg/kg at an average bulk density of 1.46 g/cm^3. TIP declined from

EXHIBIT 3-28

Soil TP, TIP, and TOP Concentrations for PSTA Peat Treatments (POR)





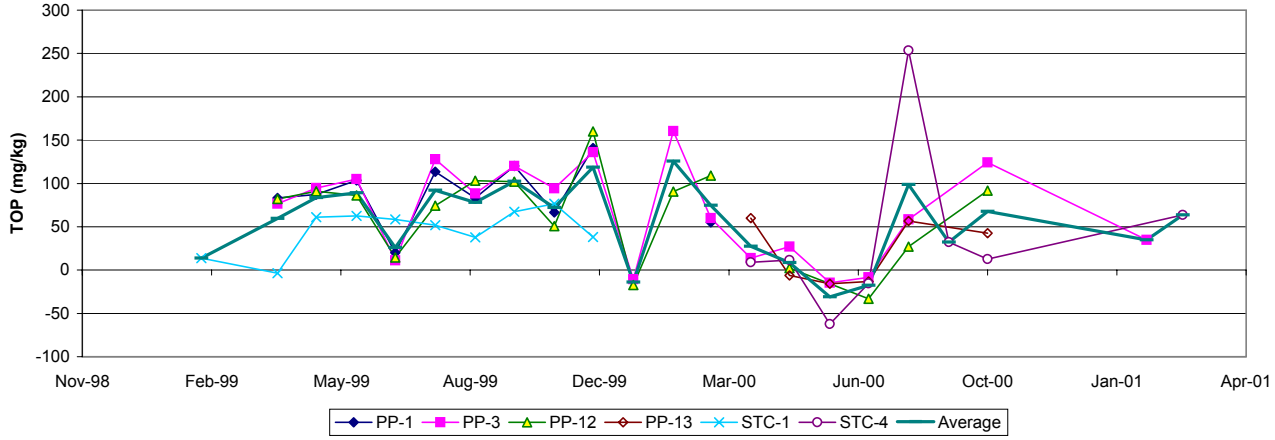
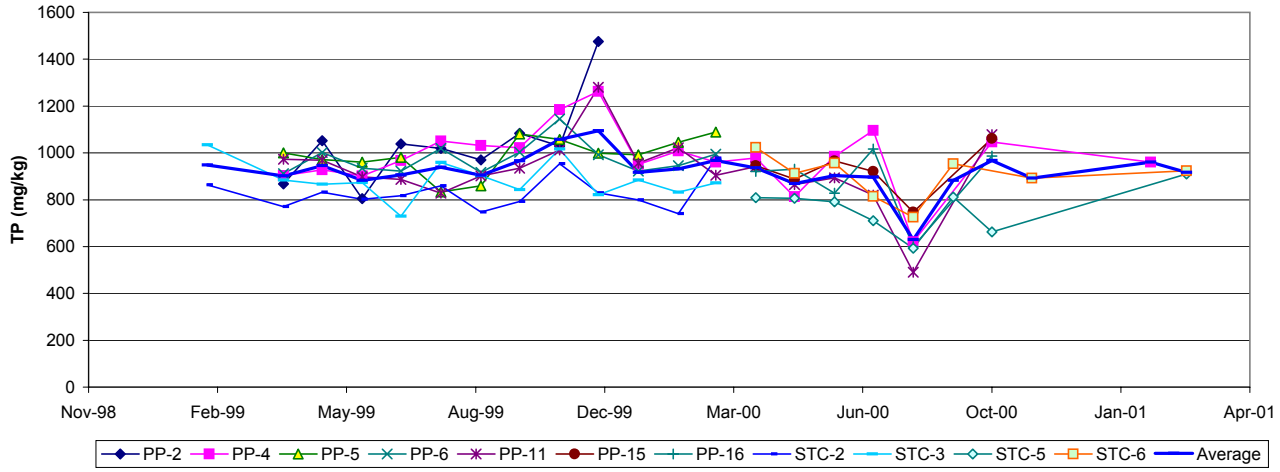
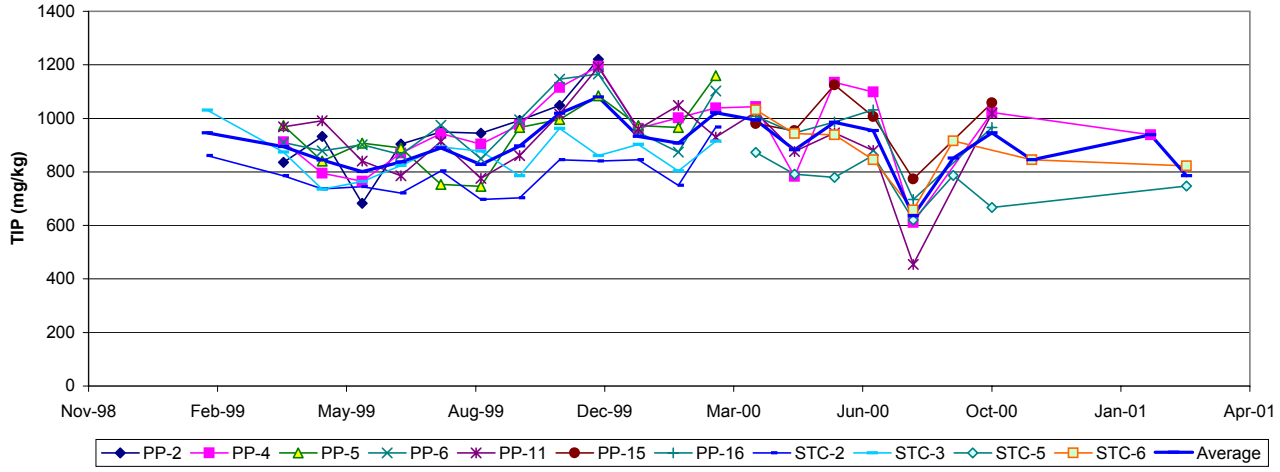


EXHIBIT 3-29

Soil TP, TIP, and TOP Concentrations for PSTA Shellrock Treatments (POR)





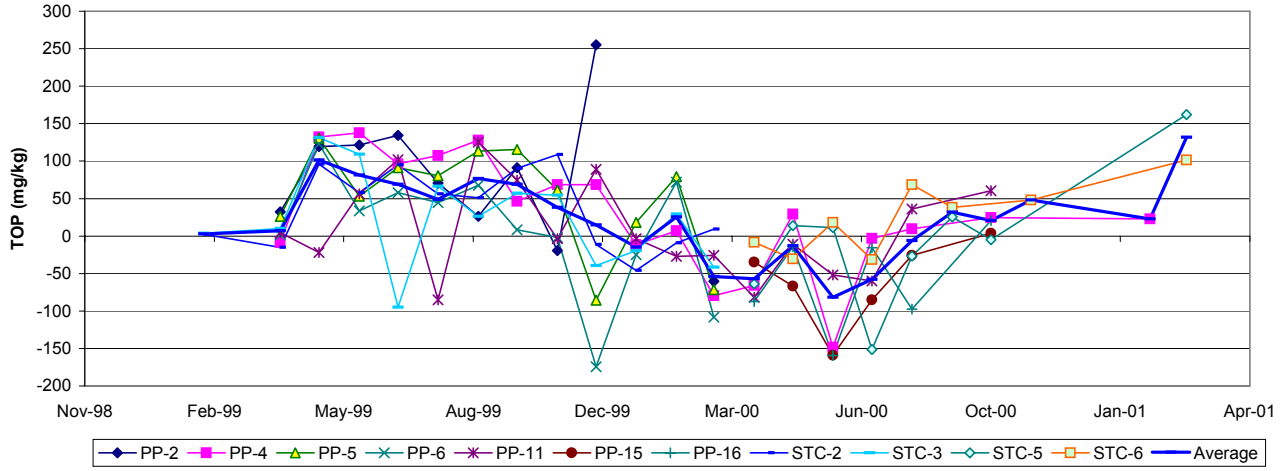
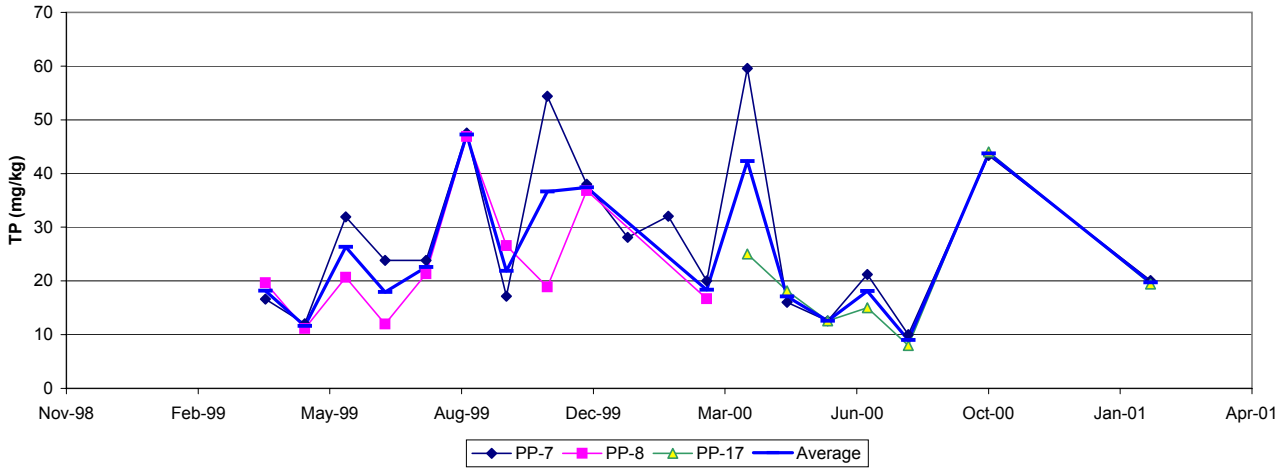
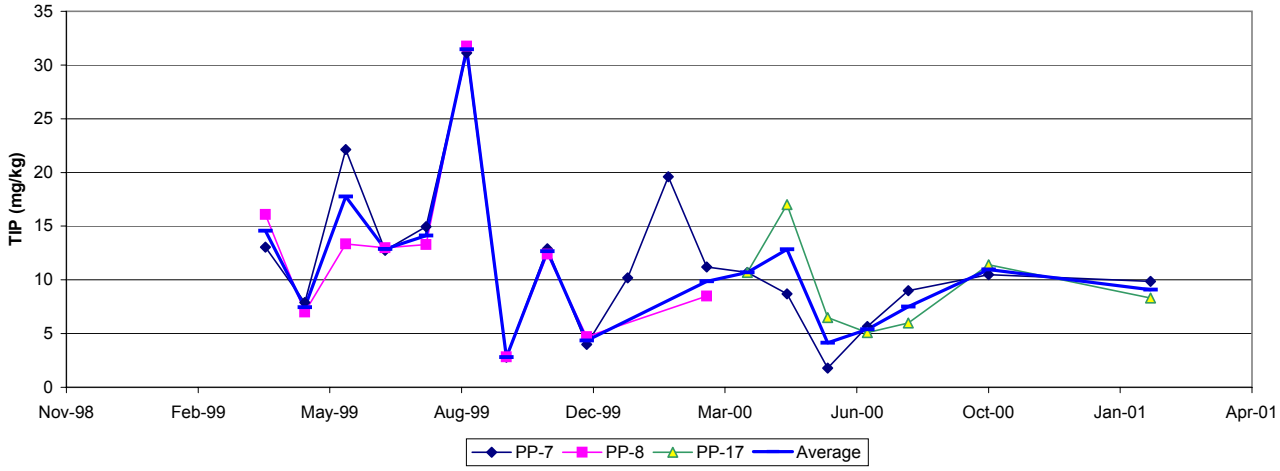
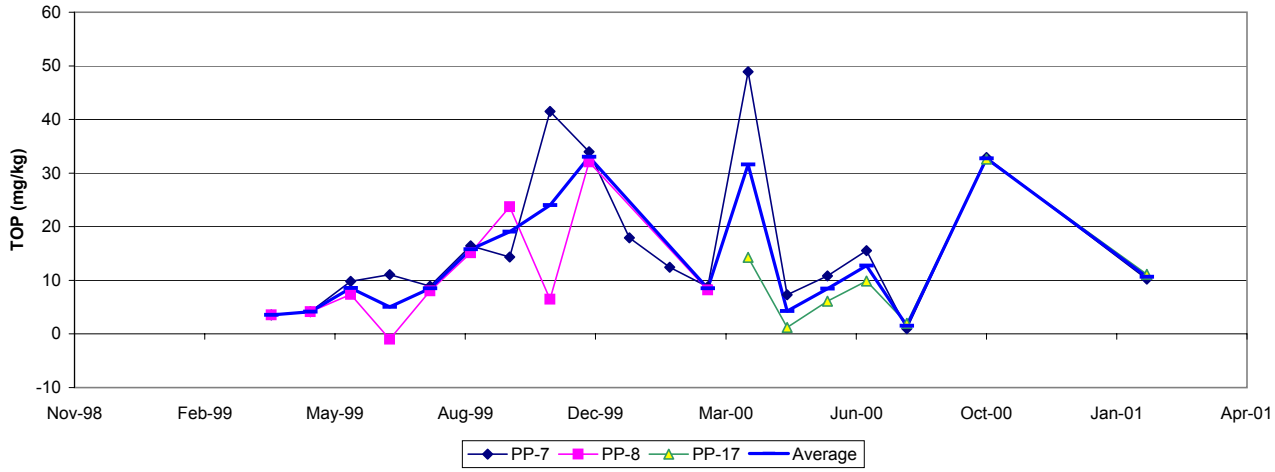


EXHIBIT 3-30

Soil TP, TIP, and TOP Concentrations for PSTA Sand Treatments (POR)







approximately 10.7 to 8.3 mg/kg in this treatment. Based on a 20-cm soil depth, the estimated decrease of TP in these soils is equivalent to an estimated 0.12 g/m^2 for the period of this research.

Although average TP soil concentrations in the shellrock treatments were much higher than in the peat soils in Phase 2, the labile inorganic P concentration in the peat soils is higher. This finding strengthens the Phase 1 report conclusion that a continuing potential exists for release of inorganic P from the organic soils in STC-1/4 (CH2M HILL, August 2000). While the mass release of labile P from these peat soils is probably too small to detect in the trend plots, this release likely contributed to the higher observed outflow TP concentration and the lower k_{1TP} value in this treatment.

Mesocosm soils represent the largest storage of P as highlighted below assuming a 20-cm soil depth:

- **Peat-based soils:** Based on a dry bulk density of 0.3 g/cm^3 and an average TP concentration of 200 mg/kg, peat-based systems contain approximately 12 g P/m^2. In February 2001, approximately 9.1 g P/m^2 was measured in the peat-based Porta-PSTAs during destructive sampling.
- **Shellrock soils:** Assuming a dry bulk density of 1.3 g/cm^3 and an average TP concentration of 1,000 mg/kg, shellrock soils contain approximately 260 g P/m^2. In February 2001, approximately 267 g P/m^2 was measured in shellrock Porta-PSTAs during destructive sampling.
- **Sand soils:** Based on a dry bulk density of 1.3 g/cm^3 and an average TP concentration of 30 mg/kg, sand contains approximately 7.8 g P/m^2. In February 2001, approximately 5.7 g P/m^2 was measured in sand Porta-PSTAs during destructive sampling.

Small return fluxes of P from the mesocosm soils could result in net TP removal rates that are much less than the actual gross removals by periphyton/ macrophyte growth and sediment accretion.

These soil TP masses are significantly larger than the small mass of TP in the water column (approximately 0.006 to 0.012 g/m^2), in the plants and periphyton (typically less than 1 g/m^2), or the net amount removed in these test systems during the POR (0.06 to 0.57 g P/m^2). Small return fluxes of P from the mesocosm soils could result in net TP removal rates that are much less than the actual gross removals by periphyton/macrophyte growth and sediment accretion.

3.5.2 Periphyton Phosphorus

Total and inorganic P concentrations were also quantified in the periphyton community on a monthly basis throughout the study period. Non-reactive forms of P in the periphyton were determined quarterly. Exhibit 3-31 summarizes these periphyton P data by treatment and soil type. Overall periphyton TP treatment averages ranged from 183 to 1,440 mg/kg. Shellrock treatments reported the highest TP concentrations, with an overall average of 740 mg/kg. Peat treatments had an average TP concentration of 448 mg/kg in the peri-

EXHIBIT 3-31

Periphyton Mat Phosphorus Fractions (mg/kg) in the PSTA Mesocosms

						Routine Periphyton Cores (Monthly)			Detailed Phosphorus Fractionation (Quarterly)					
										Inorganic Phosphorus Fractions		Organic Phosphorus Fractions		
Treatment	Phase	Cell	Substrate	Depth	HLR	TP	TIP	TOP	TP	Labile	Calcium-Bound	Labile	Moderately Labile	Residual
PP-1	1	9,11,18	PE	D	L	346	88	258	251	3	81	96	51	51
PP-2	1	4,7,8	SR	D	L	617	263	353	370	2	268	63	-3	44
PP-3	1, 2	12,14,17	PE	S	L	399	110	289	298	3	91	161	23	46
PP-4	1, 2	3,5,10	SR	S	L	800	259	541	571	2	320	46	1	38
PP-5	1	2,13,16	SR	D	H	744	212	532	456	2	284	92	11	47
PP-6	1	1,6,15	SR	V	V	706	236	470	539	1	330	39	-4	29
PP-7	1, 2	19	SA	S	L	385	49	335	154	1	69	45	13	20
PP-8	1	20	SA	D	L	295	36	259	103	1	41	78	38	25
PP-9	1	21	PE (AS)	D	L	366	119	247	268	3	63	98	5	34
PP-10	1	22	SR (AS)	D	L	554	326	227	214	2	54	78	8	25
PP-11	1, 2	23	SR	S	L	1,124	479	644	720	2	437	75	-7	62
PP-12	1, 2	24	PE	S	L	737	200	538	483	4	156	289	-3	92
PP-13	2	9,11,18	PE (Ca)	S	L	283	184	99	277	2	133	94	20	44
PP-14	2	4,7,8	LR	S	L	183	67	115	355	2	221	121	7	46
PP-15	2	2,13,16	SR	S	R	579	275	303	535	2	245	204	27	74
PP-16	2	1,6,15	SR	V	V	712	350	362	353	2	228	56	22	35
PP-17	2	20	SA (HCl)	S	L	205	65	140	90	3	47	51	11	29
PP-18	2	21	None	S	L	220	90	130	120	2	95	72	8	33
PP-19	2	22	AM	S	L	405	188	218	234	2	194	85	5	40
STC-1	1	13	PE	D	L	393	96	298	428	4	137	308	21	105
STC-2	1	8	SR	D	L	512	150	362	409	2	183	132	33	71
STC-3	1	3	SR	V	V	422	103	319	656	3	208	196	24	89
STC-4	2	13	PE (Ca)	S	L	793	220	573	653	24	125	306	63	90
STC-5	2	8	SR	S	L	669	128	540	311	3	69	187	24	36
STC-6	2	3	SR	V	V	1,440	345	1,095	508	2	266	204	32	93
			PE			448	123	326	338	3	104	192	22	68
			PE (Ca)			538	202	336	503	15	128	221	46	71
			SR			740	261	479	499	2	257	117	14	56
			LR			183	67	115	355	2	221	121	7	46
			SA			340	43	297	142	1	63	52	19	21
			SA (HCl)			205	65	140	90	3	47	51	11	29
			None			313	139	174	177	2	145	78	6	36
			ALL			556	186	370	374	3	174	127	17	52

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

phyton mat, except for the calcium-amended treatment, which averaged 538 mg/kg. The periphyton in the limerock treatment averaged 183 mg/kg TP. The sand treatments had between 205 and 340 mg/kg TP, and the Aquamat treatment averaged 405 mg/kg TP. The non-soil control tank grew periphyton with an average TP concentration of 220 mg/kg.

Final destructive sampling in February 2001 further fractionated the periphyton TP and determined that TP concentrations depend to some extent on the periphyton growth habit. Benthic periphyton had the highest TP concentration in all treatments, except the sand treatment where the wall periphyton had higher TP concentrations.

These results indicate that periphyton in calcium-rich waters and over calcium-rich soils accumulate more TP than those over sandy or organic soils. An appreciable amount of the periphyton TP is in unavailable forms, both inorganic and organic. These are the fractions that are most likely to be accreted and can result in long-term removal of P from the PSTA water column.

Periphyton TIP was typically highest in the shellrock treatments with an average concentration of 261 mg/kg. The peat treatments were lower at 123 mg/kg TIP, except for the calcium-amended treatments with an average of 202 mg/kg TIP. The sand treatment had the lowest TIP concentrations (43 mg/kg). Non-soil controls were intermediate with an average of 139 mg/kg. Calcium-bound (non-reactive) TIP varied from 41 to 437 mg/kg in the periphyton. The shellrock and limerock treatments had the highest amount of calcium-bound TIP, while the sand treatments had the least.

A large fraction of the periphyton TP was in a labile organic form. The highest concentration of labile organic P was found in the peat treatments, with an average of 192 mg/kg. The shellrock treatments averaged 117 mg/kg, and the sand treatments averaged 52 mg/kg.

These results indicate that periphyton in calcium-rich waters and over calcium-rich soils accumulate more TP than those over sandy or organic soils, which are relatively low in calcium. Clearly, a portion of the TP is in the form of soil particles lifted by benthic periphyton mats and re-deposited throughout the water column as metaphyton and floating mats. However, the periphyton P is much more available than the soil P described earlier. From 15 to 65 percent of this TP is labile organic P, whereas very little of the TIP is labile. An appreciable amount of the periphyton TP is in unavailable forms, both inorganic and organic. These are the fractions that are most likely to be accreted and can result in long-term removal of P from the PSTA water column.

3.5.3 P Accretion Rates

Net accretion of P-bearing sediments was difficult to assess in the PSTA mesocosms. Benthic periphyton mats developed in most treatments and were subsequently lifted by gas bubble formation and re-deposited or stranded at the water surface as floating mats. Horizon markers were variably exposed and re-covered by this periphyton mat movement and were not successfully retrieved at the end of the study. Independent assessment of a net accretion rate was not feasible over the time frame of this research, leaving estimation of net losses of P to

differences in water mass loads. Gross sediment accretion rates were estimated from sediment trap data. Wet accretion refers to the unconsolidated settled material. Dry accretion is the oven dry weight of the trapped material. TP accretion is based on the dry weight times the TP content of the collected sediment, as summarized in Exhibit 3-32. A large difference in the amount of TP deposited in the traps was observed between treatments, depending on soil type. The overall average TP accretion rate was estimated as approximately 0.66 g TP/m^2/yr, based on an average wet accretion of approximately 5 cm/yr of sediments. The average TP accretion rate for the shellrock treatments was higher at 0.93 g TP/m^2/yr . Based on field observations, a fraction of the TP deposition in the shellrock treatments is in the form of shellrock soils that were lifted with the benthic periphyton mat and then re-deposited as sediments. The average TP deposition rate was lower in the peat-based mesocosms (0.18 g/m^2/yr), and was even lower in the sand-based controls (0.09 g/m^2/yr). The Aquashade control mesocosms had TP sedimentation rates approximately equal to the peat-based mesocosms with 0.17 to 0.20 g TP/m/yr. The non-soil controls had very high wet accretion rates (average 10.8 cm/yr) and moderate TP accretion rates (0.42 g/m^2/yr).

3.5.4 Effects of Snail Grazing

The effect of snail density on average TP k_1 values was consistently detrimental.

High snail populations were not observed in the three PSTA Test Cells, but snails were a dominant grazer in a subset of the Porta-PSTA mesocosms. In these systems, snails did not have a consistent effect on average periphyton biomass measured with cores; however, they did have an apparent effect on the average outflow TP concentration and on the net TP removal rate k_1 (Exhibit 3-33). At an average snail density greater than approximately 30 per m^2, the long-term outflow TP concentration was typically increased by approximately 1 to 3 µg/L.

The effect of snail density on average TP k_1 values was consistently detrimental. In PP-6 (shellrock with variable HLR), the k_1 value decreased by 40 percent at a snail density of 37 snails/m^2 and by 12 percent at a snail density of 52.3 snails/m^2. In PP-5 (deep shellrock with high HLR), k_1 was reduced by approximately 46 percent at a snail density of 21.2 snails/m^2. In PP-16 (shellrock with variable HLR), with a snail density of 32 snails/m^2, the k_1 value was reduced by 25 percent. Between the two sand controls (with different depths), a snail density of 93.6 snails/m^2 reduced k_1 by 52 percent.

Differences in snail density between the Porta-PSTAs appear to have been related to stochastic effects. Because of a lack of visual observations or counts of fish and birds, the lack of a snail population increase in the Test Cells is assumed to be related to the ability of larger predators (birds and larger fish) to better manage snail populations as a result of the larger mesocosm scale. Therefore, snails are not likely to be a nuisance in a full scale system. This assumption requires further study and verification.

EXHIBIT 3-32

Sediment Trap Data from the PSTA Mesocosms (POR)

Treatment	Phase	Cell	Substrate	Depth	HLR	Wet Accretion (cm/yr)	Dry Accretion ($g/m^2/yr$)	TP Accretion ($g/m^2/yr$)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Wet Weight (g)	Dry Weight (g)	Moisture Content (%)	TP (mg/kg)	Ash (%)
PP-1	1	9,11,18	PE	D	L	0.96	390	0.19	1.00	0.039	36.84	1.38	96.01	484	43
PP-2	1	4,7,8	SR	D	L	1.46	493	0.22	0.89	0.039	49.67	1.92	95.56	596	64
PP-3	1, 2	12,14,17	PE	S	L	1.35	452	0.23	1.27	0.026	59.29	1.45	97.55	594	32
PP-4	1, 2	3,5,10	SR	S	L	4.30	3476	2.18	0.95	0.089	124.26	13.02	90.74	618	79
PP-5	1	2,13,16	SR	D	H	1.45	512	0.32	0.90	0.041	54.80	2.27	95.56	688	64
PP-6	1	1,6,15	SR	V	V	0.94	552	0.36	0.86	0.070	31.18	2.38	91.87	725	72
PP-7	1, 2	19	SA	S	L	4.22	1868	0.16	1.18	0.065	100.80	7.03	93.36	54	78
PP-8	1	20	SA	D	L	0.15	67	0.03	0.87	0.043	5.92	0.29	95.00	454	78
PP-9	1	21	PE (AS)	D	L	0.49	217	0.17	1.00	0.049	21.39	0.96	95.13	770	47
PP-10	1	22	SR (AS)	D	L	1.49	219	0.20	0.61	0.015	39.69	0.97	97.48	908	70
PP-11	1, 2	23	SR	S	L	3.41	1388	0.87	1.56	0.055	76.19	5.32	92.63	492	74
PP-12	1, 2	24	PE	S	L	1.11	191	0.13	1.13	0.016	40.87	0.61	98.57	797	30
PP-13	2	9,11,18	PE (Ca)	S	L	11.46	1485	0.56	0.47	0.020	135.51	4.45	96.31	394	61
PP-14	2	4,7,8	LR	S	L	1.31	262	0.07	1.16	0.023	23.87	0.79	97.08	300	65
PP-15	2	2,13,16	SR	S	R	5.90	1635	0.98	1.12	0.038	127.62	4.67	96.31	638	64
PP-16	2	1,6,15	SR	V	V	7.05	1728	0.84	0.71	0.044	98.34	5.18	94.22	490	73
PP-17	2	20	SA (HCl)	S	L	7.84	2684	0.43	0.45	0.034	106.08	8.04	92.42	159	77
PP-18	2	21	None	S	L	12.35	1529	0.38	0.34	0.012	125.58	4.58	96.35	247	64
PP-19	2	22	AM	S	L	9.35	2467	0.46	0.57	0.026	158.70	7.39	95.34	188	67
STC-4	2	13	PE (Ca)	S	L	7.04	5188	2.50	0.76	0.070	282.76	21.06	90.72	680	76
STC-5	2	8	SR	S	L	10.09	2765	2.06	0.74	0.030	347.37	13.13	95.64	691	63
STC-6	2	3	SR	V	V	16.16	1938	1.23	0.35	0.014	154.73	5.80	96.11	650	58
			PE			0.98	312	0.18	1.10	0.032	39.60	1.10	96.82	661	38
			PE (Ca)			9.25	3337	1.53	0.62	0.045	209.14	12.76	93.52	537	69
			SR			5.23	1470	0.93	0.87	0.044	110.38	5.47	94.61	649	68
			LR			1.31	262	0.07	1.16	0.023	23.87	0.79	97.08	300	65
			SA			2.18	968	0.09	1.03	0.054	53.36	3.66	94.18	254	78
			SA (HCl)			7.84	2684	0.43	0.45	0.034	106.08	8.04	92.42	159	77
			None			10.85	1998	0.42	0.45	0.019	142.14	5.98	95.85	218	65
			ALL			5.00	1432	0.66	0.86	0.039	100.07	5.12	95.00	528	64

Notes:

Mesocosm Treatments: PP = Porta-PSTAs, STC = South Test Cells

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

Depth: S = shallow (30 cm), D = deep (60 cm), V = variable (0-30 cm or 0-60 cm)

HLR: L = low (6 cm/d), H = high (12 cm/d), V = variable (0-6 cm/d or 0-12 cm/d), R = recirculate

Sample Area = 154 cm^2 (14.0 cm diameter)

EXHIBIT 3-33

Effects of Snail Density on Periphyton Biomass, Average TP Outflow Concentrations, and k_1 Values for Porta-PSTA Treatments

Treatment	Soil	Porta-PSTA Tank	Average Snail Density (#/m^2)	Average Periphyton Ash-Free Dry Weight (g/m^2)	Average TP Out (mg/L)	k_1 (m/yr)
PP-1	PE	9	1.7	617.6	0.014	7.9
		11	0.8	500.9	0.021	-1.2
		18	3.1	555.2	0.018	1.7
PP-2	SR	4	2.5	163.1	0.016	8.2
		7	0.2	226.4	0.017	6.0
		8	2.3	134.4	0.018	2.2
PP-3	PE	12	2.9	431.2	0.019	8.3
		14	2.1	257.7	0.014	16.5
		17	9.6	536.1	0.020	6.2
PP-4	SR	3	1.9	112.1	0.016	13.5
		5	2.2	131.8	0.016	13.1
		10	7.5	110.0	0.017	10.9
PP-5	SR	2	3.0	141.4	0.019	10.9
		13	21.2	109.1	0.019	9.1
		16	0.1	177.8	0.016	17.0
PP-6	SR	1	37.0	118.8	0.019	3.6
		6	52.3	117.3	0.017	5.3
		15	0.0	126.4	0.016	6.0
PP-7	SA	19	0.5	148.8	0.017	10.5
PP-8	SA	20	93.6	182.7	0.020	-0.6
PP-9	PE (AS)	21	0.9	951.1	0.019	5.5
PP-10	SR (AS)	22	0.1	170.8	0.016	9.5
PP-11	SR	23	5.1	131.3	0.020	7.3
PP-12	PE	24	12.5	362.6	0.020	7.2
PP-13	PE (Ca)	9	1.5	1785.8	0.020	14.8
		11	1.8	446.4	0.017	18.3
		18	0.0	889.6	0.020	11.3
PP-14	LR	4	2.3	113.7	0.013	25.3
		7	2.5	138.2	0.017	17.2
		8	2.3	93.5	0.017	16.9
PP-15	SR	2	1.8	243.1	0.018	15.4
		13	6.7	324.4	0.019	12.4
		16	2.2	90.3	0.016	15.2
PP-16	SR	1	32.2	173.7	0.017	19.2
		6	3.5	122.8	0.019	29.1
		15	3.2	191.9	0.016	22.4
PP-17	SA (HCl)	20	12.5	191.9	0.014	20.9
PP-18	None	21	NS	287.4	0.017	17.9
PP-19	AM	22	NS	174.7	0.015	20.3

Notes:

Mesocosm Treatments: PP = Porta-PSTAs

Substrate: PE = peat, SR = shellrock, LR = limerock, SA = sand, None = no substrate, AM = Aquamat, AS = Aquashade

NS = not sampled

3.6 Summary of PSTA Effectiveness

The PSTA project provided the following findings relevant to the effectiveness for TP reduction:

- Under the study conditions, the minimum achievable outflow TP concentrations from PSTA mesocosms constructed on shellrock soils were approximately 11 to 12 µg/L (during 2 years of operation). The lowest long-term average TP outflow concentrations were 17 µg/L on peat soils, 15 µg/L on sand soils, 11 µg/L on acid-rinsed sand soils, and approximately 14 µg/L on limerock soils and in non-soil controls.
- TP removal rate constants generally increased following 3 to 5 months of startup to relatively high levels during the first year of operation. TP removal rates remained high in shellrock and sand-based PSTA mesocosms, but were variable or declined in peat mesocosms during the second year of operation.
- Antecedent soil type and conditions appear to have an effect on P removal performance during startup and to a lesser extent during continuing operation up to 2 years. Labile reactive P in antecedent soils results in reduced performance and higher TP outflow concentrations. Batch-mode studies indicate that internal TP loading mechanisms are still active with the peat soil types tested even after 1 year of operation. This internal loading is likely responsible for the finding of a "glass floor" for TP outflow concentrations under the conditions of this PSTA research project.
- Higher TP loading rates result in higher TP mass removal rates with a related rise in average outflow concentrations. This finding indicates that mass load removals could be maximized if allowable outflow concentration limits can be relaxed upward.
- The scale of the PSTA research mesocosms may have an effect on observed TP outflow concentrations and k values. Performance estimates from smaller-scale mesocosms may be overly optimistic compared to results from full-scale treatment units.
- Increased outflow TP concentrations and variable removal rate constants in the Aquashade control mesocosms demonstrate the complex details related to P cycling in these PSTA test units. While high photosynthetic activity may be important for lowering TP to the lowest achievable concentrations, the presence of macrophytes, and to a lesser extent periphyton, may also slightly lower the net TP mass removal rate.
- TP accretion rates are generally comparable to net TP removal rates estimated by inflow-outflow mass balances. Wet accretion represents an average of approximately 5 cm/yr. Actual accreted sediments would be less than this amount, providing a preliminary indication that as long as adequate levee free board is provided, harvesting to remove accumulated sediments would not be required during the expected project life (>50 years).

These results indicate that PSTAs can be designed to remove TP from agricultural waters at very low inlet TP concentrations typical of post-STA waters. Periphyton-dominated systems on substrates with low levels of labile P are able to achieve average outflow concentrations of 11 µg/L or less. However, net removal rate constants are not high at low inlet loading rates. This indicates that these periphyton-dominated treatment systems will require large land areas to achieve very low outlet TP concentrations.

By necessity, this research project has had a limited duration. For this reason, the long-term effectiveness of PSTAs for P management has not yet been fully proven. Some trends indicate that treatment performance may improve over time, especially if antecedent soils have low concentrations of labile P. Other data indicate that on organic soils that have a prior history of farming and fertilization, many years may be required to exhaust pre-existing P storages and fully integrate that P into newly-accreted periphyton residuals.

SECTION 4

PSTA Forecast Model, Conceptual Design, and Sustainability

4.1 Introduction

The PSTA Research and Demonstration Project has determined that periphyton-dominated mesocosms can remove TP from surface water inflows to relatively low outlet concentrations, comparable to or less than observed for any other non-chemical, advanced treatment technology alternative. However, because of the limited timeframe and scale of PSTA research facilities during Phase 1 and 2, the current assessment of sustainability of this removal performance and the overall cost of implementing and operating full-scale PSTAs remains preliminary.

This section provides the current rationale and conceptual design of a full-scale PSTA for stormwater treatment of P. The basis of this conceptual design is performance forecasting using a PSTA Forecast Model calibrated with the most appropriate data collected during the Phase 1 and 2 PSTA Research and Development Project. Results of the PSTA research and PSTA footprint estimates derived from the PSTA Forecast Model are in turn used as the basis of a PSTA Supplemental Technology Standards of Comparison (STSOC) analysis to allow comparison to other Advanced Treatment Technologies (ATTs).

In addition to developing a cost estimate for construction and operation of a full-scale PSTA, the STSOC analysis requires consideration of issues related to sustainability. Sustainability refers to the "maintenance of function over a long time period" and specifically, the "continuing capability to remove and store P in a stable form" (Kadlec, 2001).

To be considered sustainable, PSTAs must have the following characteristics:

- They must be able to consistently lower average concentrations of TP to levels protective of downstream environments for a long enough period to justify their implementation (capital and O&M) costs.

- Their ecological succession must be predictable enough to anticipate how often macrophyte management will need to occur.
- They must retain stored P in forms that will not create unpredictable future releases under foreseeable conditions of system dryout and flooding.
- They must not create short- or long-term internal or downstream nuisance conditions that will offset their beneficial P removal performance.

At this point in time, estimates of PSTA sustainability must be based on a combination of forecast modeling using computer-generated extrapolations from the existing database, from review of information from other research, including periphyton-dominated systems that are ecologically mature, and from the results of the STSOC. Current evidence concerning PSTA sustainability is summarized in this section along with a description of the PSTA Forecast Model and the results of the STSOC analysis.

4.2 PSTA Performance Forecasting

Computer models provide a useful tool for gathering information that cannot otherwise be obtained from experiments. The timeframe of the EFA and the cost of experimentation have required the construction of performance forecasting models of all of the "green" advanced treatment technologies. These models are grounded on the best data that are available and are constructed to answer questions about performance and sustainability while incorporating the maximum complexity that can be supported by the data. Highly complex models with numerous state variables cannot be supported by the data and have been found to have limited usefulness for performance forecasting. Simpler models with three to four state variables are being used for modeling of dynamic STA responses. The PSTA Forecast Model is similar in model structure and complexity to the Dynamic Model for Stormwater Treatment Areas (DMSTA) being constructed as a platform for comparing all of the "green" P treatment technologies (Walker and Kadlec, 2000).

The DMSTA model is applicable to PSTA and provides a relatively accurate description of the observed P removal performance. However, the DMSTA model does not include key ecological components of importance to specific ecosystem-based technologies. For example, the DMSTA model provides no indication of the amount of organic matter that accumulates because of the primary productivity of green treatment systems and does not include the seasonal influence of solar radiation—one of the principal external energy inputs driving processes in treatment wetlands. Understanding the carbon-based storages in addition to P is important in foreseeing management issues that will arise as green technologies mature.

4.2.1 PSTA Forecast Model Description

Methods for forecasting PSTA operation and performance range in complexity from single- to multiple-parameter models. One- and two-parameter model calibration results (k_1 and k-C^* models) were presented in the *PSTA Research and Demonstration Project Phase 1 Summary Report* (CH2M HILL, August 2000). In

addition, a "Level 2" PSTA Model was developed using a Microsoft® Access platform and was partially calibrated to provide a more complete and mechanistic method for performance forecasting. This interim model was prepared to provide insight into the ongoing PSTA research but was subsequently deemed to have more complexity than could ultimately be supported by experimental data generated by this study. The interim model was described in the *PSTA Research and Demonstration Project 5th Quarterly Report* (CH2M HILL, January 2000).

The final PSTA Forecast Model uses Microsoft® Excel as an operating platform rather than Access. This change was made to widen the audience that could use the PSTA Forecast Model for assessing expected performance. The Phase 2 PSTA Forecast Model includes the following modifications from the "Level 2" Access model described in earlier project reports:

- Inclusion of external forcing functions to provide the best understanding of processes that control the natural periphyton-based treatment system, including sunlight (seasonally variable), rainfall (both direct and through stormwater inputs), and atmospheric inputs/outputs (ET and atmospheric P loads).
- Simplification of the Level 2 model to only include predictions of TP data.
- Addition of a more dynamic water balance with stage-storage relationships.
- Consideration of human management influences (construction of landform, water pumping and depth control, biomass removal, maintenance, and related actions).

4.2.2 Data Sources

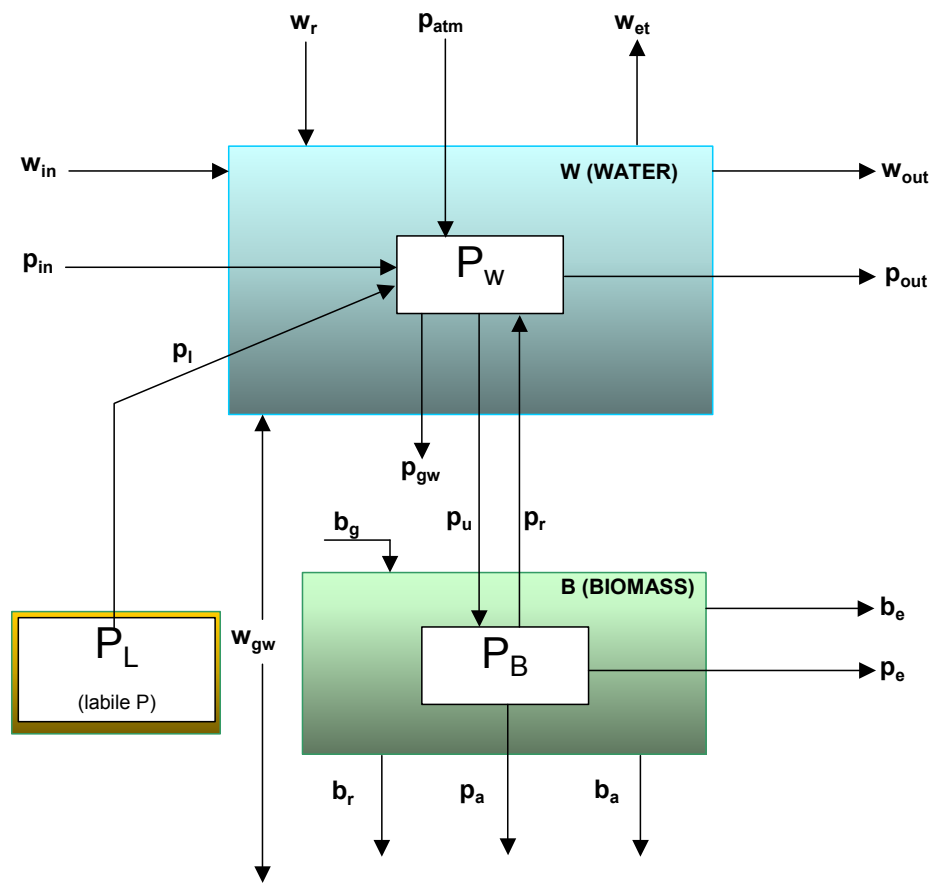
Data from three South Test Cells for the 24-month operational period were used to calibrate the final PSTA Forecast Model. Each of these cells is approximately 0.2 ha. The Porta-PSTA mesocosms were not used for model calibration because of their relatively small scale and because of the multitude of treatment variables. Those datasets could be used for model validation in the future, if desired. The Field-Scale PSTAs commenced operations in the summer of 2001. Data from these systems will provide the opportunity for future validation of the model calibrated using the PSTA Test Cell data.

4.2.3 Model Construction

Exhibit 4-1 presents a diagram of the PSTA Forecast Model along with the major state variable equations and definitions of variables. The model consists of four principal component storages:

- water (W)
- TP in the water column (PW)
- periphyton biomass (B)
- TP in the biomass (PB)

EXHIBIT 4-1
PSTA Phase 2 Forecast Model Diagram



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

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

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

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

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

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

In addition, an initial storage of labile P (P_L) is included to allow simulation of startup releases of TP from pre-existing soils and decaying vegetation. Each of these state variables is described in detail in the following paragraphs. Exhibit 4-2 summarizes the equations used to calculate each pathway or storage component and identifies the data sources that are available for model calibration.

4.2.3.1 Water Column (W)

The water column component is represented by a general water balance equation. The water "state" at any time is the difference between the sum of the flow inputs (pumped inflow and precipitation) and outputs (flow over the weir, ET, and groundwater exchange).

For model calibration, the pumped inflow and outflow over the weir were measured in the field. Precipitation data were provided by the District using on-site rain gauges. District ET data were utilized for estimates of this water loss at the PSTA research and demonstration site. No groundwater interactions were expected for water budgets for the PSTA Test Cells because all of these PSTA mesocosms are lined.

The final PSTA Forecast Model utilizes a single well-mixed tank hydraulic framework. This is based on the single-cell configuration of all of the PSTA research test units. Actual tracer data from the PSTA mesocosms indicated that their tracer residence time distributions could be best described as between 1.4 and 4.1 tanks-in-series (TIS). A 1.8 TIS model was constructed and tested. It was found that this model framework did not provide a better fit to the actual operational data than the single well-mixed tank model.

Based on treatment wetland theory, it is currently assumed that higher performance is likely at higher numbers of TIS (Kadlec and Knight, 1996; Kadlec, 2000). This theoretical performance enhancement has not been confirmed in any PSTA research and was not apparent in comparisons early and late in the PSTA project when the tracer-measured TIS increased. For these reasons, the PSTA Forecast Model platform was not re-built to allow testing of multiple TIS. However, the existing DMSTA model platform with the PSTA Forecast Model equations was used for the sensitivity analysis as described later in this section.

Water outflow in the PSTA Forecast Model is based on the weir design. The model provides either a horizontal or a v-notch weir. The v-notch weir expression was used to calibrate the model with data from the PSTA Test Cells. The horizontal weir with variable width was used for simulation of larger-scale PSTA systems.

4.2.3.2 Water Column TP (P_W)

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

EXHIBIT 4-2

PSTA Forecast Model State Variables, Coefficients, and Definitions

Variable		Calculated as	1° Units	Description
A	=	Wetted area	m^2	PSTA footprint area
W	=	$W_{initial} + \dot{W}dt$	m	water
$\dot{W}$	=	$w_{in} - w_{out} + w_r - w_{et} - w_{gw}$	m/d	water rate of change
w_{in}	=	Q_{IN} / A	m/d	pumped inflow
w_{out}	=	Q_{OUT} / A	m/d	water out
w_r	=	Rain	m/d	rainfall
w_{et}	=	ET	m/d	evapotranspiration
w_{gw}	=	seepage rate	m/d	groundwater exchange
P_w	=	$(P_{w_initial} + \dot{P}_w dt)/W$	gTP/m^3	water column TP
$\dot{P}_W$	=	$p_{in} - p_{out} + p_{atm} - p_u + p_r - p_{gw} + p_l$	$gTP/m^2/d$	water column TP rate of change
p_{in}	=	$(C_{IN} * Q_{IN})/A$	$gTP/m^2/d$	TP in pumped inflow
p_{out}	=	$(P_W * Q_{OUT})/A$	$gTP/m^2/d$	TP in surface outflow
p_{atm}	=	C_{ATM} * Rain	$gTP/m^2/d$	bulk atmospheric deposition
p_u	=	$k_u \cdot P_W * B$	$gTP/m^2/d$	TP uptake by biomass
p_r	=	$b_r * P_B/B$	$gTP/m^2/d$	TP returned to water column from biomass/sediments
p_{gw}	=	$P_W * w_{gw}$	$gTP/m^2/d$	TP in groundwater exchange
p_l	=	$k_l P_L$	$gTP/m^2/d$	TP input from initial labile storage
B	=	$B_{initial} + \dot{B}dt$	g $AFDW/m^2$	Biomass (ash-free dry weight)
$\dot{B}$	=	$b_g - b_d - b_e - b_a$	g $AFDW/m^2/d$	Biomass rate of change
b_g	=	$k_g * (I/(k_{si} + I)) * (P_W/(k_{sp} + P_W)) * B$	g $AFDW/m^2/d$	biomass growth
b_r	=	$k_r * B^2$	g $AFDW/m^2/d$	biomass respiration rate
b_e	=	HB	g $AFDW/m^2/d$	biomass harvest
b_a	=	$k_a * B$	g $AFDW/m^2/d$	biomass accretion
H	=	user defined	d^{-1}	harvesting coefficient
P_B	=	$P_{B\text{-}initial} + \dot{P}_B dt$	gTP/m^2	TP in biomass
$\dot{P}_B$	=	$p_u - p_r - p_a - p_e$	$gTP/m^2/d$	TP in biomass rate of change
p_u	=	$k_u \cdot P_W * B$	$gTP/m^2/d$	TP uptake by biomass growth and luxury uptake
p_r	=	$b_r * P_B/B$	$gTP/m^2/d$	TP returned to water column from biomass/sediments
p_a	=	$b_a * P_B/B$	$gTP/m^2/d$	TP in accreted biomass
p_e	=	$b_e * P_B/B$	$gTP/m^2/d$	TP exported in harvested biomass
P_L	=	$PL_{\text{-}initial} + \dot{P}_L dt$	gTP/m^2	Initial labile TP
$\dot{P}_L$	=	$- p_l$	$gTP/m^2/d$	Labile TP rate of change
p_l	=	$k_l P_L$	$gTP/m^2/d$	TP input from initial labile storage

EXHIBIT 4-2

PSTA Forecast Model State Variables, Coefficients, and Definitions

Variable		Calculated as	1° Units	Description
k_g	=		d^{-1}	biomass growth rate
k_{si}	=		$E/m^2/d$	half saturation constant for PAR
k_{sp}	=		gTP/m^3	half saturation constant for water column TP
k_r	=		$m^2/gAFDW/d$	biomass respiration rate constant
k_a	=		d^{-1}	accretion rate constant
k_u	=		$m^3/gAFDW/d$	periphyton luxury uptake constant
k_l	=		d^{-1}	P release from labile storage rate constant
k_{1TP}	=	$(p_a+p_e-p_l)/P_W*365$	m/y	TP net settling rate
Q_{in}			m^3/d	inflow
Q_{out}			m^3/d	outflow
Rain			m/d	rainfall
ET			m/d	evapotranspiration
Weir Ht.			ft	weir height
C_{inTP}			mgTP/L	TP inflow concentration
C_{atmTP}			mgTP/L	TP in rainfall
I (PAR)			$E/m^2/d$	photosynthetically active radiation

For calibration, inflow and outflow TP concentrations were directly measured as part of routine monitoring. Bulk atmospheric P deposition was assumed to be equivalent to 17.64 µg/L (wet P = 10 µg/L and dry P = 10 mg/m^2/yr). Uptake of TP by biomass was derived from dry weight measurements of TP from algae and macrophyte samples. The return from sediments and biomass was estimated during the calibration process.

4.2.3.3 Biomass (B)

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

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

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

4.2.3.4 Biomass TP (P_B)

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

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

4.2.3.5 Labile TP Storage (P_L)

Startup data from most of the PSTA mesocosms indicated that there were initial storages of labile TP in the antecedent soils that entered the water column upon flooding. These initial storages are modeled as a tank that is initially full of TP with a single outlet to the water column. This addition to the model helps duplicate the startup behavior observed, not only at the beginning of the project, but also at the mid-point of the project when the sediments in the peat-based PSTA Test Cell were highly disturbed.

4.2.3.6 PSTA Dry-out

PSTA Test Cell 3 (treatment STC-3/6) was operated in a periodic dry-out mode

to determine the effects of periphyton dry-out on a large scale. The PSTA Forecast Model was found to be unstable as water levels declined to near dry-out conditions. For this reason, it was decided to incorporate some logic switches to capture the main effects of dry-out. Two types of switches are included in the model. The first reduces the rates of biomass growth and decay by 90 percent when water depth falls below 1 cm. The second switch stops calculating P_W when water levels are less than 15 cm. This switch is necessary to prevent mathematical integration problems associated with zero values.

4.2.4 Coefficient Estimation

As shown in Exhibit 4-2, the following 7 adjustable coefficients are required by the model:

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

PSTA mesocosm data were analyzed to develop preliminary estimates for some of these parameters. Only the shellrock treatment data were reviewed for this range-finding effort.

These correlations were found to be unsatisfactory for precise model calibration (see below). While they provide an initial understanding of the strengths and weaknesses of causative relationships between model variables, these data were not collected from experimental treatments where all variables except one were controlled. For this reason, final calibration of the PSTA Forecast Model used the Excel Solver routine to adjust all coefficients at one time to minimize the sum of squares for all of the major state variables simultaneously.

4.2.4.1 Biomass Growth Rate (k_g)

Biomass growth partially depends on the amount of biomass already present in the system at any given time. Measures of photosynthetic activity, such as GPP, provide insight into the rate at which the biomass community is growing. GPP estimates in units of DO change (g $O_2/m^2/d$) have been converted to ash-free dry weight by multiplying by a factor of 2x.

Regression analysis of monthly average values for GPP and total biomass in all of the shellrock treatments showed no clear correlation between these two parameters. This correlation suffers from the fact that many factors other than

biomass and GPP vary during the operational period. However, for model calibration, the slope of the regression line provides an initial value for k_g of 0.0178 d^{-1}.

4.2.4.2 Half Saturation Constants for PAR and TP

The rate of biomass growth is also partially limited by solar radiation (i.e., photosynthesis) and the availability of nutrients. The PSTA Forecast Model assumes that both light and nutrient availability follow the Michaelis-Menten model, which implies that reaction rates increase with substrate concentration until a maximum reaction rate is approached. At that point, the addition of substrate no longer affects the reaction rate. The half saturation constant describes the substrate concentration required for the reaction to proceed at half its maximum rate.

Regressions of average monthly relationships between GPP and PAR in the shellrock treatments were prepared to provide a preliminary estimate of the light half-saturation constant. The reciprocals of GPP and PAR were plotted to linearize the Michaelis-Menten relationship. Datasets that follow the Michaelis-Menten equation plot as a line with a positive slope and a negative x-intercept. The value of the half saturation constant is given as -1/x-intercept. The average value of the half saturation constant for PAR, k_{si}, was 84.5 $E/m^2/d$. This value was used as a starting point for model calibration.

A similar regression was used to provide a preliminary estimate of the reciprocals of GPP and water column TP concentration in shellrock treatments. No clear Michaelis-Menten relationship was apparent for these data. The range of observed water column TP concentrations has probably not been wide enough to show the assumed limiting effect of TP on biomass growth. A value of 0.0 mg/L was used for the initial half saturation constant for TP (k_{sp}).

4.2.4.3 Biomass Respiration Rate (k_r)

Operational data were also used to develop a regression between biomass and CR in the PSTA shellrock-based treatments. There was no apparent correlation observed between these two parameters. However, because the model was found to be very sensitive to k_r and the CR rate, it was decided to use a quadratic drain to model this process. CR measurements are used to approximate the decay rate of biomass in the mesocosms. The slope of the regression line (0.0001 d^{-1}) was used as the initial model value for k_r.

4.2.4.4 Biomass Accretion Rate (k_a)

The rate of biomass accretion (k_a) at the sediment/water interface was not directly measured during the PSTA research. Horizon markers could not be recovered after an 18-month operational period. Sediment traps were used to estimate total accretion, but these values were a better representation of gross accretion than net accretion. Because no direct measure of net biomass and TP accretion was possible, this rate coefficient was estimated through the model calibration described below.

4.2.4.5 Periphyton Luxury Uptake Rate Constant (ku)

The rate of P uptake by the periphyton was not directly measured. Therefore, this model parameter was estimated through the calibration described below.

4.2.4.6 Release Rate Constant From Labile Storage (k_l)

This rate coefficient was estimated through the model calibration described below.

4.2.5 Model Calibration

The PSTA Forecast Model was calibrated using POR and OPP data from the three PSTA Test Cells. These systems were operated for slightly more than 2 years. The POR included approximately March 1999 through March 2001. The OPP varied slightly for the three PSTA Test Cell treatments. For treatment STC-1/4 (peat), the OPP included data from July 1999 through January 2000 and from July 2000 through March 2001. For STC-2/5 (shellrock, constant water regime) and STC-3/6 (shellrock, variable water regime), the OPP used for calibration was July 1999 through March 2001.

The PSTA Forecast Model was calibrated separately for the three test systems because of their very different soil types and water regimes. Test Cell 8 (treatments STC-2/5) provides a dataset for a shellrock-based PSTA with stable water levels. Test Cell 3 (treatments STC-3/6) represents a shellrock PSTA with fluctuating water depths, including dry-out. Test Cell 13 (treatments STC-1/4) data are applicable to a PSTA built on organic soils with high antecedent soil P concentrations.

Calibration was conducted as a preliminary fit of the actual and model data using the rate constants described above. Goodness of fit was determined by calculating the sum of squares of differences between individual records of P_W, P_{out}, k_{1TP}, B, P_B, P_B/B, b_g, b_r, and W. The Solver routine in Excel was used to automatically optimize adjustable coefficients to provide the lowest total sum of these individual sums of squares. POR and OPP average values for the actual data and the model were also calculated and referred to during model calibration. Various calibration runs were performed with differing groups of input parameters being varied. Effects of individual and grouped input parameters on each state variable were examined, and final parameter selection was based on the best overall fit to all of the state variables in the model.

Exhibit 4-3 illustrates a representative PSTA Forecast Model calibration sheet for Test Cell 8 (shellrock, constant water depth). An accompanying sheet was used to overlay model and actual values for a visual assessment of goodness of fit (Exhibit 4-4). The ability to correlate the model output to actual data from multiple measured parameters provided significant power in calibration.

Exhibits 4-5 through 4-7 illustrate calibrated model fits for each of the three PSTA datasets for the POR datasets. Comparisons between actual data and model output are shown for W, TP_{out}, k_{1TP}, and b_g. All of the general trends in the actual data are reasonably well simulated by the PSTA Forecast Model.

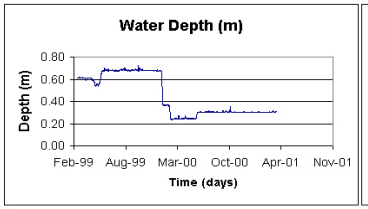
EXHIBIT 4-3

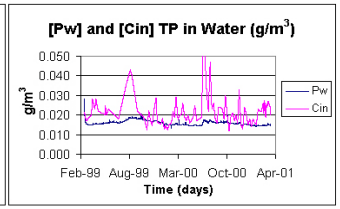
Example PSTA Phase 2 Model Calibration Spreadsheet Illustrating PSTA Test Cell 8 Input Parameters and Model Output

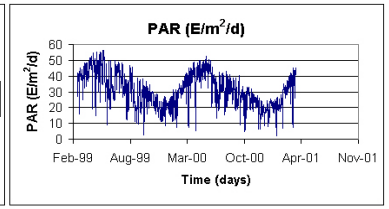
Periphyton Stormwater Treatment Area (PSTA) Research and Demonstration Project - CH2MHILL
PSTA Phase 2 Phosphorus Forecast Model - South Test Cell 8

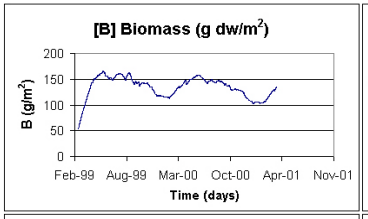
Wetland grade =	14.3	ft	Initial Pw =	0.028213	g/m^3	Time Step =	0.1	d
Starting Stage =	16.3	ft	Initial B =	53.2	g/m^2	Weir Equation =	90o V-notch	
Wetland Area at grade =	2240	m^2	Initial P_B =	0.2349	g/m^2	Weir Width =	1	ft
Volume below grade =	0	m^3	Initial P_L =	0.0860	g/m^2			
Leakance Rate =	0	m/d						

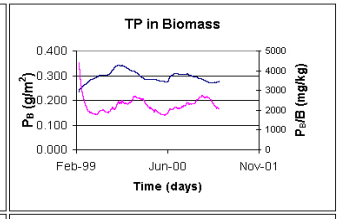
Note: User inputs in red

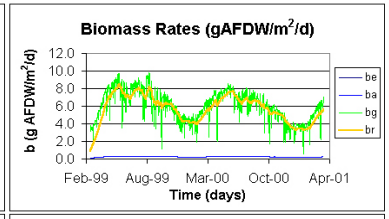


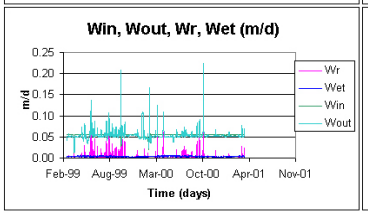


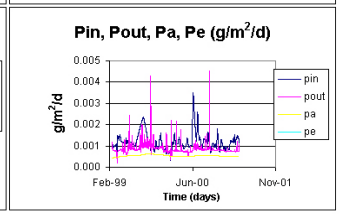


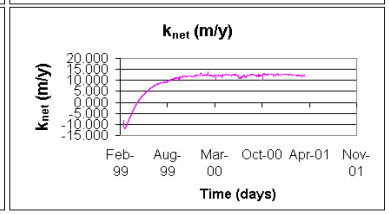












Adjustable Constants	
k_r =	0.000308086
k_g =	0.405816977
k_{si} =	31.53180233
k_{sp} =	0.053830944
k_a =	0.001814181
k_l=	0.01219983
k_u =	0.006008365
H =	0

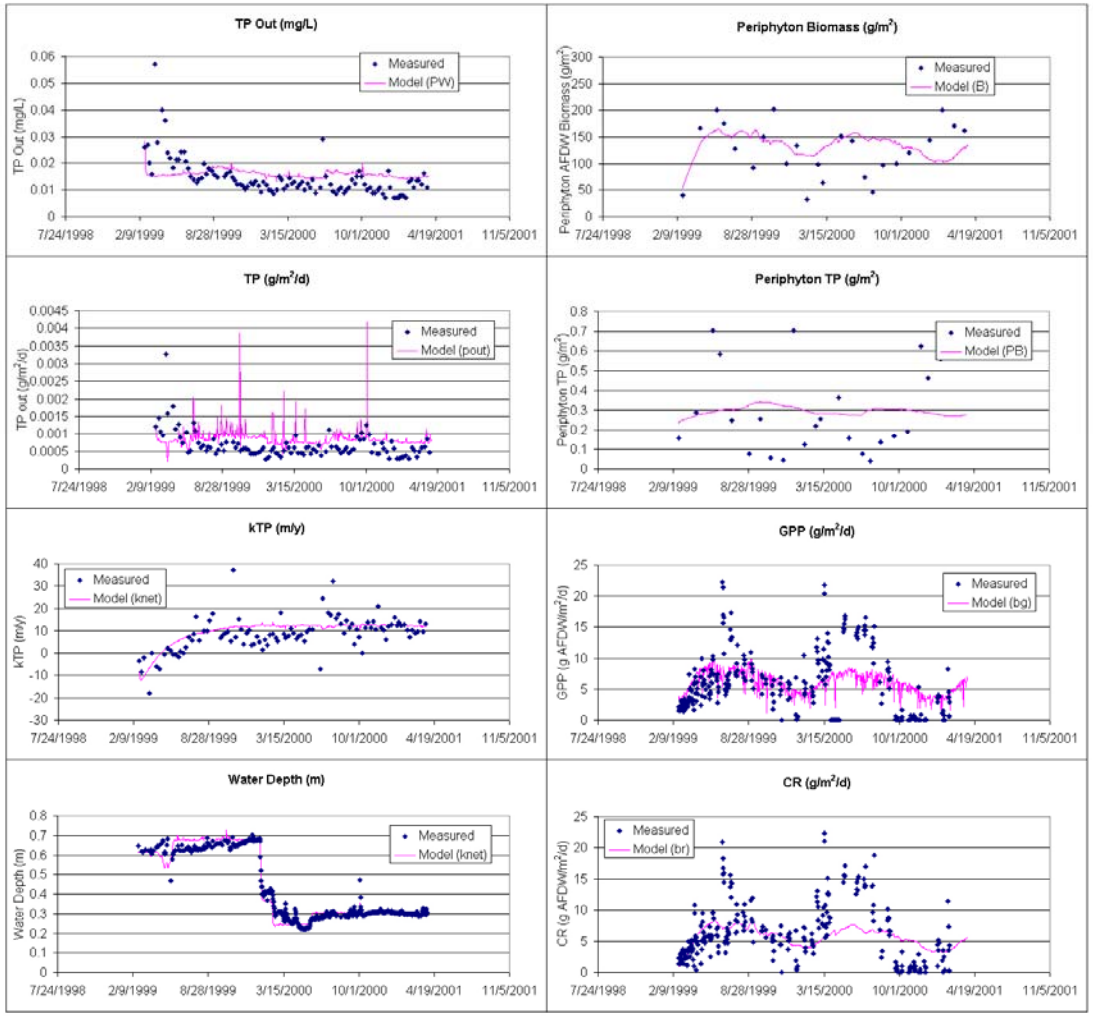
Parameter	P.O.R Avg Model	P.O.R Avg Data
HLR (m/y)	19.78	
TPin (g/m^3)	0.022	
TPout (g/m^3)	0.016	0.015
k_{1TP} (m/y)	6.54	8.31
W (m)	0.449	0.39291
P_W (g/m^3)	0.016	0.01456
B (g AFDW/m^2)	134.3	130.727
P_B (g/m^2)	0.296	0.29596
P_B/B (mg/kg AFDW)	2249	2284.65
b_g (g AFDW/m^2/d)	6.026	5.46425
b_r (g AFDW/m^2/d)	5.676	6.10028

Parameter	R^2	Sum Squares	%
P_w(mg/L)	-0.0186	0.005383286	0
p_{out}(g/m2/d)	-0.6090	2.50171E-05	0
k_{net}(m/y)	0.3069	4015.01	0
B(g/m2)	-0.0437	85841.10	0
P_B(g/m2)	-0.0510	1.20	0
P_B/B (mg/kg)	0.1643	32672877.72	0
b_g(g/m2/d)	0.1316	6179.96	0
b_r(g/m2/d)	0.2174	4841.10	0
W(m)	0.9622	0.55	0
			0

EXHIBIT 4-4

Example PSTA Phase 2 Model Calibration Spreadsheet Illustrating Actual and Predicted Results (Goodness of fit) for PSTA Test Cell 8

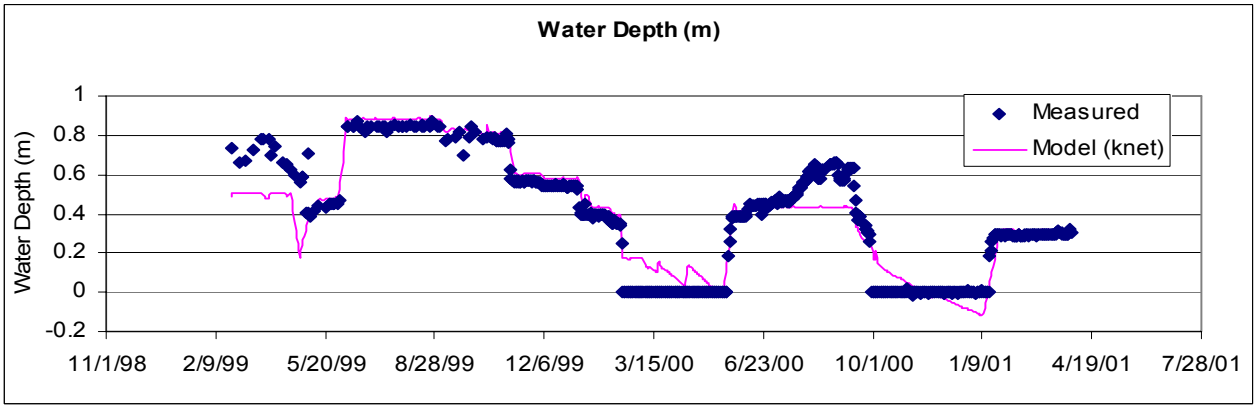
Periphyton Stormwater Treatment Area (PSTA) Research and Demonstration Project - CH2MHILL
PSTA Phase 2 Phosphorus Forecast Model - South Test Cell 8

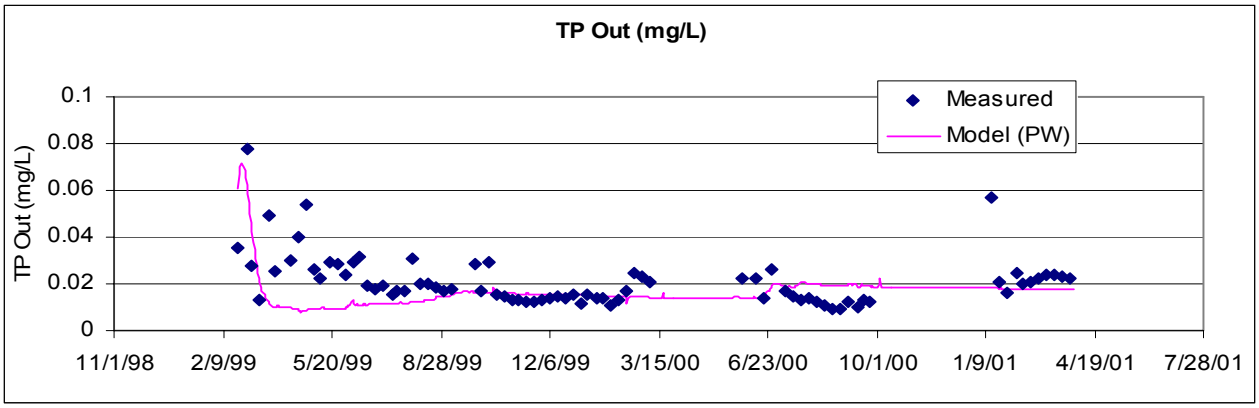


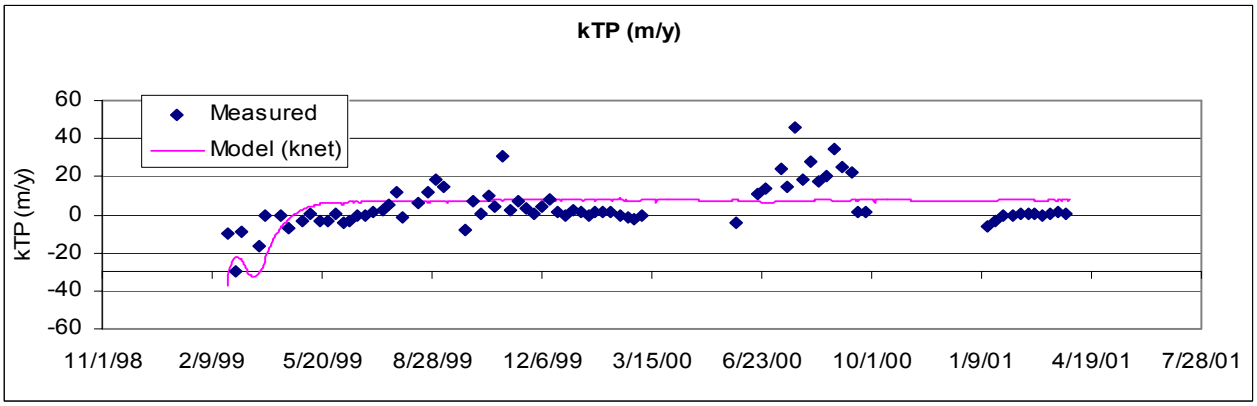
Adjustable Constants	
k_r =	0.000308086
k_g =	0.405816977
k_{si} =	31.53180233
k_{sp} =	0.053830944
k_a =	0.001814181
k_l =	0.01219983
k_u =	0.006008365
H =	0

Parameter	R^2	SS
P_w(mg/L)	-0.019	0.0054
p_{out}(g/m2/d)	-0.609	3E-05
k_{net}(m/y)	0.3069	4015
B(g AFDW/m2)	-0.044	85841
P_B(g/m2)	-0.051	1.2007
P_B/B (mg/kgAFDW)	0.1643	3E+07
b_g(g AFDW/m2/d)	0.1316	6180
b_r(g AFDW/m2/d)	0.2174	4841.1
W(m)	0.9622	0.5497

Parameter	P.O.R Avg Model	P.O.R Avg Data
HLR (m/y)	19.78	
TPin (g/m³)	0.022	
TPout (g/m³)	0.016	0.015
k_{1TP} (m/y)	6.54	8.31







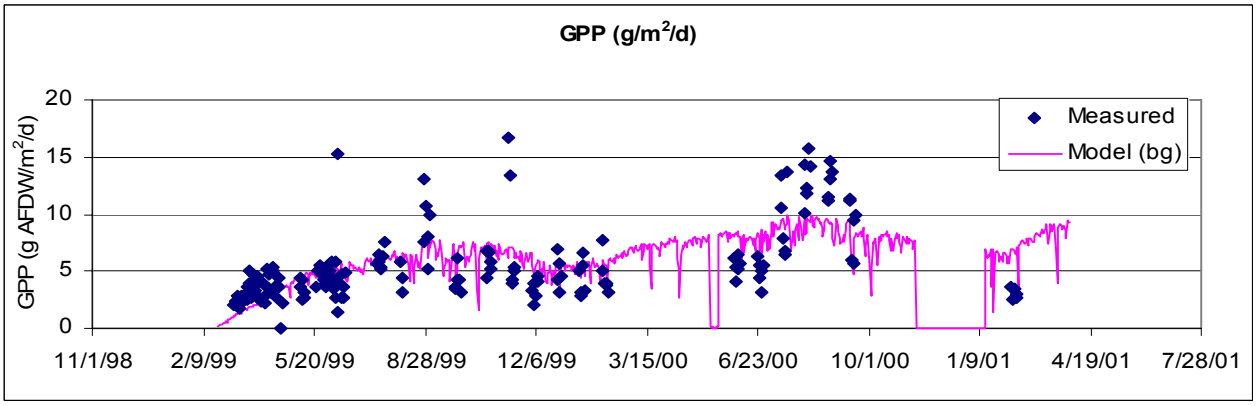


EXHIBIT 4-5
Detailed Comparison of PSTA Phase 2 Model Estimates and Actual Data from PSTA Test Cell 3 – Shellrock, Variable Water Regime

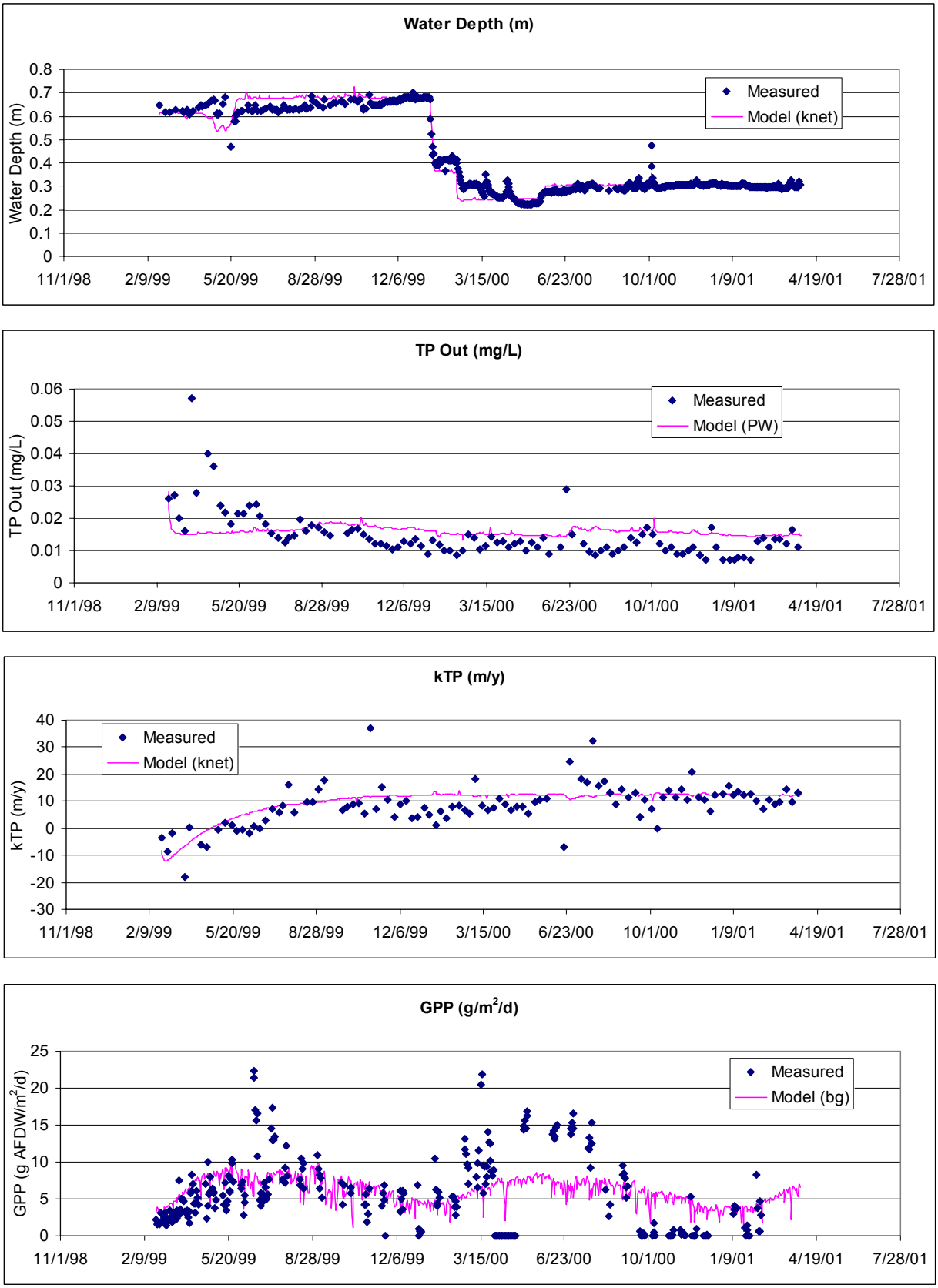


EXHIBIT 4-6

Detailed Comparison of PSTA Phase 2 Model Estimates and Actual Data from PSTA Test Cell 8 – Shellrock, Constant Water Regime

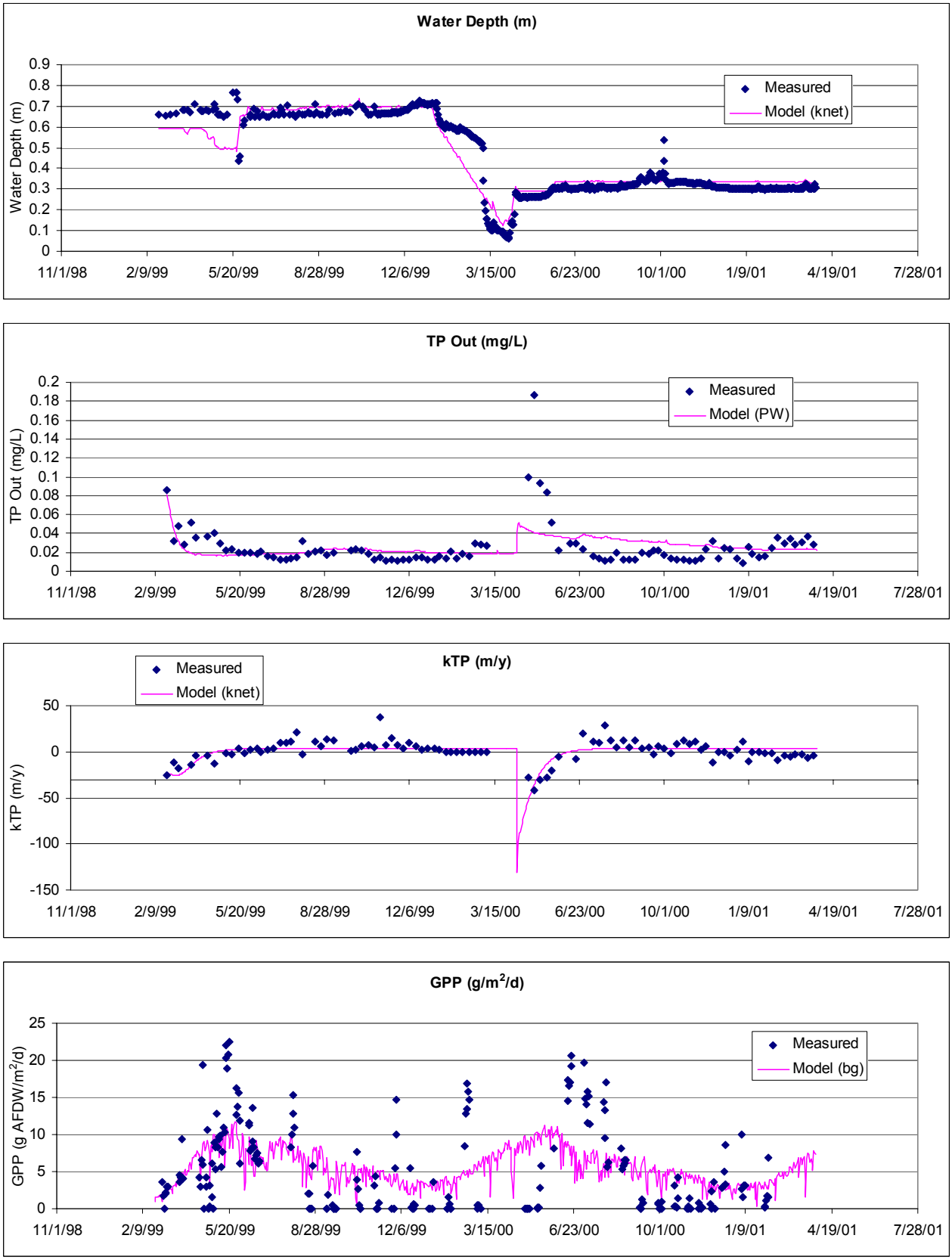


EXHIBIT 4-7
Detailed Comparison of PSTA Phase 2 Model Estimates and Actual Data from PSTA Test Cell 13 – Peat, Constant Water Regime, Soil Amendment

Exhibit 4-8 provides values for all of the adjustable coefficients and initial conditions for each of the calibration datasets for both the POR and for the OPP. A relatively small range in calibrated model coefficients was found between the three PSTA Test Cells. There were noticeable changes between the calibrations for the POR and the OPP.

EXHIBIT 4-8
Comparison of PSTA Forecast Model Initial Values and Adjustable Coefficients for PSTA Test Cells

	Test Cell 8 (shellrock)		Test Cell 13 (peat)		Test Cell 3 (shellrock)	
	POR	**OPP**	**POR**	**OPP**	**POR**	**OPP**
Wetland Grade	14.3	14.3	14.3	14.3	14.2	14.2
Starting Stage	16.3	16.5	16.2	16.4	15.8	15.7
Wet Area (m^2)	2240	2240	2240	2240	2240	2240
Initial W (g/m^3)	0.028	0.014	0.081	0.012	0.061	0.020
Initial Biomass (g/m^2)	53	168	27	67	2	112
Initial P in Biomass (g/m^2)	0.2349	0.1734	0.0461	0.1173	0.0119	0.1201
Initial Labile P (g/m^2)	0.086	0.000	0.085	0.000	0.103	0.000
k_r (m^2/gAFDW/d)	0.000308	0.000325	0.000300	0.000300	0.000623	0.000668
k_g (d^{-1})	0.406	0.154	0.200	0.211	0.200	0.200
k_{si} (E/m^2/d)	31.5	66.7	114.2	118.4	15.7	17.6
k_{sp} (g TP/ m^3)	0.054	0.000	0.000	0.000	0.014	0.010
k_a (d^{-1})	0.00181	0.00142	0.00104	0.00040	0.00134	0.00093
k_l (d^{-1})	0.0122	0.0086	0.0603	0.0520	0.0597	0.0451
k_u (m^3/gAFDW/d)	0.00601	0.00829	0.00281	0.00527	0.00982	0.01511

Notes:
POR = period-of-record
OPP = optimum performance period

4.2.6 Sensitivity Analysis

Exhibit 4-9 provides the results of a sensitivity analysis of the adjustable coefficients for the shellrock test cell (Test Cell 8 OPP). Each coefficient was tested at one-half and at twice its calibrated value. The coefficients that consistently resulted in the largest changes in k_{1TP} and TP_{out} were k_u and k_r. The biological state variables and rates of productivity and respiration were also most affected by changes to the biomass growth and respiration rates (k_g and k_r, respectively) and the light half saturation constant (k_{si}).

4.2.7 Model Simulations

4.2.7.1 Effects of Different Forcing Functions

The PSTA Forecast Model calibrated to the shellrock test cell (Test Cell 8) OPP data has been tested for five general operational/management alternatives. These include the following hypothetical scenarios:

EXHIBIT 4-9

Results from a Sensitivity Analysis of Adjustable Coefficients for South Test Cell 8 (shellrock, constant water regime)

Adjustable Constants	Initial Value	Percent Adjustment	Adjusted Value		HLR (m/yr)	TP_{in} (g/m^3)	TP_{out} (g/m^3)	k_{1TP} (m/y)	W (m)	B (g AFDW /m^2)	P_B (g/m^2)	P_B/B (mg/kg AFDW)	b_g (g AFDW /m^2/d)	b_r (g AFDW /m^2/d)
				Actual Data Averages	19.8	0.022	0.012	11.8	0.38	128	0.268	2115	5.5	6.6
				Model Averages	19.8	0.022	0.012	11.9	0.41	136	0.296	2261	6.3	6.2
				Delta Δ (%)	**0.0**	**0.0**	**-0.7**	**1.1**	**9.8**	**6.3**	**10.4**	**6.9**	**14.6**	**-5.9**
k_r	0.000325	50%	0.000488	**Model**	19.8	0.022	0.015	7.4	0.41	92	0.251	2844	4.3	4.3
				Delta Δ (%)	**0.0**	**0.0**	**25.1**	**-37.6**	**9.8**	**-28.1**	**-6.7**	**34.5**	**-22.2**	**-34.8**
		-50%	0.000163	**Model**	19.8	0.022	0.007	21.6	0.41	265	0.360	1396	12.3	11.7
				Delta Δ (%)	**0.0**	**0.0**	**-39.0**	**83.1**	**9.8**	**107.4**	**34.2**	**-34.0**	**122.5**	**78.6**
k_g	0.154	50%	0.230	**Model**	19.8	0.022	0.012	12.1	0.41	204	0.298	1516	14.3	13.9
				Delta Δ (%)	**0.0**	**0.0**	**-1.6**	**2.6**	**9.8**	**59.2**	**11.1**	**-28.3**	**157.6**	**111.1**
		-50%	0.077	**Model**	19.8	0.022	0.013	11.4	0.41	70	0.291	4420	1.6	1.7
				Delta Δ (%)	**0.0**	**0.0**	**1.9**	**-3.2**	**9.8**	**-45.2**	**8.5**	**109.0**	**-70.4**	**-74.1**
k_{si}	66.7403	50%	100.11	**Model**	19.8	0.022	0.012	11.8	0.41	102	0.295	3034	3.6	3.5
				Delta Δ (%)	**0.0**	**0.0**	**0.3**	**-0.4**	**9.8**	**-20.3**	**9.7**	**43.5**	**-35.7**	**-46.5**
		-50%	33.3702	**Model**	19.8	0.022	0.012	12.1	0.41	207	0.298	1469	14.6	14.2
				Delta Δ (%)	**0.0**	**0.0**	**-1.6**	**2.7**	**9.8**	**62.2**	**11.1**	**-30.5**	**164.4**	**116.8**
k_a	0.00142	50%	0.00213	**Model**	19.8	0.022	0.011	13.9	0.41	134	0.265	2054	6.2	6.0
				Delta Δ (%)	**0.0**	**0.0**	**-10.0**	**17.8**	**9.8**	**4.7**	**-1.2**	**-2.9**	**12.9**	**-8.7**
		-50%	0.00071	**Model**	19.8	0.022	0.014	9.8	0.41	138	0.334	2514	6.4	6.4
				Delta Δ (%)	**0.0**	**0.0**	**10.8**	**-17.2**	**9.8**	**8.0**	**24.5**	**18.9**	**16.3**	**-3.0**
k_l	0.0086	50%	0.0129	**Model**	19.8	0.022	0.012	11.9	0.41	136	0.296	2261	6.3	6.2
				Delta Δ (%)	**0.0**	**0.0**	**-0.7**	**1.1**	**9.8**	**6.3**	**10.4**	**6.9**	**14.6**	**-5.9**
		-50%	0.0043	**Model**	19.8	0.022	0.012	11.9	0.41	136	0.296	2261	6.3	6.2
				Delta Δ (%)	**0.0**	**0.0**	**-0.7**	**1.1**	**9.8**	**6.3**	**10.4**	**6.9**	**14.6**	**-5.9**
k_u	0.00818	50%	0.01228	**Model**	19.8	0.022	0.009	17.2	0.41	136	0.335	2564	6.3	6.2
				Delta Δ (%)	**0.0**	**0.0**	**-23.7**	**45.4**	**9.8**	**6.3**	**24.9**	**21.2**	**14.6**	**-5.9**
		-50%	0.00409	**Model**	19.8	0.022	0.018	4.6	0.41	136	0.215	1630	6.3	6.2
				Delta Δ (%)	**0.0**	**0.0**	**44.0**	**-61.3**	**9.8**	**6.3**	**-20.0**	**-22.9**	**14.6**	**-5.9**

- PSTAs constructed on a leaky site with a vertical leakance rate of 0.02 or 0.04 m/d
- PSTAs receiving a steady inflow TP concentration of 100 ppb
- PSTAs receiving a steady inflow TP concentration of 50 ppb
- PSTAs with a harvest rate (H) of 0.001 d^{-1}
- PSTAs with a harvest rate of 0.0001 d^{-1}

A matrix of the above factors was examined to provide an overall picture of model response. Existing inflow TP and environmental data were copied to provide a synthetic 5-year input dataset. Stable water depths of 30 cm and inflow rates of 134 m^3/d were tested. A summary of the model output is provided in Exhibit 4-10.

EXHIBIT 4-10
PSTA Phase 2 Model Performance for South Test Cell 8 (shellrock) Under a Variety of Test Conditions Including Vertical Leakage, Harvest, and Elevated Inflow TP Concentrations

		Vertical Leakance		Harvest	
Parameter	**Baseline**	**0.04 m/d**	**0.02 m/d**	**0.001 d^{-1}**	**0.0001 d^{-1}**
Inflow TP concentration = variable 5 year					
HLR (m/y)	21.83	21.83	21.83	21.83	21.83
Tpin (g/m^3)	0.023	0.023	0.023	0.023	0.023
PW (g/m^3)	0.0146	0.0146	0.0146	0.0121	0.0143
k1TP (m/yr)	9.60	9.59	9.60	13.70	10.05
W (m)	0.3707	0.3465	0.3606	0.3707	0.3707
B (g AFDW/m^2)	141.37	141.37	141.37	138.34	141.07
PB (g/m^2)	0.3589	0.3590	0.3589	0.2915	0.3508
PB/B (mg/kg AFDW)	2643.3	2644.1	2643.5	2193.7	2589.4
bg (g AFDW/m^2/d)	6.8738	6.8738	6.8738	6.7297	6.8594
br (g AFDW/m^2/d)	6.6977	6.6977	6.6977	6.4214	6.6698
Inflow TP concentration = 0.050 g/m^3					
HLR (m/yr)	21.83	21.83	21.83	21.83	21.83
TPin (g/m^3)	0.050	0.050	0.050	0.050	0.050
PW (g/m^3)	0.0294	0.0294	0.0294	0.0244	0.0288
k1TP (m/yr)	11.58	11.58	11.58	15.64	12.03
W (m)	0.3707	0.3465	0.3606	0.3707	0.3707
B (g AFDW/m^2)	141.37	141.37	141.37	138.34	141.07
PB (g/m^2)	0.7195	0.7196	0.7196	0.5848	0.7034
PB/B (mg/kg AFDW)	5302.1	5303.1	5302.5	4404.9	5194.7
bg (g AFDW/m^2/d)	6.8738	6.8738	6.8738	6.7297	6.8594
br (g AFDW/m^2/d)	6.6977	6.6977	6.6977	6.4214	6.6698
Inflow TP concentration = 0.100 g/m^3					
HLR (m/yr)	21.83	21.83	21.83	21.83	21.83
TPin (g/m^3)	0.100	0.100	0.100	0.100	0.100
P_W (g/m^3)	0.0566	0.0566	0.0566	0.0471	0.0555

EXHIBIT 4-10
PSTA Phase 2 Model Performance for South Test Cell 8 (shellrock) Under a Variety of Test Conditions Including Vertical Leakage, Harvest, and Elevated Inflow TP Concentrations

		Vertical Leakance		Harvest	
Parameter	**Baseline**	**0.04 m/d**	**0.02 m/d**	**0.001 d^{-1}**	**0.0001 d^{-1}**
k_{1TP} (m/yr)	12.42	12.41	12.42	16.45	12.86
W (m)	0.3707	0.3465	0.3606	0.3707	0.3707
B (g AFDW/m^2)	141.37	141.37	141.37	138.34	141.07
P_B (g/m^2)	1.3829	1.3831	1.3829	1.1247	1.3520
P_B/B (mg/kg AFDW)	10203.7	10205.1	10204.3	8484.3	9998.1
b_g (g AFDW/m^2/d)	6.8738	6.8738	6.8738	6.7297	6.8594
b_r (g AFDW/m^2/d)	6.6977	6.6977	6.6977	6.4214	6.6698

4.2.7.2 Effects of Leakance

A simulated average vertical leakance rate of 2 cm/d resulted in a very slight increase in k_1 and no significant decrease in TP_{out} for each of the PSTA configurations tested. Increasing the leakance rate to 4 cm/d did not affect the modeled performance of the test cells with constant water regime.

4.2.7.3 Effects of Periphyton Harvesting

Harvesting at a rate of 3.65 percent per year (H = 0.0001 d^{-1}) provided a slight improvement in long-term average PSTA outlet TP concentrations. Harvesting periphyton at a rate of 36.5 percent per year (H = 0.001 d^{-1} or approximately 7.3 wet metric tonnes per hectare per year [mt/ha/yr] or approximately 70 g dry weight/m^2/yr) slightly lowered projected TP outflow concentrations by approximately 2 to 3 ppb. Additional model runs (not illustrated in Exhibit 4-10) indicated that for harvesting to increase k_1 to approximately 17 m/yr and TP_{out} less than 10 ppb for the Test Cell 8 (shellrock, constant water regime) base case, it would be necessary to harvest approximately twice as much, or 15 wet mt/ha/yr (H = 0.002 d^{-1}).

4.2.7.4 Effects of Higher Inlet TP Concentrations

Exhibit 4-10 also illustrates the modeled predictions for higher inflow TP concentrations of 50 and 100 ppb at the same hydraulic loading rate (HLR) as the Test Cell research (approximately 22 m/yr). For 50 ppb inflow, it is projected that a PSTA system built on shellrock would achieve an average outflow concentration of approximately 29 µg/L. At a steady inflow concentration of 100 µg/L TP, the average projected outflow TP would be 57 ppb. The respective k_1 values are estimated as approximately 11.6 and 12.4 m/yr for these two cases.

4.2.7.5 Simulation Using STA-2 Synthetic Dataset

The District's synthetic post-STA-2 dataset was used to provide a preview of PSTA performance under a 10-year period of variable inflows and TP concentrations. The average TP concentration into the PSTA for this period is approximately 37 ppb and the flow-weighted mean inflow concentration is 50 ppb. The average inflow rate for this dataset is approximately 531,000 m^3/d. The maximum daily inflow rate for this 10-year period is 6,270,000 m^3/d.

Performance of the proposed PSTA was tested with a variety of PSTA footprint areas, ranging from 500 to 8,000 ha. Projected long-term average outflow concentrations from the PSTA Forecast Model were 27 ppb for the design loading rate of approximately 5.3 cm/d (1,000 ha). At a higher loading rate of 11 cm/d (500 ha), the projected average outflow TP average is 32 ppb, with a flow-weighted mean concentration of 38 µg/L. The PSTA Forecast Model estimates that the PSTA area must be increased to approximately 2,672 ha to achieve a flow-weighted mean TP_{out} concentration of 20 ppb. Exhibit 4-11 illustrates the model predictions for this hypothetical case.

4.2.8 Potential PSTA Model Enhancements

The PSTA Forecast Model can be upgraded based on continuing data collection. Data from the PSTA Field- Scale Cells should be used to validate or modify the PSTA Forecast Model coefficients and performance.

A variety of changes could be made to the structure of the PSTA Forecast Model. These include additional work to simulate multiple PSTA cells in series. Research necessary to calibrate that model may be provided by additional work being planned in the North and South Test Cells. Improved performance and lower outflow TP concentrations will theoretically result from linking several PSTA cells in series. The PSTA model could also be upgraded by adding a macrophyte state variable. This addition would provide an integrated model that could be used to project the performance of a mixture of macrophytic and periphytic plant communities in an STA. During calibration of the PSTA Forecast Model, it was found that incorporation of biomass, community productivity, and community respiration were important for simulating the behavior of P dynamics.

The DMSTA model already provides a workable, Excel platform that can deal with variable TIS, variable numbers of cells in series and/or in parallel, and with comprehensive reporting capabilities. It is recommended that any additional PSTA modeling efforts build on the DMSTA platform. Incorporation of sunlight and plant functional and structural measures in the DMSTA model would also provide a better basis for estimating factors affecting performance of all of the potential "green technologies."

4.3 PSTA Conceptual Design

PSTA conceptual design is based on footprint estimates provided by the PSTA Forecast Model described above. Considerations to be included in the conceptual design are dictated by the STSOC methodology as described by PEER Consultants/Brown and Caldwell (1999) and outlined below. The final PSTA conceptual design has significant uncertainties related to the time and spatial scale of the PSTA Research and Demonstration Project. The impact of these uncertainties is a conservative estimate of size and cost for a full-scale PSTA. The actual magnitude of uncertainty associated with these estimates will only be clarified through continuing research at larger scales and over longer time periods.

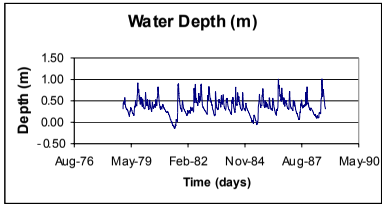
EXHIBIT 4-11

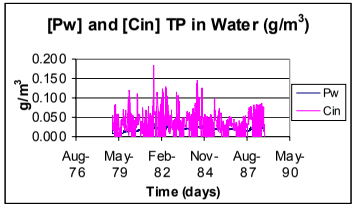
PSTA Phase 2 Model Spreadsheet Illustrating Simulation Using Post STA-2 Synthetic Dataset

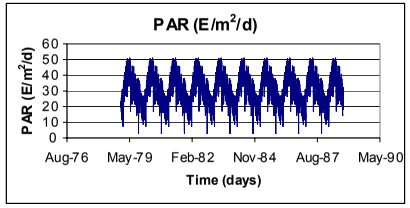
Periphyton Stormwater Treatment Area (PSTA) Research and Demonstration Project - CH2MHILL
PSTA Phase 2 Phosphorus Forecast Model - Post STA-2 10-Year Simulation

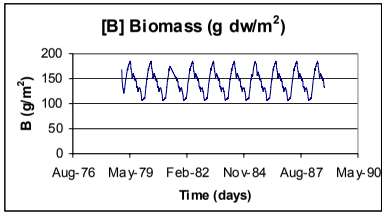
Wetland grade =	0	ft	Initial Pw =	0.02	g/m^3	Time Step =	0.2	d
Starting Stage =	1.0	ft	Initial B =	168.5	g/m^2	Weir Equation =	Rectangular	
Wetland Area at grade =	30,189,186	m^2	Initial P_B =	0.1734	g/m^2	Weir Width =	200	ft
Volume below grade =	0	m^3	Initial P_L =	0.0000	g/m^2	Note: User inputs in red		
Leakance Rate =	0	m/d						

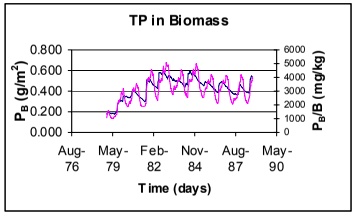
STA-2 Standard of Comparison Dataset - Post STA - No Bypass

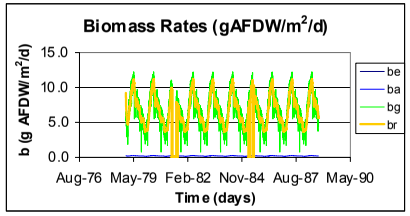


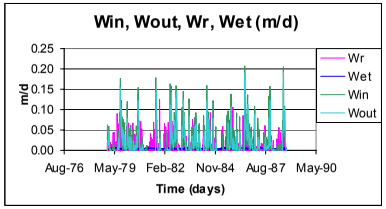


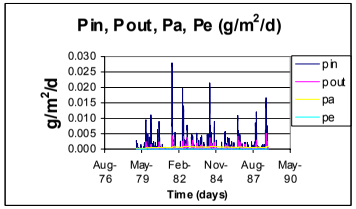


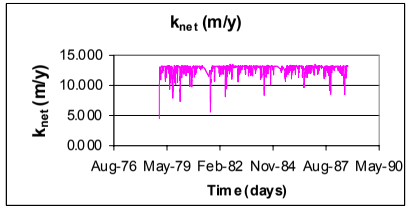












Adjustable Constants	
k_r =	0.000325408
k_g =	0.153562572
k_{si} =	66.74030767
k_{sp} =	0
k_a =	0.001417107
k_l =	0.00858974
k_u =	0.008293138
H =	0

Parameter	P.O.R Avg
HLR (m/y)	6.42
TPin (g/m^3)	0.037
TPout (g/m^3)	0.017
k_{1TP} (m/y)	5.88
W (m)	0.3652
P_W (g/m^3)	0.0174
B (g AFDW/m^2)	143.49
P_B (g/m^2)	0.428
P_B/B (mg/kg AFDW)	3080.7
b_g (g AFDW/m^2/d)	6.7492
b_r (g AFDW/m^2/d)	6.5561
Flow-Weighted	
TPin (g/m^3)	0.050
TPout (g/m^3)	0.020

Area (ac)	7460
Max Depth (ft)	3.33
Days	3560

4.3.1 Standards of Comparison Methodology

The STSOC methodology consists of nine informational requirements for each of the ATTs. As outlined below, five of the informational requirements are considered primary; the remaining four are characterized as ancillary:

Primary:

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

Ancillary:

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

This comparison of technologies requires the use of the best available data related to P, removal performance, flexible engineering and operational components to attain maximum P-removal levels, and development of costs associated with the conceptual engineering design. It also mandates a comparison of the possible environmental effects of each technology with regard to the disposal of by-products and the effects on downstream waters.

The PSTA concept is one of the ATTs under review. CH2M HILL recently completed the two-phased evaluation of this technology at the STCs and Porta-PSTA mesocosms. PSTA research remains ongoing at the field-scale. Because completion of the STSOC analysis is time-sensitive, it is being conducted based solely on the results from the first two phases of the PSTA project's research efforts performed at the largest available research platform—the PSTA Test Cells.

Data from selected treatments (optimal design variations including shellrock and peat soils) were used to design and calibrate the PSTA Forecast Model. The purpose of this model is to predict long-term behavior and performance of a PSTA, based on extrapolation of existing data, both within and outside the loading rates tested in the mesocosm research. There are currently no full-scale PSTA datasets that could be used for additional model validation. The model results provide crucial information for use in comparing PSTA feasibility to that of the other ATTs.

The calibrated PSTA Forecast Model was subsequently used to simulate a 10-year POR using a synthetic dataset of TP concentrations and flows from STA-2 (post-STA), as provided by the District. Because PSTA was not tested at higher inflow TP concentrations, this STSOC analysis does not include an evaluation of design and costs to treat post-Best Management Practices (BMPs) (STA-2 inflow) waters. Requirements of the STSOC methodology include using the PSTA Forecast Model to determine the PSTA footprint area necessary to achieve 10 (or lowest consistently achievable outflow concentration) and 20 µg/L flow-weighted mean outflow TP concentrations under 0, 10, and 20 percent inflow bypass scenarios. Since a sustained outflow TP level of 10 µg/L was not attained, the post-STA-2 evaluation is based on the lowest sustained outflow concentration (12 µg/L).

By necessity, the PSTA Forecast Model was used to estimate PSTA performance outside of the range of calibration data for some critical parameters. Some of the inflow concentrations tested for the STSOC analysis were above the observed averages in the PSTA research, as were ranges of hydraulic loading, water depths, and periods of dry out. Any use of the model outside of the calibration range is subject to greater error in estimated performance. All model-derived estimates are subject to some uncertainties.

This section summarizes information and findings related to each of the primary and ancillary STSOC data requirements listed above. In addition to answering those questions based on available information, it also provides conceptual designs and cost estimates of full-scale PSTAs for post-STA-2 water treatment. Finally, this section identifies the sensitivity of a number of PSTA design variables and the resulting uncertainty in estimated project costs. Additional critical research issues identified by this uncertainty assessment are described.

4.3.2 Description of Data Collection and Synthesis Methods

PSTA mesocosm operational data for chemical and physical water quality parameters were collected between February 1999 and April 2001 (see CH2M HILL 1999, 2000, 2001 for interim reports describing data collection methods and results). In addition to routine sampling throughout this 26-month operational period, there was a 5-week verification period with higher data collection intensity in two representative mesocosms. Data from the operational and verification collection periods have been combined to support the STSOC analysis described in this report.

4.3.2.1 STSOC Verification Sampling

Field data collection for STSOC verification was conducted from February 26 to April 4, 2001. Water samples were collected for chemistry analysis, and physical parameters were also measured at the time of sampling. Sampling was conducted using methods identified in CH2M HILL's Florida Department of Environmental Protection (FDEP)-approved Comprehensive Quality Assurance

Plan (CompQAP) No. 910036G and clarified in the PSTA QAPP approved by the District. P analyses were conducted by the University of Florida IFAS under their CompQAP No. 910051. Environmental Conservation Laboratories (ENCO) analyzed the total organic carbon (TOC) samples per their CompQAP No. 960038. PPB Environmental Laboratory (PPB) analyzed the remaining parameters under their CompQAP No. 870017G.

4.3.2.2 Sampling Locations

PSTA research has been ongoing at three Test Cells within the STA 1-W Project for 2 years. STSOC verification period monitoring was performed at two of these cells, South Test Cell 8 (PSTA Treatment STC-5: shellrock base, 30-cm water depth) and South Test Cell 13 (PSTA Treatment STC-4: peat base with calcium amendment, 30-cm water depth). These Test Cells represent the largest scale PSTAs tested to date and were typical of the other PSTA mesocosms, in terms of operational conditions and treatment performance. Water quality was monitored at the south head cell outlet and at the outlets from the two individual PSTA Test Cells.

4.3.2.3 Flow Measurements

Inflow measurements from the south head cell were calculated according to District data and knowledge of the inflow orifice size. Inflows to the STCs are relatively constant because they all originate from a single head cell. The water level in the south head cell is maintained within a relatively small range by an automatic pumping system.

Outflows from the PSTA Test Cells were calculated based on weir staff gauge measurements (approximately two per week) and the equation for flow over a 90-degree V-notch weir.

4.3.2.4 Water Quality Parameters and Sampling Methods

Composite samples were collected three times per week during a 5-week period (approximately five HRTs) using automated ISCO samplers. Samples were collected at the frequencies given and analyzed for parameters listed in Exhibit 4-12.

Samples were transferred into pre-cleaned and properly labeled sample containers following collection. Sample preservatives were either included in the sample containers provided by the laboratory or added to the sample immediately after collection. TDP, DRP, and the dissolved metal parameters were filtered using a 0.45 micrometer (µm) filter. All samples were placed in coolers with ice immediately following collection, filtering, and/or preservation and shipped to the appropriate laboratory the same day by overnight express.

EXHIBIT 4-12
STSOC Water Quality Parameter and Sampling Frequencies

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

Notes:
NA = Not applicable; field readings will be collected *in situ*.
NS = Not specified in the STSOC guidelines
°C = degrees Celsius
TDP = total dissolved phosphorus
TDS = total dissolved solids
TSS = total suspended solids

[a]Twice per week grab collected to meet FDEP filtering requirements and short holding times (48 hours).
[b]To be consistent with current monitoring at the PSTA Test Cells, nitrate/nitrite will be reported instead of each component separately.
[c]Aluminum samples below approximately 100 µg/L are analyzed by EPA 202.2 (GFAA); samples above approximately 100 µg/L are analyzed by EPA 200.7 (ICP).

4.3.2.5 Quality Assurance

All testing and sample handling was completed as outlined in the QAPP prepared for execution of field activities using proper completion of chain-of-custody forms, sample preservation, and handling of samples. Sample kit preparation, tracking, analysis of samples, and data validation procedures were followed by laboratory personnel as outlined in the laboratory's CompQAP.

Field meters were calibrated by the field team in accordance with the manufacturer's recommendations. Calibration results were recorded and maintained with the field data sheets for each event.

Field QA/QC samples were collected at the following rate:

- Duplicates (10 percent of total samples)
- Equipment Blanks (5 percent of total samples)

Exhibit 4-13 shows the number of field samples and QA/QC samples collected during the data verification stage of the STSOC sampling.

EXHIBIT 4-13

Number of STSOC Water Quality Samples by Parameter Group

Parameter Group	STSOC Suggested	PSTA Samples				
		Total per Station	No. of Stations	Total Field Samples	QA/QC Samples	Total Samples
A	40[a]	15	3	45	8	53
B	40[a]	10	3	30	5	35
C	13	5	3	15	3	18
D	5	5	3	15	3	18
E	Not specified	10	3	30	0	30

Note:
[a]Includes TP, TDP, and DRP

4.3.3 Summary of PSTA Performance

The STSOC methodology requires summarization of ATT performance. Performance measures that must be assessed include:

- Minimum achievable outflow TP concentration (flow weighted, seasonal means, minimum, maximum, standard deviation, and percentiles)
- TP mass removal efficiency (effects of TP mass loading, inflow TP concentration, HLR, HRT, and water depth)

Sections 2 and 3 of this report provide a complete summary of the study results for both of the two completed project phases. Those sections indicate that data from the three PSTA Test Cells (treatments STC-1/4 – peat, constant water regime; STC-2/5 – shellrock, constant water regime; and STC-3/6 – shellrock, variable water regime) are representative of the typical performance of the Porta-PSTA mesocosms that share the same treatment variables. Results from the peat- and shellrock-based PSTA Test Cells are used for this STSOC analysis and were used to calibrate the PSTA Forecast Model. Results from two of those PSTA Test Cells (STC-1/4 and STC-2/5) were subsequently used for STSOC verification testing.

Performance results for the two above-referenced PSTA Test Cells are briefly summarized below for three periods:

- POR: all data collected from startup to completion (February 1999 through April 2001)
- Optimal (post-startup) performance period: July 1999 through April 2001
- STSOC Verification Performance Period (VPP): March and April 2001

4.3.3.1 Routine PSTA Monitoring

Period-of-Record

POR results for the entire Phase 1 and 2 period (February 1999 to April 2001), which include the period during system startup, are summarized in Exhibit 4-14. All mean concentrations are reported as flow-weighted. An average inflow TP of 23 µg/L was reduced to an average of 15 µg/L by the shellrock-based treatment system, and an average of 26 µg/L in the peat-based treatment system. It is suspected that release of P from the peat resulted in higher TP concentrations in Test Cells outflows than in inflows. Results for all of the other monitored parameters are also summarized in Exhibit 4-14.

Time series plots of the TP for Test Cell inflows and outflows from each of the two Test Cells for the POR are provided in Exhibit 4-15. In general, the shellrock-based PSTA Test Cell was more effective at reducing various P forms, nitrogen forms, and concentrations of other water quality parameters.

Optimal Performance Period

The dates for the OPPs for the shellrock-based and peat-based PSTA Test Cells were slightly different because of operational changes made between Phases 1 and Phase 2. The shellrock-based Test Cell operated optimally from July 1999 through early April 2001. The peat-based Test Cell operated optimally from July 1999 through January 2000. It also operated optimally following plant removal and lime applications from July 2000 (following a second startup release of labile P from the peat soils) through early April 2001.

Operational results for these periods are summarized in Exhibit 4-16. The average inflow TP of 23 µg/L was reduced to an average of 12 µg/L in the shellrock-based treatment system, and from an average inlet concentration of 24 µg/L to an outflow average of 18 µg/L in the peat-based treatment system. Results for all of the other monitored parameters are also summarized in Exhibit 4-16. During the OPP, the peat-based PSTA Test Cell was more effective than the shellrock-based PSTA Test Cell at reducing various nitrogen forms and concentrations of several other water quality parameters. Performance for both Test Cells was better during the OPP than during the startup periods (typically 4 months in length) that are excluded from this data set.

EXHIBIT 4-14

PSTA Test Cell STSOC Weekly Averaged Data for the Period-of-Record

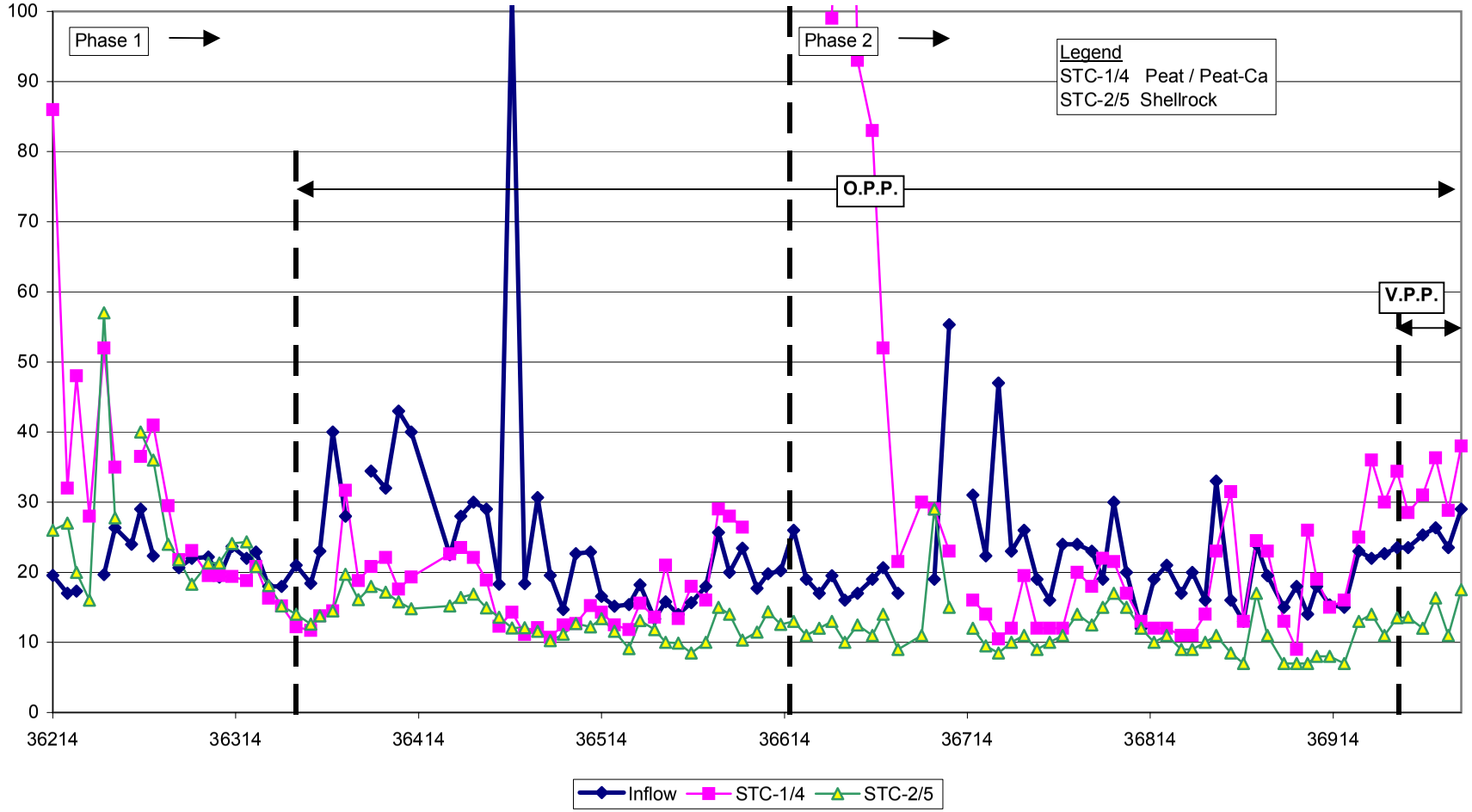
TREATMENT		STC 1/4 (Peat/Peat-Ca)						STC 2/5 (Shellrock)					
CELL		13						8					
PARAMETER	STN	Average	Median	StdDev	Max	Min	N	Average	Median	StdDev	Max	Min	N
TP (µg/L)	Inflow	23.4	21.0	11.2	102.0	12.0	97	23.1	21.0	11.0	102.0	12.0	103
	Outflow	25.5	19.5	23.1	186.0	9.0	100	14.6	12.9	7.1	57.0	7.0	106
TPP (µg/L)	Inflow	10.3	9.0	7.0	43.0	1.0	72	9.3	8.0	6.9	43.0	0.0	78
	Outflow	12.0	8.2	13.7	83.0	0.0	99	5.8	4.9	5.4	46.0	0.0	105
TDP (µg/L)	Inflow	11.5	11.0	3.2	21.0	1.9	73	12.2	11.7	3.6	27.8	1.9	79
	Outflow	13.4	11.0	11.2	103.0	5.0	100	8.8	8.0	3.8	22.4	4.0	106
SRP (µg/L)	Inflow	5.5	4.0	8.4	75.0	1.5	79	5.3	3.9	8.1	75.0	1.5	85
	Outflow	2.9	2.5	2.6	17.0	0.2	48	2.7	2.0	3.1	16.6	0.7	47
DOP (µg/L)	Inflow	7.1	7.3	3.2	14.0	0.0	55	8.3	8.0	3.5	17.6	0.0	61
	Outflow	9.6	8.0	4.3	25.9	3.4	48	7.5	6.2	4.2	19.0	0.2	47
TN (mg/L)	Inflow	2.11	2.20	0.51	3.55	0.85	56	2.07	2.14	0.58	3.48	0.62	56
	Outflow	1.90	2.05	0.80	3.46	0.44	25	1.85	1.97	0.66	3.22	0.62	26
TKN (mg/L)	Inflow	2.07	2.10	0.45	3.52	0.83	57	2.03	2.08	0.52	3.45	0.62	57
	Outflow	1.90	2.08	0.86	3.46	0.05	29	1.96	2.05	0.66	3.22	0.62	30
NO_2NO_3 (mg/L)	Inflow	0.07	0.05	0.06	0.24	0.00	57	0.07	0.05	0.06	0.22	0.00	57
	Outflow	0.01	0.00	0.02	0.08	0.00	29	0.01	0.00	0.01	0.03	0.00	30
NH_3 (mg/L)	Inflow	0.08	0.06	0.06	0.23	0.02	29	0.08	0.06	0.06	0.23	0.02	29
	Outflow	0.02	0.02	0.02	0.11	0.00	23	0.02	0.02	0.02	0.07	0.00	23
OrgN (mg/L)	Inflow	2.00	2.03	0.54	3.35	0.77	29	1.91	2.03	0.63	3.28	0.59	29
	Outflow	1.82	1.92	0.95	3.35	0.05	23	1.88	2.08	0.73	3.22	0.60	23
TOC (mg/L)	Inflow	36.63	36.50	6.00	50.10	21.65	65	36.08	35.40	5.89	50.10	21.65	71
	Outflow	40.29	40.70	9.89	69.00	20.70	29	38.79	39.50	6.78	53.10	23.45	30
TSS (mg/L)	Inflow	3.07	3.00	2.46	14.00	0.50	64	3.15	3.00	2.49	14.00	0.50	70
	Outflow	3.77	3.75	2.66	10.00	0.50	27	3.91	3.00	4.03	22.00	0.50	29
Ca (mg/L)	Inflow	69.23	71.60	14.29	100.00	34.00	60	69.54	71.27	12.80	100.00	44.95	66
	Outflow	47.25	54.00	17.48	71.00	15.70	23	56.36	62.00	13.38	75.50	30.00	25
Alkalinity (mg/L)	Inflow	252	257	44	318	120	64	252	257	42	318	120	70
	Outflow	206	223	59	278	100	27	229	246	46	288	123	29
Wtr Temp (^oC)	Cell Avg	24.45	24.91	4.46	31.39	11.90	93	24.28	24.43	4.61	32.49	12.48	104
pH (units)	Cell Avg	7.98	7.72	0.67	9.57	7.09	92	7.93	8.02	0.50	9.20	7.01	103
Conductivity (µmhos/cm)	Cell Avg	1062	1087	179	1407	559	92	1072	1095	172	1371	602	103
TDS (g/L)	Cell Avg	0.69	0.71	0.10	0.85	0.41	80	0.70	0.71	0.10	0.88	0.41	97
DO (%)	Cell Avg	57.07	45.22	44.79	157.95	2.68	86	77.51	91.42	40.41	145.86	2.16	104
DO (mg/L)	Cell Avg	4.92	3.86	3.52	11.95	0.21	93	6.40	7.53	3.25	11.90	0.17	104

Note: Calculations based on weekly averages.

µmhos/cm = microhoms per centimeter

EXHIBIT 4-15

PSTA Test Cell Weekly Average TP Concentration Performance Summary Timeseries



Note(s):
POR = Entire Period-of-Record
OPP = Optimal Performance Period
VPP = Verification Performance Period

EXHIBIT 4-16

PSTA Test Cell STSOC Weekly Averaged Data for the Optimal Performance Period

TREATMENT		STC 1/4 (Peat/Peat-Ca)						STC 2/5 (Shellrock)					
CELL		13						8					
PARAMETER	STN	Average	Median	StdDev	Max	Min	N	Average	Median	StdDev	Max	Min	N
TP (µg/L)	Inflow	24.0	22.7	12.2	102.0	12.0	67	23.4	20.6	11.9	102.0	12.0	86
	Outflow	18.4	15.8	7.4	38.0	9.0	68	12.4	12.0	3.4	29.0	7.0	88
TPP (µg/L)	Inflow	10.2	10.0	6.1	37.0	1.0	53	9.3	8.0	7.0	43.0	0.5	72
	Outflow	7.8	6.0	4.9	22.3	0.0	67	4.6	4.5	2.4	14.0	0.0	87
TDP (µg/L)	Inflow	11.0	11.0	2.9	20.0	1.9	54	12.0	11.7	3.2	21.0	1.9	73
	Outflow	10.5	9.8	3.5	20.4	5.0	68	7.8	7.6	2.6	22.4	4.0	88
SRP (µg/L)	Inflow	5.5	3.1	10.3	75.0	1.9	51	4.9	3.1	9.0	75.0	1.5	68
	Outflow	2.0	2.0	0.9	4.3	0.9	29	1.9	1.5	1.0	4.4	1.0	30
DOP (µg/L)	Inflow	6.9	7.3	3.3	13.0	0.0	38	8.1	8.0	3.3	14.3	0.0	55
	Outflow	8.7	7.1	3.2	15.7	5.1	29	6.2	5.6	3.2	19.0	2.0	30
TN (mg/L)	Inflow	2.20	2.34	0.47	2.94	0.85	36	2.18	2.30	0.56	3.48	0.62	41
	Outflow	1.86	2.07	0.61	2.60	0.44	16	2.05	2.08	0.56	3.22	0.65	21
TKN (mg/L)	Inflow	2.16	2.23	0.40	2.76	0.83	37	2.14	2.21	0.50	3.45	0.62	42
	Outflow	1.89	2.09	0.76	2.96	0.05	20	2.13	2.14	0.56	3.22	0.65	25
NO_2NO_3 (mg/L)	Inflow	0.07	0.05	0.06	0.20	0.00	36	0.06	0.05	0.06	0.22	0.00	41
	Outflow	0.01	0.00	0.01	0.03	0.00	20	0.01	0.00	0.01	0.03	0.00	25
NH_3 (mg/L)	Inflow	0.08	0.06	0.06	0.23	0.02	19	0.08	0.06	0.06	0.23	0.02	24
	Outflow	0.02	0.02	0.01	0.04	0.00	15	0.02	0.02	0.02	0.07	0.00	18
OrgN (mg/L)	Inflow	2.06	2.16	0.49	2.72	0.77	19	2.03	2.11	0.61	3.28	0.59	24
	Outflow	1.79	2.05	0.86	2.94	0.05	15	2.10	2.13	0.65	3.22	0.63	18
TOC (mg/L)	Inflow	37.69	37.00	5.90	50.10	21.65	41	36.97	36.50	5.83	50.10	21.65	55
	Outflow	41.01	40.85	9.62	69.00	26.40	20	40.01	40.50	6.33	53.10	29.00	25
TSS (mg/L)	Inflow	3.05	2.00	2.50	13.00	0.50	40	2.97	2.00	2.39	13.00	0.50	54
	Outflow	3.46	3.04	2.64	10.00	0.50	18	4.08	3.00	4.38	22.00	0.50	24
Ca (mg/L)	Inflow	75.91	77.45	11.34	100.00	55.20	36	73.47	73.80	10.70	100.00	52.30	50
	Outflow	50.60	56.50	15.97	71.00	22.80	14	58.14	62.50	11.49	75.50	40.00	20
Alkalinity (mg/L)	Inflow	269	268	30	318	197	40	262	260	29	318	197	54
	Outflow	218	237	52	278	100	18	231	244	41	288	130	24
Wtr Temp (^oC)	Cell Avg	23.60	22.72	4.58	31.39	11.90	66	23.87	23.45	4.78	32.49	12.48	85
pH (units)	Cell Avg	7.73	7.58	0.52	9.30	7.09	65	7.79	7.84	0.45	9.20	7.01	84
Conductivity (umhos/cm)	Cell Avg	1061	1080	151	1407	636	65	1076	1078	143	1350	673	84
TDS (g/L)	Cell Avg	0.68	0.69	0.09	0.83	0.42	66	0.69	0.68	0.09	0.86	0.41	85
DO (%)	Cell Avg	45.37	36.12	37.62	157.95	2.68	66	71.27	70.68	41.79	145.86	2.16	85
DO (mg/L)	Cell Avg	3.75	3.03	2.94	11.94	0.21	66	5.93	6.35	3.41	11.90	0.17	85

Note: Calculations based on weekly averages.

4.3.3.2 STSOC Verification Performance Period Results

Phosphorus Results

Detailed P results for the 5-week VPP are presented in Exhibit 4-17. Individual inflow TP values ranged from 19 to 30 µg/L over this period, with an average inflow value of 25 µg/L. Individual TP outflow values from the shellrock-based test cell (South Test Cell 8) ranged from 8 µg/L to 19 µg/L with an average outflow value of 14 µg/L. It consistently showed a reduction in P concentration throughout the time period evaluated. South Test Cell 13, the peat-based PSTA system, exhibited outflow values ranging from 20 µg/L to 41 µg/L, with an average outflow value of 33 µg/L, showing a net increase of TP in the system during the VPP. Exhibit 4-18 provides a graphical representation of TP values collected over the 5-week period. Exhibit 4-19 provides a detailed summary of weekly values for all parameters sampled during the VPP.

EXHIBIT 4-17

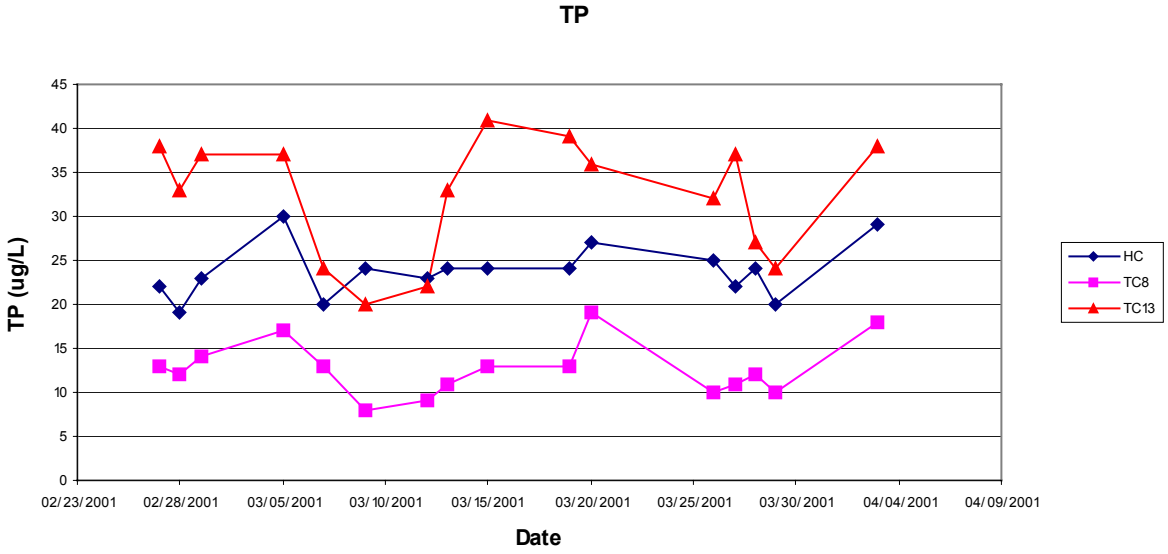
Detailed PSTA Phosphorus Results for the Verification Performance Period, February through April 2001

Date	Head Cell (PSTA Inflow)			South Test Cell 8 Outflow			South Test Cell 13 Outflow		
	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)
02/27/01	22	15	3	13	9	1	38	18	2
02/28/01	19	--	--	12	--	--	33	--	--
03/01/01	23	14	3	14	4	2	37	19	4
03/05/01	30	15	3	17	9	2	37	18	3
03/07/01	20	10	2	13	8	2	24	15	3
03/09/01	24	--	--	8	--	--	20	--	--
03/12/01	23	--	--	9	--	--	22	--	--
03/13/01	24	11	2	11	7	1	33	17	2
03/15/01	24	13	3	13	7	3	41	18	3
03/19/01	24	--	--	13	--	--	39	--	--
03/20/01	27	15	4	19	7	5	36	14	3
03/26/01	25	--	--	10	--	--	32	--	--
03/27/01	22	11	8	11	7	3	37	15	2
03/28/01	24	10	2	12	6	1	27	13	2
03/29/01	20	10	2	10	6	1	24	13	2
04/03/01	29	--	--	18	--	--	38	--	--

TP removal in the peat-based PSTA Test Cell during the 5-week verification sampling period was not typical of performance over the longer OPP. Prior to this VPP, routinely collected outflow TP data from the peat-based PSTA Test Cell were normally lower than the TP inflow concentrations. Starting in December 2000 and during the STSOC VPP in February through April 2001, outflow TP concentrations from this cell were typically higher than inflow concentrations. The reason for this rise in P export was not confirmed.

Similar net increases in TP were also commonly observed in the District's STA optimization research at the STA-1W STCs that were colonized with cattails (SFWMD, 2001).

Exhibit 4-18
Inflow and Outflow TP Concentration Trends from the STA 1-W PSTA Test Cells 8 (Shellrock) and 13 (Peat)



Although there was some seasonal decline in TP removal efficiency in the shellrock-based PSTA Test Cells during the VPP (late winter with sub-optimal periphyton community development), the results from these Test Cells were more typical of results that had been observed during the previous OPP.

These observations indicate that the STSOC VPP data sets should not be used alone for drawing final conclusions concerning the ability of PSTAs to remove TP. The full OPP for the shellrock Test Cell was used as the basis for determining the lowest achievable outflow TP concentration for the full-scale PSTA conceptual design. The lowest long-term (approximately 21 months) achievable flow-weighted TP concentration for PSTAs determined by the Phase 1 and 2 research was 12 µg/L for a shellrock-based treatment. Although lower long-term outflow TP concentrations may be achievable with other treatments not tested as part of this project, 12 µg/L was used for the STSOC analysis.

General Parameter Results

Detailed analytical results for non-P parameters for the VPP are presented in Exhibit 4-19. Statistics for these data were presented in Exhibit 4-20. There was little variability observed for any of these parameters during this 5-week period.

Turbidity ranged between 0.65 and 3.5 nephelometric turbidity units (NTU) in all samples. Turbidity increased slightly between the head cell and the outflow from the peat-based PSTA cell. Alkalinity ranged from 224 to 318 mg/L as $CaCO_3$, with higher levels in the shellrock-based Test Cell outflow than in the peat-based cell. Alkalinity was reduced in the outflows of both Test Cells compared to the inflow. TOC ranged from 45 to 54 mg/L with no statistically significant change through the Test Cells and no difference observed between the two soil treatments.

EXHIBIT 4-19

PSTA STSOC General Parameter Results, February - April 2001

Station	Date	Parameter																	
		Color (CPU)	Turbidity (NTU)	Alkalinity as $CaCO_3$ (mg/L)	TOC (mg/L)	Chloride (mg/L)	Ammonia, as N (mg/L)	TKN (mg/L)	NO_2/NO_3 (mg/L)	TDS (mg/L)	TSS (mg/L)	Silica (mg/L)	SO_4 (mg/L)	Aluminum (µg/L)	Calcium (mg/L)	Iron (µg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)
Head Cell	02/28/2001	120	1.5	296	45.7	195	0.036	2.33	0.082	742	4	15.2	55	48.3[d]	76.9	8.2	31.4	16.8	144
	03/01/2001	160	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/05/2001	140	1.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/07/2001	180	0.9	318	40.5	193	0.189	2.22	0.134	788	2	21	52.4	<4.5	78	<2.5	31.4	15.8	150
	03/13/2001	150	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/15/2001	140	1.1	304	47.2	218	0.044	2.76	0.184	806	10	20.1	55	<4.5	72.8	2.15	31.4	14.9	156
	03/20/2001	160	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/27/2001	120	0.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/28/2001	160	0.65	272	49.7	234	0.051	2.72	0.123	795	4	20.3	55.6	<4.5	40	3.4	32.2	15.9	164
	03/29/2001	175	0.80	272	50.5	229	0.053	2.50	0.124	785	3	20.7	56.1	<4.5	68.7	<2.5	30.7	14.4	153
	04/03/2001	180	1.20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Test Cell 8 Outflow (Shellrock)	02/28/2001	140	1.2	274	46.8	193	0.006	2.51	<0.004	737	3	15.9	54.6	<8.0	64.2	43.4[a]	31.3	14.4	144
	03/01/2001	140	1.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/05/2001	140	3.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/07/2001	180	0.75	262	45	207	0.032	2.13	<0.004	777	5	20.9	55.2	<4.5	63.6	6.4	32.5	17.3	154
	03/13/2001	150	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/15/2001	140	1	276	48	218	0.02	2.76	<0.004	756	7	21.6	52.3	<4.5	57.9	11.5	31.2	15.5	156
	03/20/2001	160	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/27/2001	125	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/28/2001	160	1.0	244	54.3	234	0.023	2.84	<0.004	777	<2	22.7	60.5	<4.5	56.7	4.7	31.5	15.2	158
	03/29/2001	125	0.85	252	51.9	234	0.018	2.80	<0.004	788	<2	21.9	52.7	<4.5	56.5	4.1	31.6	14.9	160
	04/03/2001	75	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Test Cell 13 Outflow (Peat-Ca)	02/28/2001	160	1.3	240	50.8	190	<0.003	2.07[b]	<0.004	685[c]	7	19.0	56.7	<8.0	47.5	<4.0	33.3	14.6	147
	03/01/2001	NS	NS	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/05/2001	160	2.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/07/2001	200	1.1	236	45.3	213	0.034	2.16	<0.004	738	4	23.4	52.4	<4.5	46.4	3	33.1	17.5	154
	03/13/2001	150	2.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/15/2001	160	1.2	236	47.6	220	0.021	2.96	<0.004	690	10	20.5	49.9	<4.5	40.3	5.6	32.6	15.7	158
	03/20/2001	160	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/27/2001	125	2.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	03/28/2001	160	1.7	224	50.8	233	<0.003	2.72	<0.004	733	<2	22.6	49	<4.5	39.6	4.3	31.9	16	163
	03/29/2001	175	1.0	224	52.1	231	0.014	2.83	<0.004	742	3	22.1	48.5	<4.5	40.1	4.7	32.2	15.7	161
	04/03/2001	75	1.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Class III WQ Criteria (Fresh)		NC	<29 above background	Not depressed below 20	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	<1,000	NC	NC	NC

NOTES:

NS = No sample available; the bottle cap became loose during shipment resulting in the loss of the sample.

NC = No applicable Class III water quality criterion.

mg/L = milligram per liter

µg/L = microgram per liter

[a] PPB reported an iron concentration of 35 µg/L for the re-analysis of this sample.

[b] Value originally reported as <0.10. Sample re-analyzed by PPB

[c] Value originally reported as <3. Sample re-analyzed by PPB

[d] PPB reported an aluminum concentration of 56.4µg/L for the re-analysis of this sample

EXHIBIT 4-20

PSTA Test Cell STSOC Weekly Averaged Data for the Verification Performance Period

TREATMENT		STC 1/4 (Peat/Peat-Ca)						STC 2/5 (Shellrock)					
CELL		13						8					
PARAMETER	STN	Average	Median	StdDev	Max	Min	N	Average	Median	StdDev	Max	Min	N
TP (µg/L)	Inflow	25.1	24.4	2.2	29.0	23.5	6	25.3	24.4	2.3	29.0	23.5	6
	Outflow	32.8	32.7	4.0	38.0	28.5	6	14.0	13.6	2.5	17.5	11.0	6
TPP (µg/L)	Inflow	10.1	10.8	2.7	12.5	6.0	5	10.1	10.8	2.7	12.5	6.0	5
	Outflow	15.7	15.2	4.1	22.3	11.5	5	5.5	4.9	1.9	8.8	4.0	5
TDP (µg/L)	Inflow	14.3	12.8	3.4	20.0	11.3	5	14.5	12.8	3.8	21.0	11.3	5
	Outflow	16.1	17.0	2.2	18.7	13.6	5	7.8	8.0	0.9	8.8	6.5	5
SRP (µg/L)	Inflow	3.7	2.7	1.9	7.0	2.3	5	4.3	2.7	3.2	10.0	2.3	5
	Outflow	2.6	2.7	0.3	3.0	2.1	5	2.1	2.0	0.6	3.0	1.3	5
DOP (µg/L)	Inflow	10.6	10.3	2.2	13.0	7.3	5	10.2	10.3	1.8	12.0	7.3	5
	Outflow	13.5	14.3	1.9	15.7	11.5	5	5.7	5.7	1.1	7.0	4.5	5
TN (mg/L)	Inflow	2.64	2.73	0.25	2.94	2.35	5	2.67	2.73	0.27	2.94	2.35	5
	Outflow	2.50	2.55	0.38	2.96	2.07	5	2.55	2.52	0.27	2.82	2.13	5
TKN (mg/L)	Inflow	2.50	2.57	0.22	2.76	2.22	5	2.52	2.61	0.23	2.76	2.22	5
	Outflow	2.10	2.55	1.18	2.96	0.05	5	2.55	2.52	0.27	2.82	2.14	5
NO_2NO_3 (mg/L)	Inflow	0.15	0.13	0.05	0.20	0.08	5	0.15	0.13	0.05	0.22	0.08	5
	Outflow	0.00	0.00	0.00	0.00	0.00	5	0.00	0.00	0.00	0.00	0.00	5
NH_3 (mg/L)	Inflow	0.08	0.05	0.06	0.19	0.04	5	0.08	0.05	0.06	0.19	0.04	5
	Outflow	0.02	0.02	0.01	0.03	0.00	5	0.02	0.02	0.01	0.03	0.01	5
OrgN (mg/L)	Inflow	2.42	2.51	0.27	2.72	2.03	5	2.44	2.56	0.28	2.72	2.03	5
	Outflow	2.08	2.54	1.18	2.94	0.05	5	2.53	2.50	0.27	2.80	2.10	5
TOC (mg/L)	Inflow	46.04	46.70	3.50	50.10	40.50	5	45.84	45.70	3.48	50.10	40.50	5
	Outflow	47.52	47.60	3.17	50.80	43.50	5	47.65	46.80	3.29	53.10	44.65	5
TSS (mg/L)	Inflow	4.90	4.00	3.05	10.00	2.00	5	4.70	4.00	3.07	10.00	2.00	5
	Outflow	5.47	4.00	3.04	10.00	2.33	5	3.60	3.00	2.19	7.00	1.00	5
Alkalinity (mg/L)	Inflow	296	296	17	318	272	5	296	296	17	318	272	5
	Outflow	235	236	7	240	223	5	263	264	13	276	248	5
Color (CU)	Inflow	156	156	14	180	140	6	156	156	14	180	140	6
	Outflow	147	158	37	180	75	6	136	143	32	160	75	6
Turbidity (NTU)	Inflow	1.17	1.20	0.23	1.40	0.75	6	1.17	1.20	0.23	1.40	0.75	6
	Outflow	1.50	1.45	0.35	1.90	1.10	6	1.34	1.28	0.41	2.13	0.95	6
Chloride (mg/L)	Inflow	209.4	206.5	18.6	231.5	193.0	4	209.4	206.5	18.6	231.5	193.0	4
	Outflow	213.8	216.5	17.7	232.0	190.0	4	213.0	212.5	17.3	234.0	193.0	4
TDS (mg/L)	Inflow	781.5	789.0	27.5	806.0	742.0	4	781.5	789.0	27.5	806.0	742.0	4
	Outflow	712.6	713.8	29.1	738.0	685.0	4	763.1	766.5	20.8	782.5	737.0	4
Silica (mg/L)	Inflow	19.2	20.3	2.7	21.0	15.2	4	19.2	20.3	2.7	21.0	15.2	4
	Outflow	21.3	21.4	2.0	23.4	19.0	4	20.2	21.3	2.9	22.3	15.9	4
SO_4 (mg/L)	Inflow	54.6	55.0	1.5	55.9	52.4	4	54.6	55.0	1.5	55.9	52.4	4
	Outflow	51.9	51.2	3.5	56.7	48.8	4	54.7	54.9	1.8	56.6	52.3	4
Dissolved Ca (mg/L)	Inflow	70.5	74.9	11.0	78.0	54.4	4	70.5	74.9	11.0	78.0	54.4	4
	Outflow	43.5	43.4	4.0	47.5	39.9	4	60.6	60.8	3.9	64.2	56.6	4
Dissolved Aluminum (µg/L)	Inflow	13.8	2.3	23.0	48.3	2.3	4	13.8	2.3	23.0	48.3	2.3	4
	Outflow	2.7	2.3	0.9	4.0	2.3	4	2.7	2.3	0.9	4.0	2.3	4
Dissolved Iron (µg/L)	Inflow	3.5	2.2	3.2	8.2	1.3	4	3.5	2.2	3.2	8.2	1.3	4
	Outflow	3.8	3.8	1.6	5.6	2.0	4	16.4	9.0	18.2	43.4	4.4	4
Dissolved Magnesium (mg/L)	Inflow	31.4	31.4	0.0	31.5	31.4	4	31.4	31.4	0.0	31.5	31.4	4
	Outflow	32.8	32.9	0.6	33.3	32.1	4	31.6	31.4	0.6	32.5	31.2	4
Dissolved Potassium (mg/L)	Inflow	15.7	15.5	0.8	16.8	14.9	4	15.7	15.5	0.8	16.8	14.9	4
	Outflow	15.9	15.8	1.2	17.5	14.6	4	15.6	15.3	1.2	17.3	14.4	4
Dissolved Sodium (mg/L)	Inflow	152.1	153.0	6.5	158.5	144.0	4	152.1	153.0	6.5	158.5	144.0	4
	Outflow	155.3	156.0	6.4	162.0	147.0	4	153.3	155.0	6.5	159.0	144.0	4
Wtr Temp (^oC)	Cell Avg	22.75	22.64	0.82	23.92	21.66	6	21.00	21.69	2.21	23.45	17.14	6
pH (units)	Cell Avg	7.63	7.55	0.18	7.87	7.47	6	7.46	7.46	0.03	7.50	7.41	6
Conductivity (umhos/cm)	Cell Avg	1223	1225	39	1264	1174	6	1273	1264	40	1350	1236	6
TDS (g/L)	Cell Avg	0.78	0.79	0.03	0.81	0.75	6	0.75	0.81	0.17	0.86	0.41	6
DO (%)	Cell Avg	29.79	30.01	10.40	45.09	18.44	6	35.02	33.51	14.29	57.50	17.20	6
DO (mg/L)	Cell Avg	2.60	2.63	0.81	3.73	1.49	6	2.83	2.37	1.39	5.39	1.46	6

Note:

Calculations based on weekly averages.

CU = color unit

NTU = nephelometric turbidity unitsturbidity units

g/L = grams per liter

Chloride concentrations ranged from 190 to 234 mg/L and were conservative in both PSTA Test Cells. Inorganic nitrogen forms were reduced in both Test Cells compared to the inflow from the head cell; however, organic nitrogen concentration was not reduced in the shellrock-based Test Cell and only slightly reduced in the peat-based cell. TDS ranged from 685 to 806 mg/L, and concentrations were only slightly reduced in both PSTA Test Cells. TSS concentrations ranged from <2 to 10 mg/L. The average TSS concentration increased between the head cell and the peat-based Test Cell outflow and decreased in the shellrock-based cell. Silica concentrations ranged from 15.2 to 23.4 mg/L and increased slightly with passage through the two Test Cells. Sulfate ranged from 48 to 60 mg/L and did not change significantly with passage through the PSTA Test Cells.

Except for questionable results for one sample, aluminum concentrations were below the detection level of 4.5 µg/L. Calcium concentrations ranged from 40 to 77 mg/L and were reduced with the passage of water through both of the PSTA test cells. Iron concentrations ranged from <2.5 to 43.3 µg/L. In general, there was no apparent change in iron concentration with passage of the water through the PSTA test cells. Magnesium concentrations ranged from 31 to 33 mg/L and showed no changes through the test cells. Likewise, potassium concentrations ranged between 15 and 18 mg/L and showed no changes through the PSTA Test Cells. Sodium concentrations ranged from 144 to 161 mg/L and also were conservative with passage through the PSTA cells.

In summary, there was very little effect of the PSTA treatments on any of the general water quality parameters, including metals. The only observed significant effects were positive, with the reduction of inorganic nitrogen concentrations. Calcium concentrations were also reduced slightly. During this VPP, the peat-based PSTA Test Cell did not produce reductions of TSS and turbidity as had been previously observed. This slight increase in export of particulate matter was also reflected in the TPP results discussed earlier. As stated above, the impaired performance of the peat-based PSTA Test Cell may have been an issue related to the scale of these Test Cells or the availability of labile TP in the peat soils. As described below, assessment of performance and development of conceptual design criteria is based on the results from the shellrock-based PSTA Test Cell for the OPP.

4.3.4 Full-Scale PSTA Conceptual Design

A conceptual design for a full-scale PSTA downstream from STA-2 was developed for the purposes of providing a basis for cost evaluation and comparing this technology to other ATTs. Based on the information available to date about PSTA performance, it is premature to proceed with the actual design of anything other than a prototype or demonstration-level PSTA project. Such a project has already been engineered and constructed as Phase 3 of the District's PSTA Research and Demonstration Project. Results from that larger-scale site will be helpful in determining whether continued pursuit of the use of PSTAs in support of Everglades restoration is justified and, if so, those data will be needed to develop refined criteria for PSTA design.

The conceptual PSTA design described in this report includes the following components:

- Estimation of the PSTA footprint necessary to achieve flow-weighted mean outflow TP concentrations of 12 and 20 µg/L based on the synthetic post-STA-2 dataset and assuming three bypass options (no bypass, 10, and 20 percent bypass)
- Size and layout of engineering works, including levees, canals, pump stations, and water control structures
- Description of likely site preparation options and soil amendments
- Unit costs for principal construction items
- 50-year present worth cost estimates for the various configurations evaluated
- Sensitivity of land area and cost estimates to various forecasting and design assumptions

4.3.4.1 PSTA Footprint

PSTAs are a relatively low-management but land-intensive treatment option that is dependent on environmental energy inputs from the sun and the atmosphere. The primary energy input is solar radiation (insolation). This radiation provides key wavelengths necessary for primary productivity of the periphyton and other plants and maintains the ambient temperature of the water and biological material. The PSTA heat balance is in turn maintained in a quasi-equilibrium by evapotranspiration—the evaporation of water and transpiration by vascular plants such as emergent macrophytes within the PSTA.

Since the PSTA is a solar-powered system, it must have a large aerial extent to grow enough periphyton and other plants to capture very low TP concentrations through biological uptake and to sequester that TP in the form of calcium- and carbon-bound accreted sediments. No harvesting of biomass or sediments is envisioned for this process, so TP must be effectively stored within the PSTA footprint to achieve a useful project life (e.g., in excess of 50 years). As described above, the PSTA has been shown to be able to achieve TP outflow concentrations as low as 12 µg/L on a 2-year average basis, and possibly lower concentrations (8 to 10 µg/L) at low inlet loadings and for relatively shorter periods of time (up to a few months). Because 12 µg/L was the lowest average achieved on a sustained basis during PSTA demonstration testing, this is the lowest value used for conceptual design and cost estimating. The mass action rule (first order process) indicates that the area required to accomplish this low TP outflow concentration and possible lower concentrations is vastly greater than the area needed to achieve higher outflow concentrations.

4.3.4.2 PSTA Forecast Model Results

The only PSTA Forecast Model calibration data set used for this analysis was the one for the OPP for the shellrock Test Cell treatment (STC-2/5). This was the calibration dataset that best represents optimal performance of a PSTA built on soils with minimum startup interference from antecedent soil P loads and minimum encroachment from emergent macrophytes. No infiltration was included in these model runs because there was no recorded infiltration in the calibration dataset. It is likely that some infiltration will occur in a full-scale PSTA built on permeable soils. Because infiltration is not included in the model estimates of required PSTA areas, they will be more conservative than area estimates based on a leaky footprint.

The calibration dataset for the peat-based Test Cell PSTA was not used for STSOC analysis due to the apparent affects of start-up conditions and continuing release of labile P within the relatively short time frame of data collection. As described below, soil amendments, such as limerock, shellrock, or lime additions, or selection of a site with low available TP, will be necessary to develop a full-scale PSTA with this expected level of performance. Otherwise, necessary footprint areas are likely to be larger than those estimated below. For this preliminary conceptual design, a 2-foot cover of limerock is assumed to be needed to provide this low level of labile TP. Application of 2 feet of limerock was found to be necessary to achieve a complete cover without upwelling of organic soils during construction of the PSTA field-scale cells (Marty Braun, personal communication). Use of 2 feet of limerock is likely the most conservative (costly) method of amending pre-existing soils at the site of a full-scale PSTA. The effects of this conservative assumption on project costs are described later in this section.

The PSTA technology was not experimentally evaluated for treatment of post-BMP (high TP) agricultural runoff waters. Post-BMP TP concentrations (typically greater than 50 to 150 µg/L) result in a shift to dominance by green algae and away from the calcareous blue-green species associated with low TP concentrations. While this type of eutrophic periphyton community naturally occurs in many wetlands receiving higher TP inputs and is capable of significant TP uptake, it was not the type of periphyton community envisioned for the PSTA concept in attempting to reach a planning target of 10 ppb TP removal. For these reasons, the PSTA technology is not evaluated for treatment of post-BMP waters. Rather, this technology is only evaluated for treatment of post-STA waters (typically less than 50 µg/L of TP).

Actual inflow TP concentrations to the PSTA research cells were typically well below 50 µg/L and averaged less than half that value. This means that modeling PSTA performance starting at an inflow flow-weighted mean TP of 50 µg/L requires extrapolation outside the mean input TP data set (but not outside individual recorded TP input concentrations) used for model calibration. This adds an additional level of uncertainty related to model estimates of the necessary PSTA footprint area.

Six specific scenarios were tested with the PSTA Forecast Model:

- Flow-weighted mean outflow TP of 12 µg/L with 0, 10, and 20 percent inflow bypass
- Flow-weighted mean outflow TP of 20 µg/L with 0, 10, and 20 percent inflow bypass

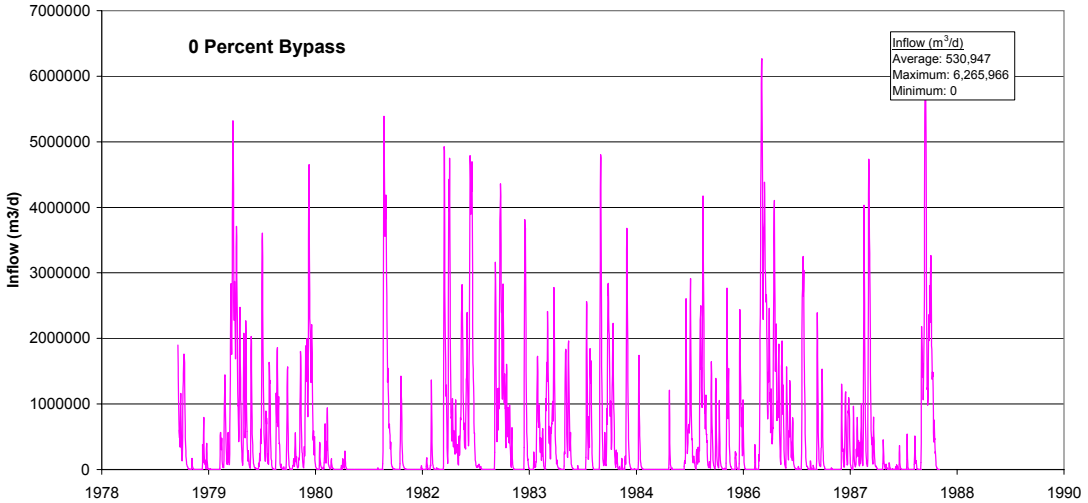
These six scenarios were simulated using a 10-year synthetic data set supplied by the District. This data set mimics the flows and TP loads resulting from hypothetical STA-2 performance for a 10-year POR. Exhibits 4-21 and 4-22 provide summaries and time-series plots of the key components of this data set in terms of average, minimum, maximum, and flow-weighted mean flows and TP concentrations for each of the bypass options. Bypass amounts were subtracted from peak flows (to the extent possible) using a bypass weir, the elevation of which was determined mathematically to capture the 10 and 20 percent bypass flows.

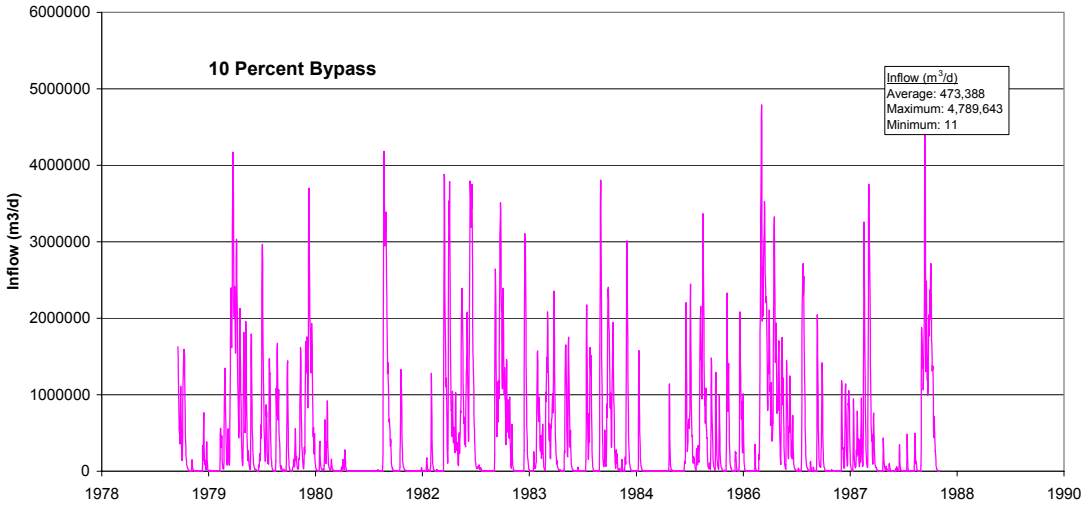
The benefits of constructing an upstream flow equalization basin (FEB) for possibly reducing the PSTA footprint were investigated by use of the PSTA Forecast Model. Water depths in the FEB were limited to 4.5 feet. Model runs determined that addition of flow equalization did not significantly reduce the overall footprint (FEB+PSTA) needed to achieve the target TP goals downstream. For this reason, the PSTA conceptual design that follows does not include flow equalization.

Exhibit 4-23 provides a summary of the estimated PSTA footprint areas needed for each of the six post-STA-2 discharge scenarios. These estimated areas range from 2,026 to 6,198 ha (5,006 to 15,316 acres). Estimated maximum outflow volumes, TP concentrations, and resulting average and maximum water depths in the PSTAs for each of these scenarios are also summarized in Exhibit 4-23. These areas, flows, and water depths were used to develop the cost estimates for full-scale PSTA construction and operation.

It is clear from these estimates that attainment of TP outflow concentrations near the apparent background attainable by these natural systems requires substantially larger land areas. Additional modeling conducted on the DMSTA platform using the PSTA Forecast Model equations has also indicated that hydraulic assumptions may have a significant effect on the estimated footprint area (Dr. Bill Walker, personal communication).

The PSTA Forecast Model is based on an assumption of one continuously stirred tank reactor (CSTR). This format was selected during model development because there was little effect of increasing the number of TIS from 1 to 1.8, the actual measured hydraulic degree of mixing measured in the PSTA Test Cells during Phase 1. At the end of Phase 2, the PSTA Test Cells were tracer-tested a second time and found to have a residence time distribution closer to 4 TIS. Since the PSTA Forecast Model was not found to be sensitive to the number of TIS during the earlier calibration test, it was finalized based on one CSTR.





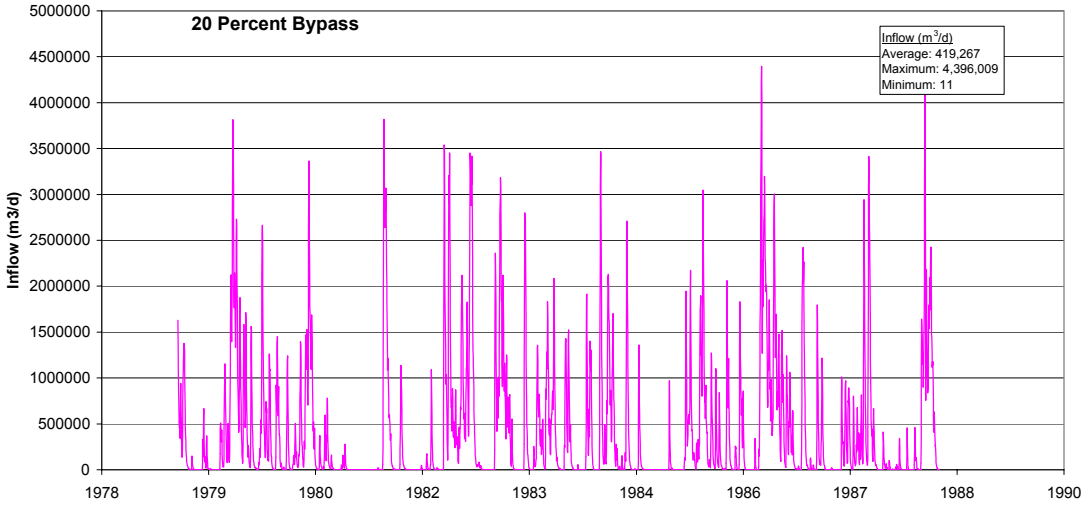


EXHIBIT 4-21
Post -STA Flow Time Series with 0, 10, and 20 Percent Bypass

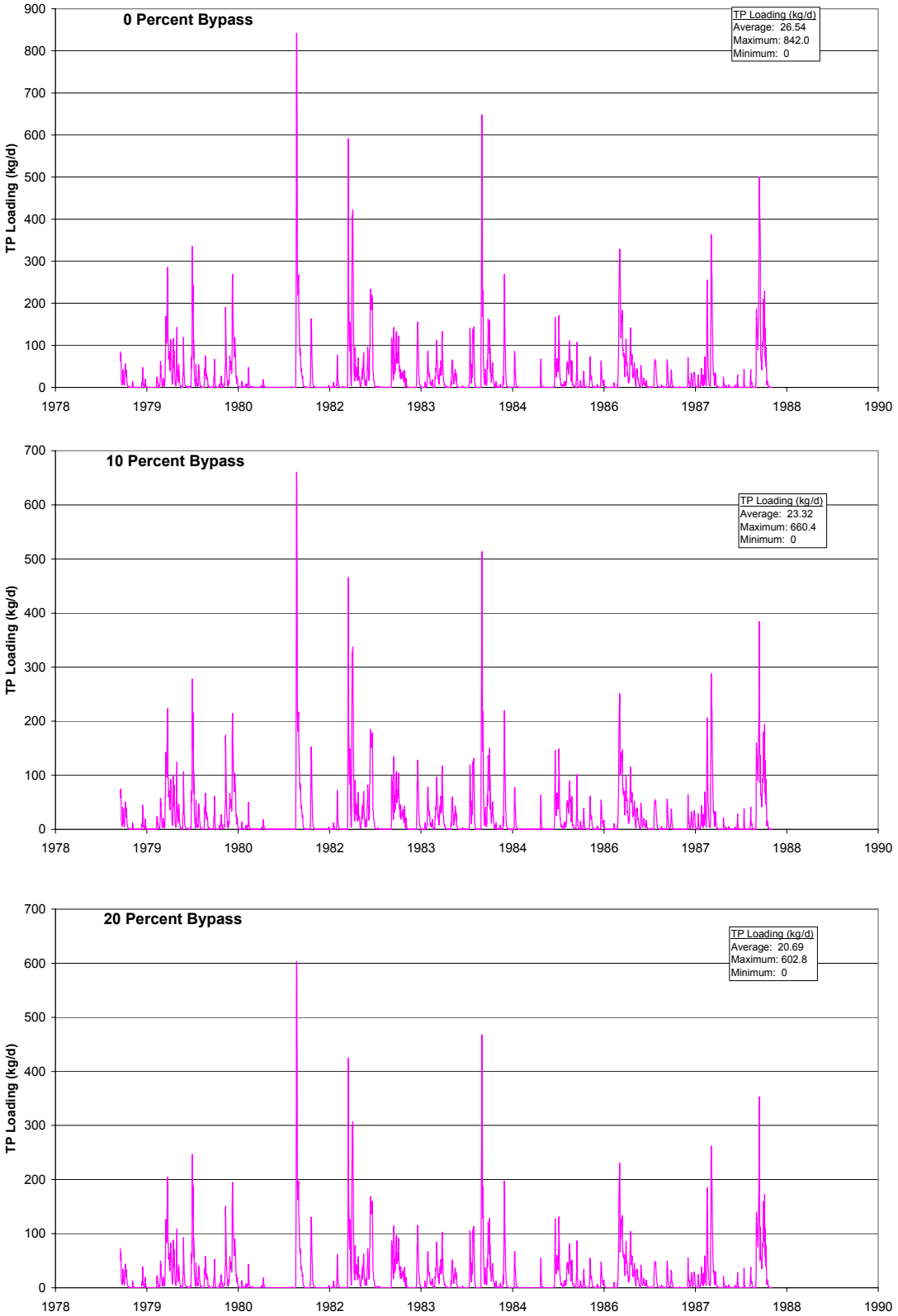


EXHIBIT 4-22
Post-STA TP Mass Load Time Series with 0, 10, and 20 Percent Bypass

EXHIBIT 4-23

Estimated PSTA Footprint Areas Needed to Meet Six Outflow TP Concentrations and Flow Bypass Options for Post-STA (1/79 - 9/88)

Percent Bypass		0	10	20
Q_in (m^3/d)	Average	530,947	473,388	419,267
	Maximum	6,265,966	4,789,643	4,396,009
	Minimum	0	11	11
TP_in (g/m^3)	Average	0.037	0.037	0.037
	Flow Weighted	0.050	0.049	0.049
	Maximum	0.184	0.184	0.184
	Minimum	0.000	0.000	0.000
TP_in (kg)	Total	94,480	83,020	73,646
Average TP_out = 0.012 g/m^3				
Q_out (m^3/d)	Average	500,682	447,366	396,198
	Maximum	4,677,323	3,629,628	3,405,009
	Minimum	0	0	0
TP_out (g/m^3)	Average	0.011	0.011	0.011
	Flow Weighted	0.012	0.012	0.012
	Maximum	0.020	0.019	0.019
	Minimum	0.006	0.006	0.006
TP_out (kg)	Total	21,392	19,112	16,927
TP_eff (%)		77.4	77.0	77.0
Required Area (ac)		**15,316**	**13,241**	**11,791**
Max Depth (ft)		3.02	2.71	2.64
Avg Depth (ft)		1.18	1.16	1.13
Percent Dry Days (%)		4.38	4.33	4.21
Average TP_out = 0.020 g/m^3				
Q_out (m^3/d)	Average	518,129	462,460	409,575
	Maximum	5,869,914	4,494,949	4,134,046
	Minimum	0	0	0
TP_out (g/m^3)	Average	0.017	0.018	0.018
	Flow Weighted	0.020	0.020	0.020
	Maximum	0.038	0.036	0.036
	Minimum	0.007	0.007	0.007
TP_out (kg)		36,894	32,929	29,165
TP_eff (%)		60.9	60.3	60.4
Required Area (ac)		**6,603**	**5,639**	**5,006**
Max Depth (ft)		3.35	2.97	2.86
Avg Depth (ft)		1.20	1.19	1.16
Percent Dry Days (%)		2.81	2.42	2.39
Q_bypass (m3/d)		0	52,974	106,286
TP_bypass (kg)		0	10,355	19,554

Notes:

PSTA outlet weir width 200 ft, bypass weir width 100 ft; bypass data are from 0.1 d timestep analysis; Time Step = .02; Areas based on flow weighted means; Total Number of days in period of record = 3,560 days

This decision was also based on the lack of an observed increase in PSTA Test Cell performance between the time of the two tracer tests and the theoretical and unproven nature of the effect of increasing TIS on PSTA performance.

The Excel platform of the PSTA Forecast Model was designed to facilitate parameter estimation and simulation but not to test the effects of hydraulic variables. When it was recognized that the number of TIS may have significant effects when sizing PSTAs to reduce TP concentrations over a relatively broad range (50 to 12 µg/L), it was decided to use the DMSTA model platform to conduct a sensitivity analysis of the effect of the number of TIS on the estimated full-scale PSTA footprint area.

Two analytical approaches were tested. In the first test, the one CSTR PSTA Forecast Model was rerun with 2 through 4 TIS to estimate the land area needed to achieve 20 and 12 µg/L at 0-percent bypass. In the second test, the PSTA Forecast Model was recalibrated on the DMSTA platform based on 3 TIS (the average value between Phase 1 and 2 tracer tests). This recalibrated model was then simulated for 1, 2, and 4 TIS. These two approaches both provide a range of estimated PSTA areas. The results of both approaches are presented to demonstrate the sensitivity of PSTA area estimates to the actual residence time distribution.

Exhibit 4-24 summarizes the effect of the number of TIS on the estimated PSTA area. In the first test, the one CSTR PSTA Forecast Model was run assuming 1 through 4 TIS. In this analysis, the estimated footprint area to achieve 20 µg/L is reduced from approximately 2,670 to 1,580 ha (6,600 to 3,900 acres) for 4 TIS, and from 6,200 to 2,870 ha (15,300 to 7,100 acres) for 12 µg/L. In the second test where the PSTA Forecast Model was recalibrated on a 3 TIS platform, the estimated area ranged from 3,440 to 2,190 ha (8,500 to 5,400 acres) for the 20 µg/L target and from 8,780 to 3,970 ha (21,700 to 9,800 acres) for 12 µg/L.

EXHIBIT 4-24

Sensitivity Analysis of Different Hydraulic Efficiencies (Tanks-in-Series [TIS]) on Estimated PSTA Areas for Post STA-2 Dataset with 50 µg/L Inflow TP

Estimated Treatment Area (ac) to Meet TP Out Goal		
# TIS	**TP = 20 ug/L**	**TP = 12 ug/L**
PSTA Forecast Model with 1 CSTR		
1	6,600	15,300
2	4,600	8,900
3	4,100	7,700
4	3,900	7,100
Recalibrated PSTA Model with 3 TIS		
1	8,500	21,700
2	6,200	12,800
3	5,800	10,800
4	5,400	9,800

Note:

This analysis was conducted on the DMSTA platform using the PSTA Forecast Model Equations and model parameters from STC 8 (shellrock) for the OPP. Post STA-2 10-Year Simulation with 0 bypass.

Uncertainty with regard to the correct number of TIS during PSTA design can be reduced by a great extent by creating internal cross levees with discreet outlet points. These cells in series are directly comparable to the TIS hydraulic model. If additional tracer research was to determine that the typical PSTA TIS averages about 2, then inclusion of two PSTA cells in series will be equivalent to the 4 TIS scenarios simulated in Exhibit 4-24.

Additional modeling was conducted to evaluate the effect of reducing the assumed inflow TP concentration on the resulting estimated PSTA footprint area. Inflow concentrations were reduced in the post-STA-2 data set, and the PSTA Forecast Model was simulated for the various target outflow TP concentrations and bypass scenarios. As expected, lowering the TP inflow concentration and load reduces the estimated PSTA footprint. Exhibit 4-25 illustrates the results of this analysis. Lowering the input TP from 50 to 25 µg/L lowered the estimated PSTA area from approximately 2,670 to 450 ha (6,600 to 1,100 acres) for an outflow goal of 20 µg/L and 0-percent bypass, and from approximately 6,200 to 2,180 ha (15,300 to 5,400 acres) for an outflow goal of 12 µg/L and 0-percent bypass. This analysis highlights the importance of using the best possible input water quality and flow estimates and modeling techniques during final design of a PSTA.

EXHIBIT 4-25

Estimated PSTA Areas Based on Alternate Post-STA Average Inflow TP Concentrations

Area Needed In Acres				
Flow Wt Avg TP Inflow (ug/L)	Flow Wt Avg TP Outflow	Percent Bypass		
		0	10	20
	Range			
25		5,391	4,581	4,069
30		7,414	6,346	5,635
40		11,410	9,855	8,766
50		15,316	13,241	11,791
	20 µg/L			
25		1,109	885	790
30		2,214	1,842	1,637
40		4,423	3,741	3,321
50		6,603	5,639	5,006

Note:

Results are based on the PSTA Forecast Model and model parameters for the OPP. Post STA-2 10-Year Simulation with 0 bypass.

One additional sensitivity analysis was conducted with the PSTA Forecast Model. Full-scale PSTA areas needed to achieve 20 and 12 µg/L with 0-percent bypass were estimated based on the effects of deep percolation losses of water with associated TP (no recycle). The effects of average leakance between 0 (base case) and 0.6 cm/d were estimated with the PSTA Forecast Model. Exhibit 4-26

summarizes the results of this analysis. The estimated PSTA footprint area needed to reduce flow-weighted TP from 50 to 20 µg/L was reduced from approximately 2,670 to 2,226 ha (6,600 to 5,500 acres) and from 6,200 to 4,371 ha (15,300 to 10,800 acres) for a goal of 12 µg/L.

EXHIBIT 4-26

Sensitivity Analyses of Effects of Deep Percolation (Leakance) on Estimated PSTA Area for the Post STA-2 Dataset with 50 µg/L Inflow TP

	Estimated Areas (acres) to Meet Flow-Weighted TP Out Concentration	
Average Leakance (cm/d)	**20 µg/L**	**12 µg/L**
0.00	6,600	15,300
0.15	6,500	14,400
0.30	6,200	13,100
0.60	5,500	10,800
1.20	4,700	7,200

Note:
Post STA-2 10-Year Simulation with 0 bypass. Results are based on the PSTA forecast model using STC 8 (shellrock) model parameters for the optimum performance period.

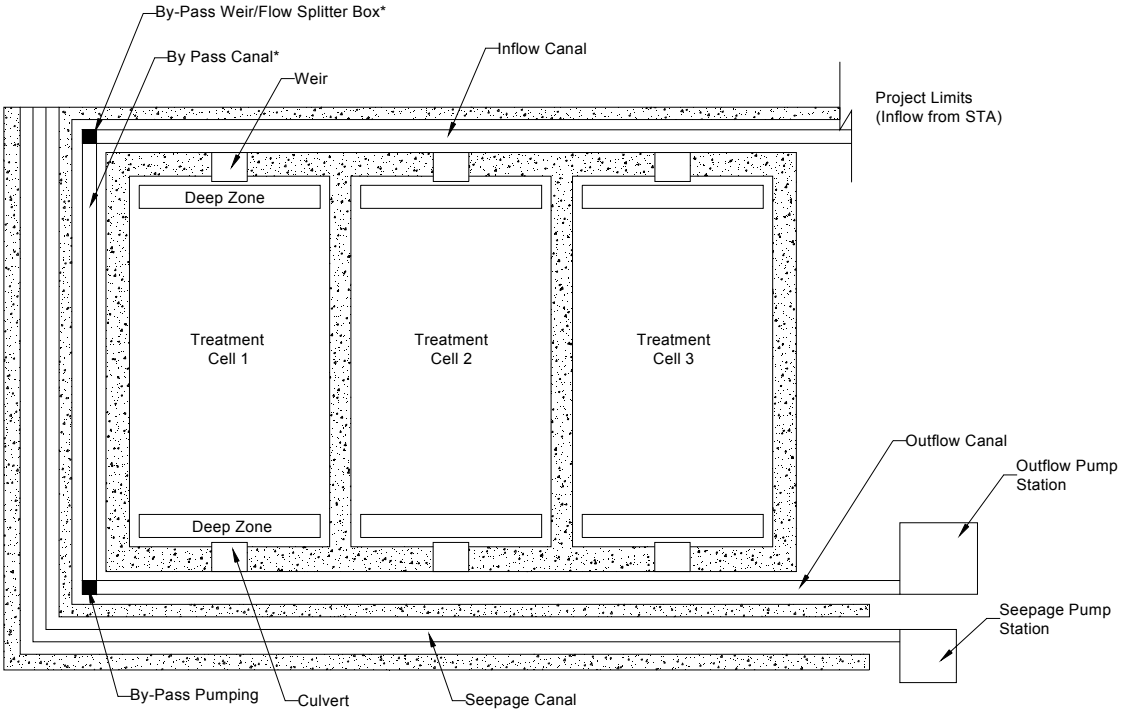
4.3.5 PSTA Conceptual Design

Exhibit 4-27 provides a plan and profile view of a conceptual post-STA-2 PSTA needed to meet the expectations required by the STSOC analysis. This conceptual design includes:

- An inflow canal
- Multiple gated inlet weirs for each treatment cell to convey water from the inlet canal into the PSTA cells
- Three parallel PSTA treatment cells with inlet and outlet deep zones for flow distribution and collection
- A bypass pumping station
- A bypass structure with weir

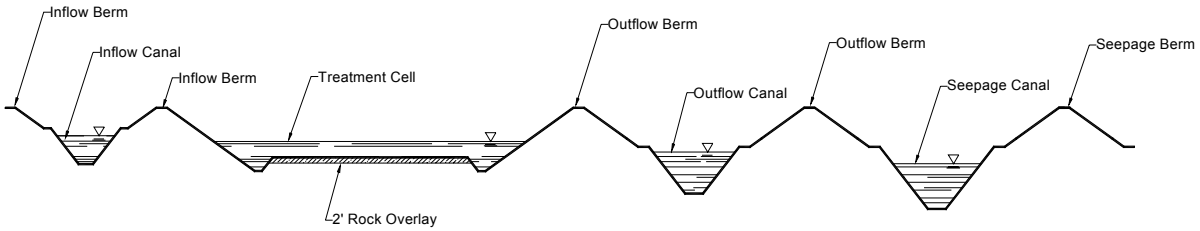
A bypass canal to convey bypasses around the PSTA

- Double-barreled culverts with gates to convey water from the treatment cells to the outflow canal
- An outflow canal
- An outflow pump station
- A seepage control canal
- A seepage pump station



* Not Required for "No By-Pass" Scenarios

Plan View



Cross Section

EXHIBIT 4-27
Plan View and Cross Section of Conceptual Full-Scale PSTA System

No inflow pumping station was incorporated into the conceptual design based on the assumption that the outflow pumping station from STA-2 would be utilized to provide inflow to the PSTA treatment system. No periphyton or macrophyte planting is envisioned for the full-scale PSTA cells. Development of calcareous periphyton and sparse emergent macrophyte cover will be encouraged through water depth control and herbicide applications. Additional assumptions used in the development of the conceptual design are presented in Exhibit 4-28.

EXHIBIT 4-28
Assumptions Used for Conceptual Design

Component	Assumption
Inflow Water TP Levels	50 µg/L (post-STA-2 level)
Treatment of Bypass Water	None
Flow Equalization Requirements	None
Aspect Ratio for Treatment Cells	1.5 L x 1 W
Number of Treatment Cells	3
Depth of Shellrock Base	2 feet
Levee Height	3 feet greater than maximum operating stage
Levee Side Slopes	2.5 H x 1 V
External Levee Top Width	10 feet
Internal Levee Top Width	6 feet
Canal Side Slopes	2 H x 1 V
Maximum Canal Velocity	2.5 feet per second

4.3.5.1 Design Considerations

As discussed previously, the nature of the onsite soils has a significant impact on PSTA performance. If existing soils have low available (water soluble) P levels (< 2 mg/kg), then minimal P leaching from the soil should occur and no soil amendment is necessary. However, if existing soils are higher in available P, then leaching of P is probable, and the site must be modified either by adding limerock over the surface of the entire PSTA or by removing the existing soils down to the underlying caprock. Another potential, intermediate option is the use of soil amendments to lock available P in the soils to prevent its release. The efficacy of each of these soil pre-treatment options has not been previously investigated at a field scale, but some research is underway (CH2M HILL, 2001). For the STSOC analysis, a worst-case scenario requiring application of a 2-foot thick cap of limerock placed over the onsite soils was evaluated.

Other factors that would significantly affect the cost and operation of a full-scale PSTA are the types and configuration of the water control structures and flow distribution methods utilized. The first consideration in the selection of water control structures was the type of structures used in previously constructed projects (i.e., STA-2). It is anticipated that using similar types and sizes of water control structures in the construction of a full-scale PSTA as are used in other Everglades restoration projects would result in the components being more readily available and less expensive than custom components. Therefore, 50-foot wide gated weirs were selected for use as inflow water control structures, and double-box culverts (varying in width from 20 to 25 feet) were used for outflow water control structures.

Flow distribution is controlled through a variety of methods: the use of gated inflow and outflow control structures, the implementation of multiple inflow water control structures, and the incorporation of deep zones within the treatment cells. All of the inflow and outflow structures were designed with gates that could be operated either locally or remotely. This design feature controls flow distribution by allowing gate settings, and thus flow through the gates, to be varied. Additionally, it provides flexibility in treatment cell operation by allowing cells to be isolated and removed from operation. Finally, the use of multiple inflow water control structures and deep zones at the head and tail of each treatment cell allows for pseudo-passive flow distribution within the system. The incorporation of each of these design components allows for maximum flexibility in operation of the full-scale system while attempting to minimize the construction and operational costs.

Bypass and seepage canals and pump stations were also included in the design. Two bypass situations (10 percent and 20 percent) were considered for each treatment scenario evaluated (e.g., outflow TP levels of 12 and 20 µg/L). The bypass structure was designed to act as a small flow equalization basin thereby limiting the actual flow into the bypass canal. The bypass canal was sized to accommodate approximately 35 and 65 cfs of flow with 0.5 feet of freeboard for the 10 percent and 20 percent bypass scenarios, respectively. Bypass flows of these magnitudes account for approximately 87 percent of the bypassed flows encountered during 10 percent bypassing and for approximately 81 percent of the bypassed flows during the 20 percent bypass scenarios. Higher flow volumes will be accommodated through storage in the bypass structure and by increased flow velocities in the bypass canal. The bypass pump station was sized to accommodate the full range of flows for both bypass situations.

The seepage canal and pumping station were sized assuming a seepage rate of 33 cubic feet per day (cf/d) per foot of levee length per foot of head. This rate was proposed as a recommended seepage loss rate for use in design of the maximum capacity of seepage collection canals and seepage return pumps by Burns & McDonnell for STA 3/4 (Burns & McDonnell, December 1999). As described above, the estimated PSTA footprint area is a function of seepage. Zero seepage was assumed for the base-case sizing estimates. However, it is acknowledged that a seepage canal will be necessary in the final design and that considerable site-specific information will be necessary to accurately predict seepage rates.

The various PSTA footprint areas and bypass features for the six investigated conceptual design scenarios resulted in differing canal and levee lengths for each option. Exhibit 4-29 summarizes the additional design details for each of these options.

4.3.5.2 Hydraulic Analysis

Detailed hydraulic analyses were not conducted in developing the full-scale PSTA concept. The PSTA Forecast Model has a water balance component but

EXHIBIT 4-29

PSTA Standards of Comparison (STSOC) Post-STA-2 Design Criteria Summary

	Various Bypass Scenarios for 20 ppb					
Design Criteria	**No 20 ppb P**	**10% 20 ppb P**	**(By-pass) 20 ppb P**	**No 12 ppb P**	**10% 12 ppb P**	**20% 12 ppb P**
Total Treatment Area, acres	6,603	5,639	5,006	15,316	13,241	11,791
No. of Treatment Cells	3	3	3	3	3	3
Treatment Cell Area, acres	2201	1880	1669	5105	4414	3930
Average Water Depth, ft.	1.14	1.14	1.13	1.18	1.17	1.15
Maximum Water Depth, ft	3.35	2.97	2.86	3.02	2.71	2.64
Total Land Required, acres	6,885	5,888	5,237	15,727	13,607	12,134
Inflow Canal Length, mi.	3.93	3.64	3.43	5.99	5.57	5.26
No. of Inflow Control Structures per Cell	4	4	4	4	4	4
Inflow Levee Length, mi.	3.93	3.64	3.43	5.99	5.57	5.26
Inflow Levee Side Slope, H:V	2.5	2.5	2.5	2.5	2.5	2.5
Inflow Levee Height, ft.	9.75	9.25	9	9.5	9	9
Outflow Canal Length, mi.	3.93	3.64	3.43	5.99	5.57	5.26
No. of Outflow Control Structures per Cell	2	2	2	2	2	2
Type of Outflow Control Structures	Gated Box Culvert	Gated Box Culvert	Gated Box Culvert	Gated Box Culvert	Gated Box Culvert	Gated Box Culvert
Outflow Levee Length, mi.	3.93	3.64	3.43	5.99	5.57	5.26
Outflow Levee Height, ft.	8.5	8	8	8.25	7.75	7.75
Interior Levee Length, mi.	2.62	2.42	2.28	3.99	3.71	3.50
Interior Levee Height, ft.	8.5	8	8.00	8.25	7.75	7.75
Side Levee Length, mi.	2.62	NA	NA	3.99	NA	NA
By-Pass Canal Length, mi.	NA	2.42	2.28	NA	3.71	3.50
No. of By-Pass Control Structures	0	1	1	0	1	1
By-Pass Levee Length, mi.	NA	2.42	2.28	NA	3.71	3.50
Seepage Canal Length, mi.	3.93	3.64	3.43	5.99	5.57	5.26
Seepage Levee Length, mi.	3.93	3.64	3.43	5.99	5.57	5.26
Side Seepage Canal Length, mi.	2.62	2.42	2.28	3.99	3.71	3.50
Side Seepage Levee Length, mi.	2.62	2.42	2.28	3.99	3.71	3.50

Notes:
ppb = parts per billion
NA = not available

does not estimate head loss through the vegetation. At question is whether a full-scale PSTA could be operated within the range of depths that have been evaluated at the mesocosm and field scales.

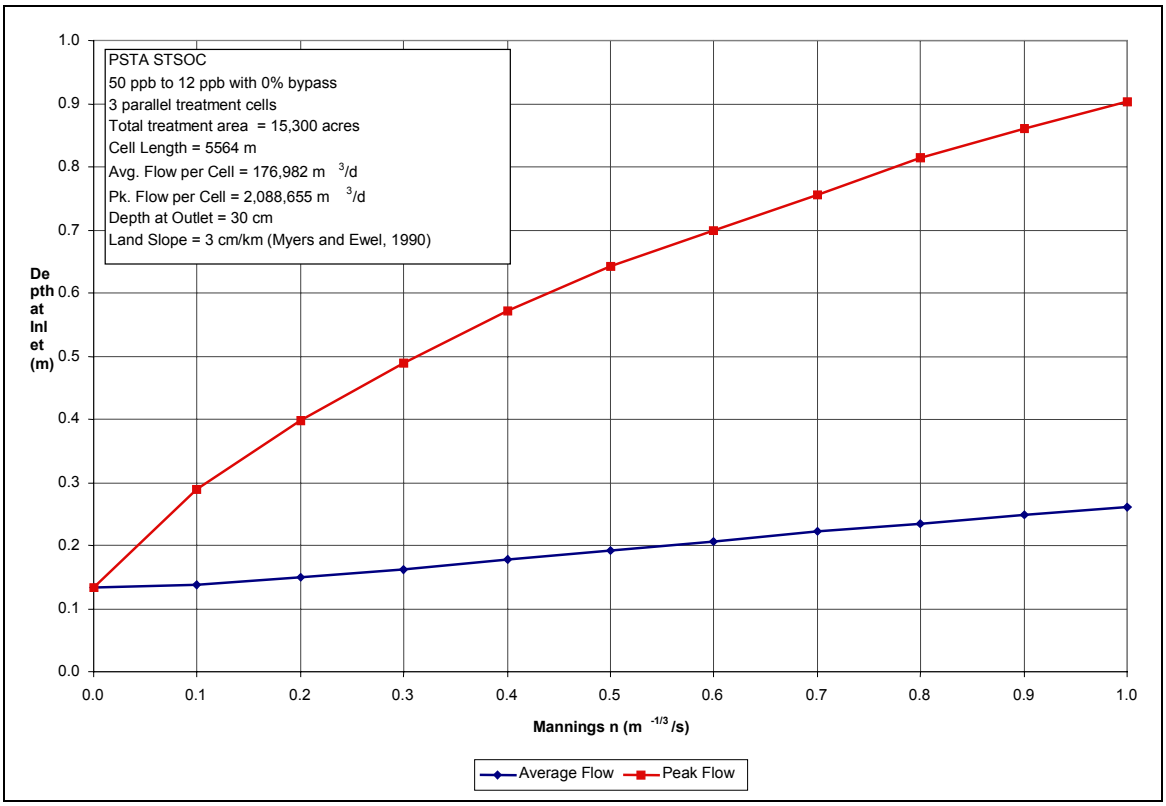
Head loss through a wetland system is a function of topographic slope, flow length, flow rate, substrate roughness, and vegetative resistance. The effects of substrate roughness and vegetative resistance are expressed in terms of a Manning's "n" value. Manning's "n" values for wetlands range from approximately 0.2 to greater than 10 $s/m^{1/3}$ (Kadlec and Knight, 1996). STA 1-W "n" values average approximately 0.8 for dense cattail stands and are typically less than 0.5 for open water/SAV. No large-scale PSTA systems have been constructed, so "n" values have not been measured in the field. It is reasonable to expect, however, that PSTA "n" values should be no higher than those for SAV systems.

A preliminary analysis of potential head loss through a full-scale PSTA was prepared for the worst-case scenario (i.e., longest flow path) that requires a reduction in TP concentrations from 50 to 12 µg/L with no bypass. Exhibit 4-30 shows the influence of variable Manning's "n" values on the inlet depth of a full-scale PSTA based on a weir-controlled outlet depth of 30 cm. This weir height is consistent with the PSTA Forecast Model. Myers and Ewel (1990) report that the natural grade in the Everglades area is approximately 3 cm/km.

At the average flow rate (177,000 cubic meters per day [m^3/d] per cell), the outlet weir controls system hydraulics. This is indicated by the calculated inlet depth being lower than the outlet depth. Kadlec and Knight (1996) refer to this condition as "distance-thickening" flow. At the peak flow rate (2,089,000 m^3/d), the inlet depth is more strongly influenced by Manning's "n." Within the range of likely "n" values (0.2 to 0.5) that might be observed in a full-scale PSTA, the inlet depth increases to approximately 65 cm (2.1 feet). Under maximum flow conditions, the weir design used in the PSTA Forecast Model results in water depths at the downstream end of the PSTA to approximately 0.8 to 1.0 m (2.6 to 3.3 feet) (Exhibit 4-22). The total water depth at the upstream end of the PSTA under maximum flow conditions would be less than 1.5 m (5 feet) for short durations. The planned inflow levee height is 2.7 to 2.9 m (9 to 9.5 feet), which should provide adequate freeboard and protection against overtopping.

EXHIBIT 4-30

Effect of Manning's "n" on Inlet Water Depth for a Full-Scale PSTA with Inflow TP of 50 µg/L, Outflow TP of 12 µg/L, and Outlet Weir Height of 30 cm at Average and Peak Flow Rates



4.3.6 Cost Estimates

Cost estimates were developed using a unit cost spreadsheet provided by the District. This spreadsheet provided specific items to be considered in the development of costs as well as unit prices for many of the items. Additional guidance for the preparation of the cost estimates was obtained from the *Basis of Cost Estimates for Full Scale Alternative Treatment Supplemental Technology Facilities* (PEER Consultants/Brown and Caldwell, 1999). Finally, cost-estimating spreadsheets provided by the District for the STSOC analysis provided guidelines for a summary of costs, present worth analyses, and unit treatment costs. Project-specific costs were developed from a combination of vendor quotations, previous construction costs for Everglades-related projects, and cost estimation (Exhibit 4-31). These costs were provided to the District for review and modified based upon District comments.

Detailed construction cost estimates for each of the six operational scenarios are provided in Appendix J. Exhibit 4-32 summarizes the overall cost analyses results, not considering additional costs for STA 2. The estimated range of total capital costs associated with achieving a TP level of 20 µg/L is approximately $321,886,000 to $408,515,000. With a target finished water TP level of 12 µg/L, this cost range increases to approximately $663,698,000 to $843,799,000.

EXHIBIT 4-31
STSOC - PSTA Project-Specific Costs

Item/Task	Unit	Unit cost
50' inflow weir with gate	per structure	$110,000
5' X 20' outflow box culvert with gate	per structure	$119,000
5' X 25' outflow box culvert with gate	per structure	$148,000
5' X 35' outflow box culvert with gate	per structure	$207,000
By-pass structure	per structure	$5,270
5' wide by-pass weir without gate	per structure	$5,000
Levees - Internal-7.5' (4.5' SWD)	$/mile	$251,000
Levees - Internal-7.75' (4.5' SWD)	$/mile	$266,000
Levees - Internal- 8' (4.5' SWD)	$/mile	$281,000
Levees - Internal-8.5' (4.5' SWD)	$/mile	$313,000
Levees - External- 7' (4.5' SWD)	$/mile	$398,000
Levees - External- 7.75' (4.5' SWD)	$/mile	$457,000
Levees - External- 8.5' (4.5' SWD)	$/mile	$525,000
Laying rock base	$/acre	$31,000
Pump Stations>3,000 cfs	$/cfs	$7,950
Canals - Maintenance	$/acre	$500
Demolition Costs	Lump sum	20% capital cost
Replacement Items	Lump sum	50% 0f outflow costs
Salvage of Land	LumpSum	original land cost
FPL Improvements	Lump sum	$211,200

Note:
See Appendix J for detailed assumptions.

EXHIBIT 4-32
Costs for Full-Scale PSTA Implementation, Including 2 Feet of Limerock Fill

Cost Component	12 µg/L, No bypass	12 µg/L, 10% bypass	12 µg/L, 20% bypass	20 µg/L, No bypass	20 µg/L, 10% bypass	20 µg/L, 20% bypass
Capital Costs	$843,798,569	$737,832,446	$663,697,737	$408,514,840	$357,406,344	$321,886,004
Operating Costs	$1,581,898	$1,483,448	$1,417,593	$1,367,755	$1,292,178	$1,255,048
Demolition/ Replacement Costs	$20,691,746	$16,867,324	$15,739,170	$20,935,504	$16,971,599	$14,797,671
Salvage Costs	($73,210,339)	($63,342,812)	($56,483,392)	($32,050,978)	($27,407,667)	($24,378,828)
Lump Sum/ Contingency Items	$761,200	$811,200	$811,200	$761,200	$811,200	$811,200

The detailed analysis of O&M costs for the PSTA is also provided in Appendix J. Estimated annual costs range from approximately $1,418,000 to $1,582,000 for a system with an outflow TP of 12 µg/L and from approximately $1,255,000 to $1,368,000 for a system with an outflow TP of 20 µg/L. These O&M costs are expected to include any costs associated with management of emergent macrophytes.

Present worth costs were calculated for a 50-year period based on an interest rate of 4 percent. Exhibit 4-33 provides a summary of the 50-year present worth costs for the PSTA alternatives described above. These costs range from $361,033,000 to $888,945,000. These costs are equivalent to unit costs of $0.17 to $0.35 per thousand gallons treated and $699 to $1,096 per pound of TP removed, as detailed in Appendix J.

EXHIBIT 4-33
Present Worth Costs for PSTA Conceptual Design Scenarios

Target	Bypass	Without STA2 Costs			With STA2 Costs		
		50-Year Present Worth Cost	$/lb TP removed	$/1000 gallons treated	50-Year Present Worth Cost	$/lb TP removed	$/1000 gallons treated
12 ppb	0	$888,942,000	$1,076	$0.35	$1,024,403,000	$1,240	$0.40
	10	$778,473,000	$1,078	$0.34	$913,935,000	$1,265	$0.40
	20	$702,761,000	$1,096	$0.35	$838,222,000	$1,307	$0.41
20 ppb	0	$455,089,000	$699	$0.18	$590,558,000	$907	$0.23
	10	$399,095,000	$705	$0.17	$534,557,000	$944	$0.23
	20	$361,029,000	$718	$0.18	$496,491,000	$987	$0.25

Finally, an analysis of costs considering the inclusion of existing STA-2 facilities was completed. It was requested that this cost analysis be included because of the assumptions that a full-scale PSTA system would receive post-STA-2 inflow, that the system would, in all likelihood, be constructed as an add-on to STA-2, and that the PSTA system would utilize some of the STA-2 components (i.e., outflow pumping station). A summary of costs, including those for STA-2, is presented in Exhibit 4-34; a summary of the 50-year present worth, modified to include STA-2 costs, is provided in Exhibit 4-33.

EXHIBIT 4-34
Costs for Full-Scale PSTA Implementation Including STA-2 Costs

Cost Component	12 µg/L, No bypass	12 µg/L, 10% bypass	12 µg/L, 20% bypass	20 µg/L, No bypass	20 µg/L, 10% bypass	20 µg/L, 20% bypass
Capital Costs	$945,680,219	$839,714,096	$765,579,387	$510,396,490	$459,287,994	$423,767,654
Operating Costs	$1,691,413	$1,592,963	$1,527,108	$1,477,270	$1,401,693	$1,364,563
Demolition/ Replacement Costs	$56,127,116	$52,302,694	$51,174,540	$56,370,874	$52,406,969	$50,233,041
Salvage Costs	($103,141,989)	($93,274,462)	($86,415,042)	($61,982,628)	($57,339,317)	($54,310,478)
Lump Sum/ Contingency Items	$761,200	$811,200	$811,200	$761,200	$811,200	$811,200

The limerock placement comprises approximately 80 to 90 percent of the PSTA construction cost. Total present worth costs would be reduced by approximately 60 to 70 percent if PSTA performance could be assured without the limerock fill, and to a lesser extent if the amount of limerock fill could be reduced. As an example of this cost differential, Exhibit 4-35 provides an estimate of the present worth and unit removal costs if the 2-foot limerock fill is reduced to 1 foot, without STA-2 costs included. Based on research conducted to date, it appears that the limerock would not be necessary if antecedent soils have low available TP concentrations or if a chemical soil amendment could be used to tie up existing soluble TP in the soil column. Preliminary estimates of the cost of a hydrated lime soil amendment for soils in the vicinity of STA-2 is approximately $1,300 per acre (as opposed to the $31,000 per acre assumed for 2 feet of lime-rock fill). Exhibit 4-35 also provides a rough cost estimate using a lime soil amendment. This assumption reduces the estimated present worth costs for a full-scale PSTA to $173,000,000 for the 20 µg/L TP goal and $234,000,000 for the 12 µg/L goal. Due to the major cost impact of this limerock fill, additional work to minimize the costs associated with initial labile TP concentrations should be undertaken prior to final PSTA alternative analysis and design.

EXHIBIT 4-35
STSOC Cost Comparison with and without Shellrock (without STA-2 costs)

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

Notes:
50 yr Present Worth in millions of dollars
Assumes lime addition=$1,300/acre

4.3.7 STSOC Analysis

This section summarizes the conclusions of the PSTA STSOC analysis for the primary and ancillary evaluation criteria:

Primary:

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

Ancillary:

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

In addition to these evaluation criteria, this section summarizes the remaining uncertainties relevant to implementation of a full-scale PSTA ATT.

Exhibit 4-36 compares each of these STSOC criteria relative to the six different operational scenarios of no bypass, 10 percent, and 20 percent diversion for mean outflow TP concentrations of 12 µg/L and 20 µg/L. Results for each evaluation criterion are further described in the following paragraphs.

EXHIBIT 4-36
STSOC Evaluation Criteria for Full-Scale PSTA Design Scenarios

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

Notes:

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

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

4.3.7.1 Level of P Concentration Reduction

Based on the data collected by the District's PSTA Research and Demonstration project summarized in Section 3, the minimum achievable TP concentration by PSTA can be assessed based on differing assumptions. These assumptions include:

- All data, including startup (POR)
- Optimal performance data averaged over approximately 18 months (OPP)
- VPP
- Minimum monthly average
- Minimum single measurement (weekly)

Exhibit 4-37 provides a summary of the minimum achievable TP concentration for PSTA based on each of these assumptions. Where possible, these concentrations are reported as flow-weighted means. Based on this summary, it appears that the minimum achievable TP outflow concentration from a constant-flow, shellrock-based PSTA receiving an average inflow concentration of approximately 23 to 24 µg/L of TP at an HLR of approximately 6 cm/d would be between 7 and 14 µg/L. For a peat-based PSTA with high antecedent available soil P concentrations, the range is 9 to 32 µg/L. Based on the observations described above for the peat-based PSTA Test Cell during the VPP, the more likely range of performance based on the OPP is from 9 to 18 µg/L of TP.

EXHIBIT 4-37
PSTA Test Cell STSOC TP Mass Removal Summary

		Flow-weighted TP (µg/L)		Mass Removal Efficiency (%)
		Inflow	Outflow	
STC 1/4	POR	22.5	25.0	-10.8
(Peat/Peat-Ca)	OPP	23.9	17.9	25.4
	VPP	24.5	32.0	-30.7
	Min Month	---	12.1	---
	Min Week	---	9.0	---
STC 2/5	POR	21.9	14.3	34.8
(Shellrock)	OPP	22.6	12.2	46.2
	VPP	24.6	13.3	46.0
	Min. Month	---	7.4	---
	Min. Week	---	7.0	---

Note:
Calculations based on weekly averages.

The shellrock-based PSTA Test Cells showed a TP removal efficiency of approximately 46 percent, and a flow-weighted mean TP outflow concentration of 12 µg/L during the OPP. Nearly all TP outflow values were lower than their respective inflow values for the shellrock-based Test Cell. A net export of TP occurred in the peat-based PSTA Test Cell during the VPP and the POR. However, during the OPP, the peat-based PSTA removed approximately 25 percent of the inlet TP mass and achieved a long-term average outflow concentration of 18 µg/L.

Percentile distributions of TP concentrations in the outflows from the two constant water regime PSTA Test Cells are illustrated in Exhibit 4-38 for each of the performance periods. This analysis indicates that median outlet TP concentrations for the peat-based PSTA range from 16 to 33 µg/L. For the shellrock-based cell, the median concentration ranges from 12 to 14 µg/L. The 75th percentile outlet TP concentrations are between 22 and 36 µg/L for the peat-based Test Cell and 14 to 16 µg/L for the shellrock-based cell. Other percentiles are also summarized on Exhibit 4-38.

For the purposes of this STSOC assessment, the long-term minimum achievable average TP of 12 µg/L from the shellrock Test Cell was used for the PSTA conceptual design.

4.3.7.2 Total Phosphorus Load Reduction

TP removal efficiencies shown in Exhibit 4-37 have been calculated on a mass basis. This approach is preferable to calculation of concentration-based reduction efficiencies unless the concentrations are flow-weighted means, in which case the two methods are identical. Based on the data summarized for all of the performance periods, the PSTA Test Cells produced the following ranges of TP mass removals:

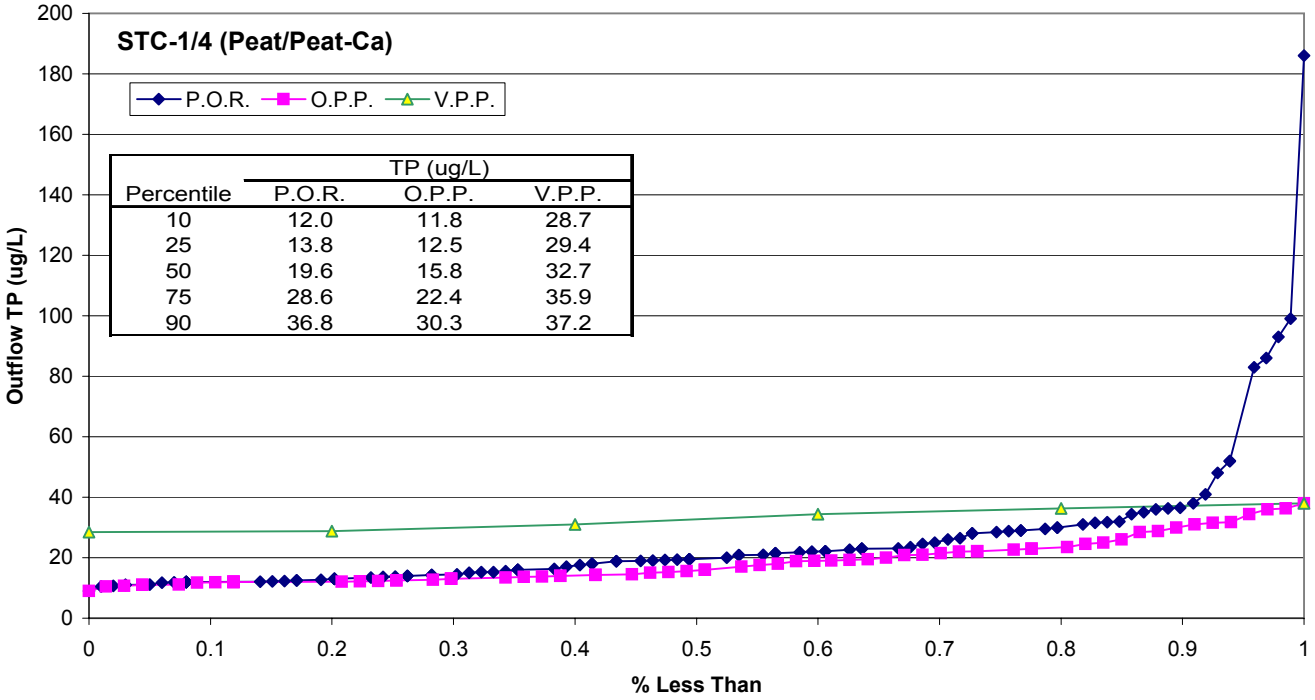
- STC-1/4 (peat, constant water depth): -31 to 25 percent
- STC-2/5 (shellrock, constant water depth): 35 to 46 percent

There are many factors that can affect TP removal in natural treatment systems. Key independent variables are evaluated in Exhibits 4-39 to 4-43 using monthly averages. The relationships developed in these regressions are tentative in nature but can provide some idea of possible causal relationships.

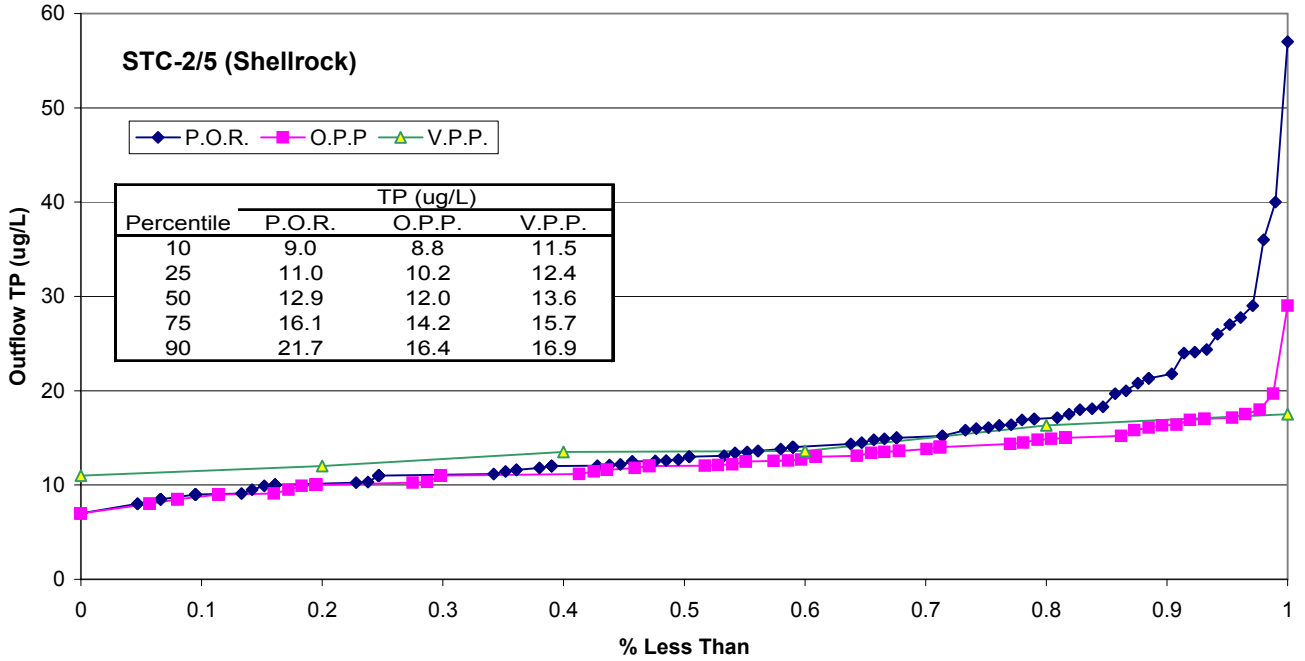
Exhibit 4-39 illustrates the observed relationships between TP inflow concentration and TP mass removal efficiency. TP mass removal efficiency for each of the PSTA Test Cells was positively correlated with inflow concentration. The fact that the highest mass removal efficiencies were observed in conjunction with the highest inflow concentrations indicates that these systems might perform even better (based on mass of TP removed) if tested at higher TP loads. For the peat-based cell, very little mass removal occurred when inflow concentrations were less than approximately 25 µg/L. Monthly average mass removals were always positive for the shellrock-based Test Cell.

EXHIBIT 4-38

PSTA Test Cell STSOC Summary of TP Concentration Percentile Distributions



Percentile	TP (ug/L) P.O.R.	O.P.P.	V.P.P.
10	12.0	11.8	28.7
25	13.8	12.5	29.4
50	19.6	15.8	32.7
75	28.6	22.4	35.9
90	36.8	30.3	37.2



Percentile	TP (ug/L) P.O.R.	O.P.P.	V.P.P.
10	9.0	8.8	11.5
25	11.0	10.2	12.4
50	12.9	12.0	13.6
75	16.1	14.2	15.7
90	21.7	16.4	16.9

Note(s):
POR = Entire Period-of-Record
OPP = Optimal Performance Period
VPP = Verification Performance Period
Percentiles based on weekly averages.

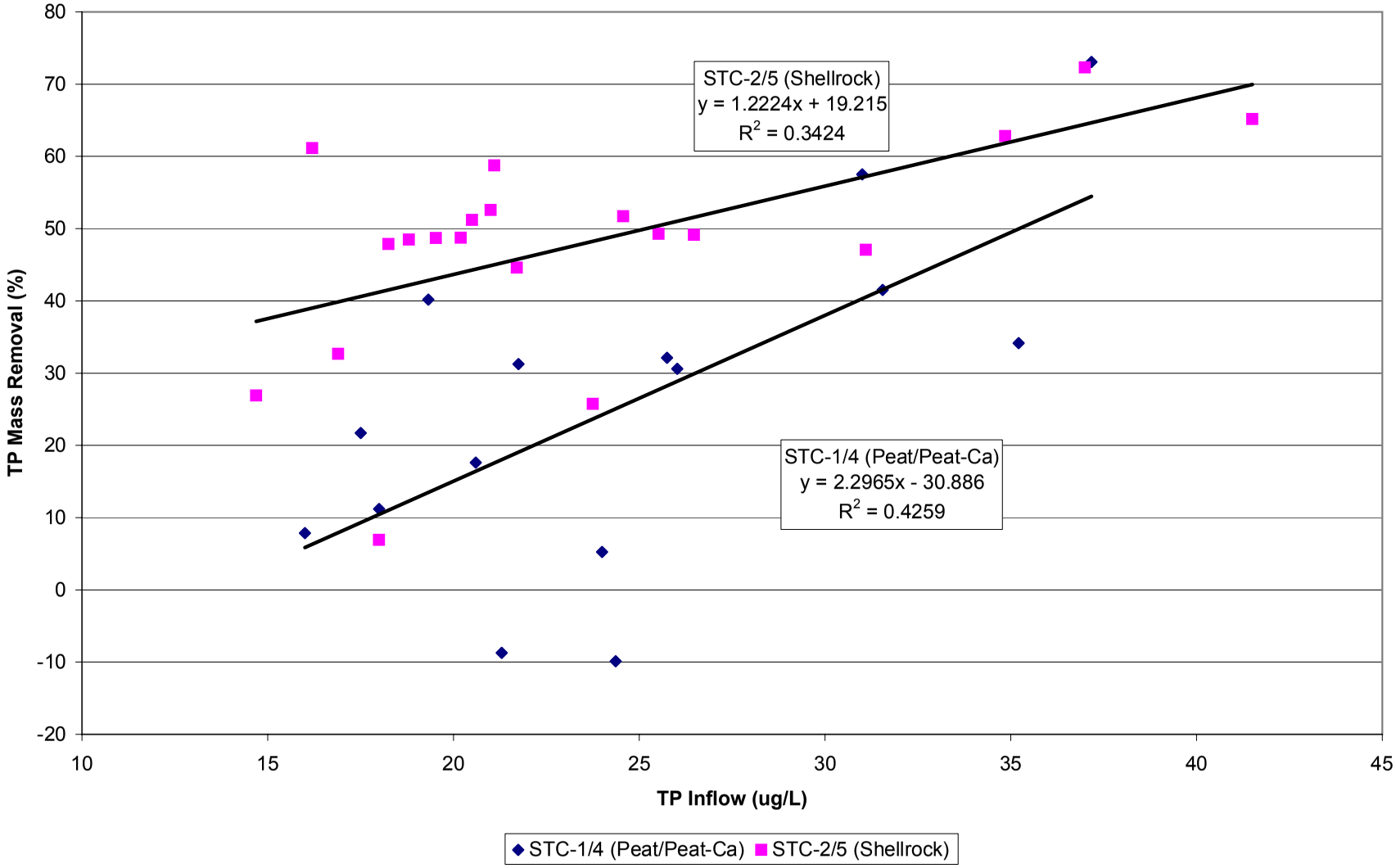


EXHIBIT 4-39

Observed Relationship Between Average Monthly Inlet TP Concentration and TP Mass Removal Efficiency in PSTA Test Cells during the OPP

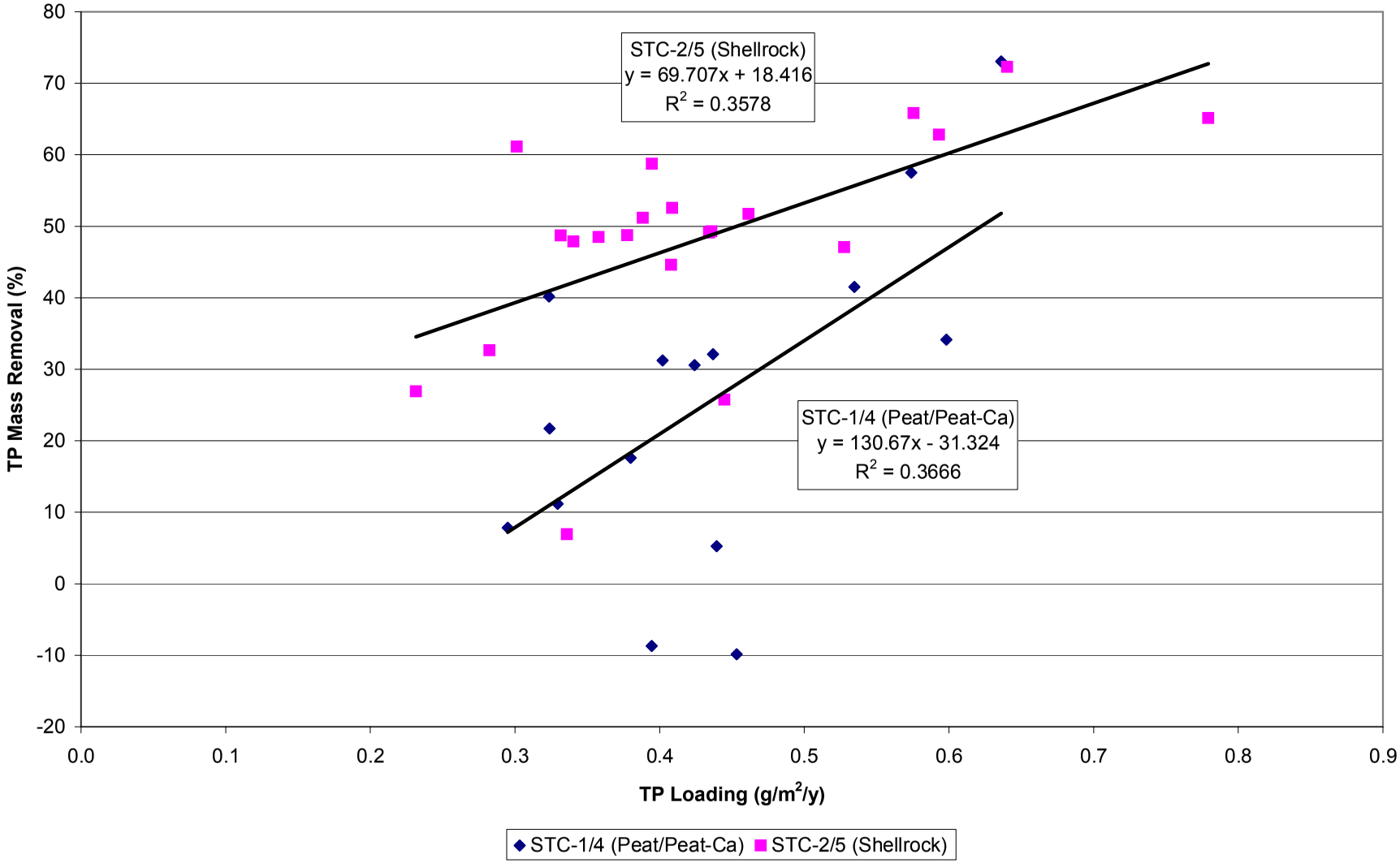


EXHIBIT 4-40

Observed Relationship Between Average Monthly TP Loading Rate and TP Mass Removal Efficiency in PSTA Test Cells during the OPP

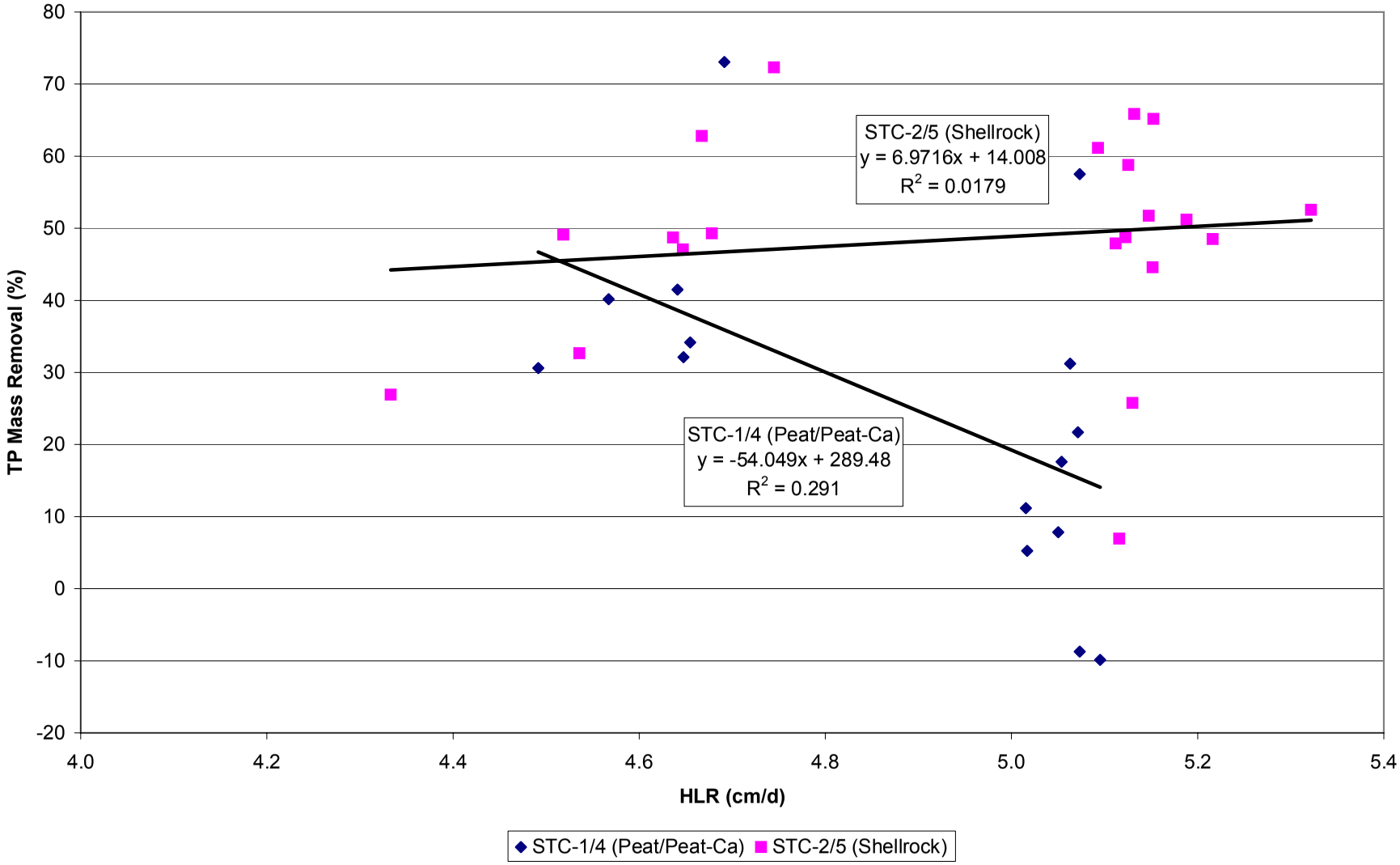


EXHIBIT 4-41

Observed Relationship Between Average Monthly HLR and TP Mass Removal Efficiency in PSTA Test Cells during the OPP

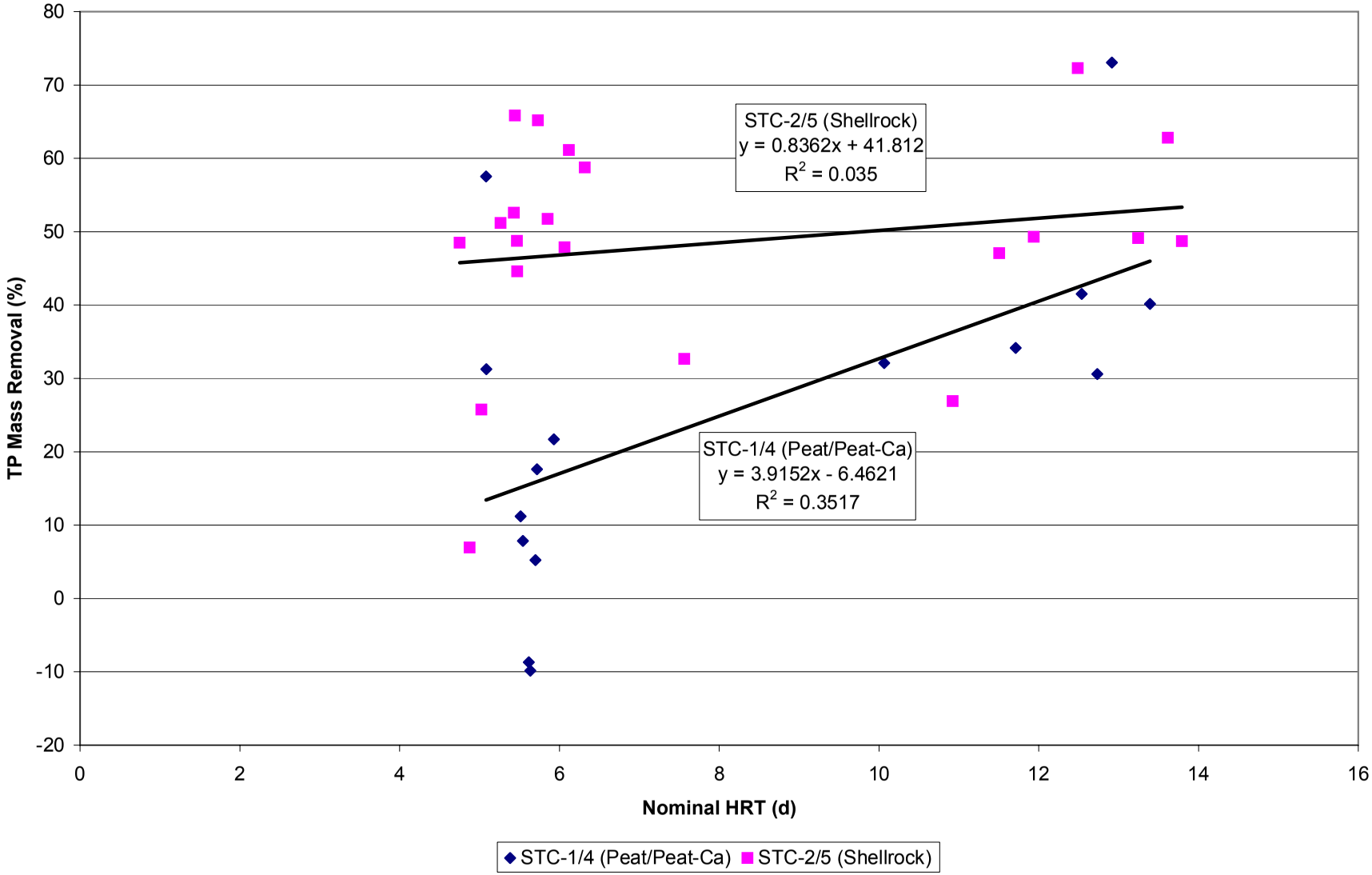


EXHIBIT 4-42

Observed Relationship Between Average Monthly Nominal HRT and TP Mass Removal Efficiency in PSTA Test Cells during the OPP

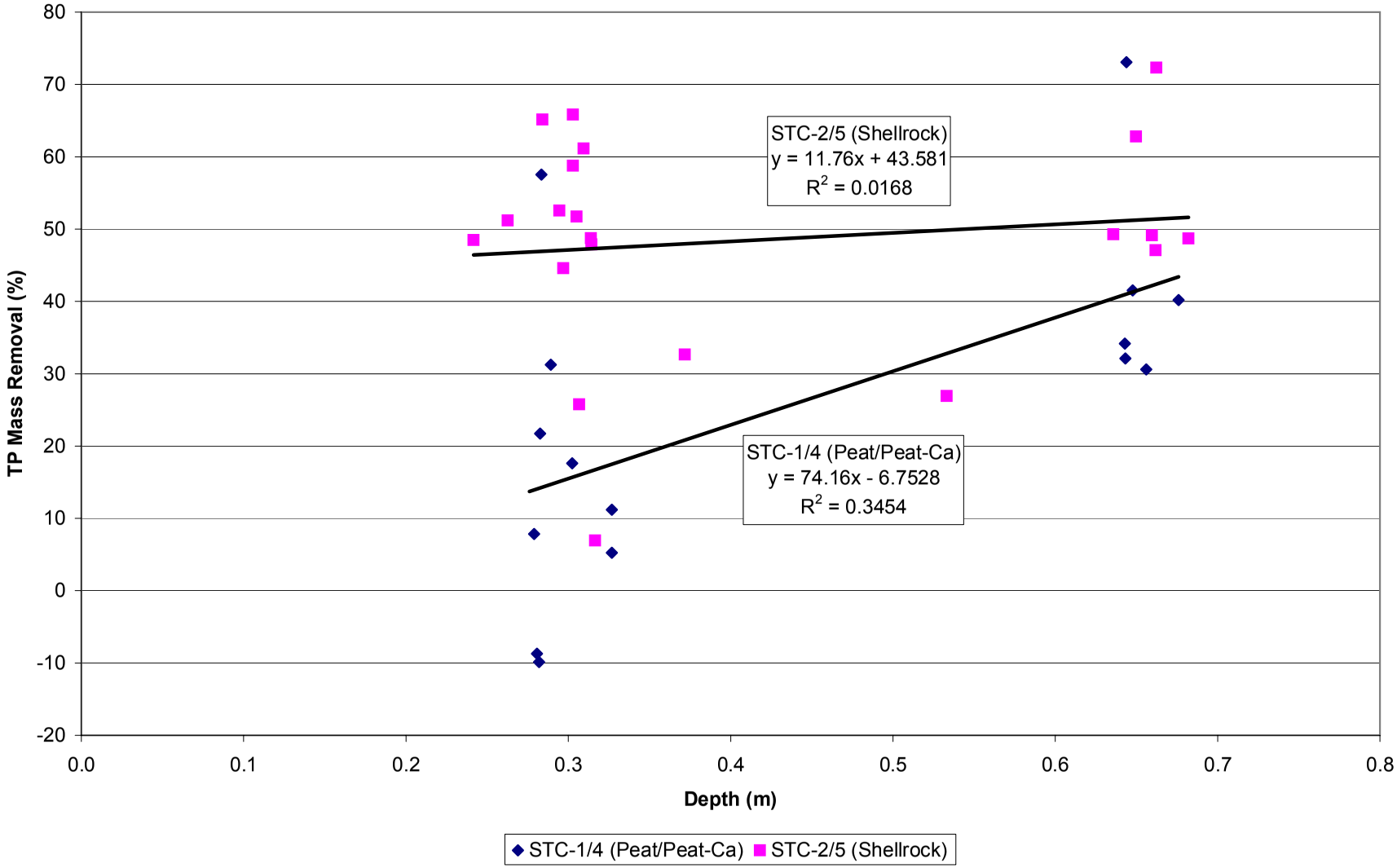


EXHIBIT 4-43

Observed Relationship Between Average Monthly Water Depth and TP Mass Removal Efficiency in PSTA Test Cells during the OPP

TP mass removal efficiency was also higher at higher TP inflow loads (see Exhibit 4-40). Approximately 36 percent of the variability in mass removal efficiency was explained by TP mass loading rate for both PSTA treatment regressions.

The PSTA Test Cells were not tested over a wide range of HLR. There was a very slight positive relationship between HLR and mass removal efficiency for the shellrock-based cell and a negative relationship for the peat-based PSTA cell (Exhibit 4-41). The regression coefficient for the peat-based Test Cell was 0.29 and for the shellrock-based Test Cell was 0.02.

Mass removal efficiency for TP was positively correlated with HRT in both PSTA Test Cell treatments (Exhibit 4-42). This relationship was more significant for the peat-based cell ($R^2 = 0.35$) than for the shellrock-based cell ($R^2 = 0.040$).

The relationship between water depth and TP mass removal efficiency in the PSTA Test Cells is illustrated in Exhibit 4-43. Removal efficiency was positively correlated with water depth for the peat-based treatment ($R^2 = 0.35$), but there was no observed effect of water depth on TP mass removal efficiency for the shellrock-based treatment cell ($R^2 = 0.02$).

4.3.7.3 Compliance with Water Quality Criteria

Any PSTA that is built will discharge to classified waters of Florida and the U.S. These water bodies have protective criteria that cannot be exceeded. Discharge permits define the actual allowable discharge water quality levels, but for the purposes of this STSOC assessment of compatibility with downstream receiving waters, it is assumed that the PSTA outflow must not exceed applicable Class III water quality standards. Exhibit 4-20 provided a summary of the data collected during the VPP. Of the parameters measured, only DO does not meet the criterion for freshwaters. Since DO is naturally depressed in the Everglades, the observation that the PSTA cells do not generally meet the 5.0 mg/L Class III standard appears moot. However, some form of discharge permit regulatory relief might be required.

Exhibit 4-44 provides a summary of the results of the biomonitoring of the PSTA Test Cells conducted by the FDEP during the STSOC VPP. These results are not easily interpreted. Sporadic survival of fish and water fleas in the control samples (laboratory dilution water) was observed during both sets of tests. When control survival was within acceptable limits, sporadic apparent toxicity to water fleas or minnows was observed for the head cell (inflow) water or for one or the other of the PSTA Test Cell outflows. FDEP indicated that some of the samples had detectable and possibly toxic levels of several pesticides, including atrazine and chlorpyrifos-ethyl. There were more tests without apparent effects than tests with negative results. There was never any detrimental effect noted in the algal toxicity test.

The Algal Growth Potential Test was also conducted by FDEP on samples collected from the PSTA Test Cells in March 2001. Insignificant algal growth was measured in the head cell and PSTA Test Cell outlets. The measured algal

EXHIBIT 4-44

Biomonitoring Results for the PSTA STSOC Verification Period

Sample	Test Start Date	Test Organism	Units	Control Result	Sample Result	Significant Effect
Head Cell	03/05/2001	waterflea	neonates/adult	23	27.4	no
Head Cell	03/05/2001	waterflea	total neonates	230	274	no
Head Cell	03/05/2001	waterflea	% survival	90	90	no
Head Cell	03/05/2001	minnow	% survival	72.5	65	invalid due to control mortality
Head Cell	03/05/2001	minnow	mg/larva	0.2813	0.2829	invalid due to control mortality
Head Cell	03/07/2001	green algae	cells/ml	380153	1795747	no
Shellrock PSTA	03/05/2001	waterflea	neonates/adult	23.1	8.4	yes
Shellrock PSTA	03/05/2001	waterflea	total neonates	208	76	yes
Shellrock PSTA	03/05/2001	waterflea	% survival	100	0	yes
Shellrock PSTA	03/05/2001	minnow	% survival	92.5	50	yes
Shellrock PSTA	03/05/2001	minnow	mg/larva	0.3203	0.1858	yes
Shellrock PSTA	03/07/2001	green algae	cells/ml	360693	2099393	no
Peat PSTA	03/05/2001	waterflea	neonates/adult	26.8	30.8	no
Peat PSTA	03/05/2001	waterflea	total neonates	268	277	no
Peat PSTA	03/05/2001	waterflea	% survival	100	100	no
Peat PSTA	03/05/2001	minnow	% survival	90	62.5	yes
Peat PSTA	03/05/2001	minnow	mg/larva	0.2551	0.206	no
Peat PSTA	03/07/2001	green algae	cells/ml	501533	1960933	no
Head Cell	04/23/2001	waterflea	neonates/adult	21.1	31.9	no
Head Cell	04/23/2001	waterflea	total neonates	169	319	no
Head Cell	04/23/2001	waterflea	% survival	80	100	no
Head Cell	04/23/2001	minnow	% survival	100	72.5	yes
Head Cell	04/23/2001	minnow	mg/larva	0.2878	0.274	no
Head Cell	04/25/2001	green algae	cells/ml	908833	2096213	no
Shellrock PSTA	04/23/2001	waterflea	neonates/adult	26.5	34.4	no
Shellrock PSTA	04/23/2001	waterflea	total neonates	265	344	no
Shellrock PSTA	04/23/2001	waterflea	% survival	100	100	no
Shellrock PSTA	04/25/2001	minnow	% survival	90	52.5	yes
Shellrock PSTA	04/25/2001	minnow	mg/larva	0.2638	0.3297	no
Shellrock PSTA	04/25/2001	green algae	cells/ml	913693	2037800	no
Peat PSTA	04/23/2001	waterflea	neonates/adult	6.4	33.6	no
Peat PSTA	04/23/2001	waterflea	total neonates	51	336	no
Peat PSTA	04/23/2001	waterflea	% survival	80	100	no
Peat PSTA	04/23/2001	minnow	% survival	87.5	95	no
Peat PSTA	04/23/2001	minnow	mg/larva	0.2796	0.3633	no
Peat PSTA	04/25/2001	green algae	cells/ml	874313	2294027	no

growth potential was 0.132 mg dry weight/L for the head cell sample and less (<0.100 mg dry weight/L) in the outflow samples from the peat and shellrock PSTA Test Cells. Limiting nutrient algal growth potential tests were not performed on these samples.

Based on existing information, there does not appear to be an adequate basis to determine if a full-scale PSTA would result in an environmental imbalance in downstream waters.

4.3.7.4 Cost-Effectiveness of Technology

Costs for the full-scale PSTA scenarios were summarized in Exhibit 4-33. Based on the conservative sizing and design criteria used in this analysis, and omitting the STA-2 costs, the 50-year present worth cost for a PSTA treating the post STA-2 flow to 20 µg/L with 0 bypass would be approximately $455,000,000, with a unit cost of approximately $700/lb of TP removed. To attain 12 µg/L, the estimated present worth cost is approximately $889,000,000, with an estimated unit cost of $1,080/lb TP removed.

These estimated costs are very sensitive to a number of factors including:

- Presence and thickness of a limerock or lime soil amendment
- The PSTA footprint area as affected by the hydraulic TIS model used for simulation
- The effects of deep percolation
- Actual inflow TP loads
- The target TP outflow concentration
- The quantity of inflow water that bypasses the PSTA

All of these variables create significant uncertainty related to the estimated costs in this STSOC. As currently evaluated, the base costs summarized in Exhibit 4-33 for 0-percent bypass are conservative. Additional information that might relax the stated design assumptions and requirements for soil amendment and that increase hydraulic efficiency are likely to result in significant cost estimate reductions.

4.3.7.5 Implementation Schedule

The startup period for PSTA was assessed in a total of 27 mesocosm studies (Test Cells and Porta-PSTAs). While there was some variability between treatments, the typical time from commencement of inflows to stable performance was from 3 to 6 months. The optimal seasons for startup were spring and summer. It is likely that startup through the fall and winter months would require a longer stabilization period.

The time needed for implementation of a full-scale PSTA is dependent on the treatment alternative selected, the site selection and acquisition process, preliminary and final engineering and design completion, bidding and contractor

selection, construction completion, and startup. The time required for each of these components is estimated based on observations from prior District projects, such as the implementation of STA-3/4, the largest of the existing STAs. Based on a start date of January 1, 1999, the estimated time required for final completion and compliance with water quality standards is December 2004 (72 months), as itemized below and illustrated in Exhibit 4-45:

- Alternative analysis, site selection, and land acquisition – 24 months
- Preliminary engineering, including site-specific studies – 6 months
- Final engineering and preparation of design drawings and specifications – 6 months
- Bidding and contractor selection – 4 months
- Construction – 20 months
- Startup and compliance with water quality standards – 12 months

4.3.7.6 Feasibility and Functionality of Full-Scale Design

In some ways, PSTA is the least developed of the supplemental technologies. Significant research on design and performance of PSTAs has only been underway for approximately 3 years. No full-scale PSTA systems have been designed, constructed, or operated, nor are any of the existing PSTA systems operated to meet specific outflow discharge permit requirements. For these reasons, the feasibility, costs, and reliability of full-scale PSTA implementation should be evaluated cautiously.

On the other hand, large-scale, periphyton-dominated areas have been providing water with a low TP concentration for decades. The southern area of WCA 2A is dominated by a mixture of calcareous periphyton and sawgrass plant communities. This area has produced a long-term average TP concentration of approximately 14.3 µg/L (arithmetic average) or 10.5 µg/L (geometric mean) (Kadlec, 1999). Further downstream in WCA-2A, annual average TP concentrations range between 5 and 12 µg/L. Payne et al. (2001) reported the median annual TP geometric mean as 8.5 µg/L at the reference stations located in WCA-2A. Wet prairie and slough areas of WCA-1 had a median geometric mean TP concentration of approximately 9.1 µg/L (Payne et al., 2001). Areas of the Everglades National Park are also dominated by calcareous periphyton plant communities and have low ambient concentrations of TP. It is important to note that none of these existing full-scale systems were specifically designed to optimize TP removal and, therefore, their greater- or lesser-performance in relation to an engineered PSTA is not known.

There are many potential research issues that could provide additional certainty prior to full-scale PSTA design and implementation. These items have been previously summarized as part of ongoing ATT team meetings. Critical research topics related to PSTA implementation include:

EXHIBIT 4-45

Implementation Schedule of a Full-scale PSTA

Year	*Month*	*Alternative analysis, site selection, and land acquisition*	*Preliminary engineering including site-specific studies*	*Final engineering and preparation of design drawings and specifications*	*Bidding and contractor selection*	*Construction*	*Startup and compliance with water quality standards*
1999	JAN						
	FEB						
	MAR						
	APR						
	MAY						
	JUN						
	JUL						
	AUG						
	SEP						
	OCT						
	NOV						
	DEC						
2000	JAN						
	FEB						
	MAR						
	APR						
	MAY						
	JUN						
	JUL						
	AUG						
	SEP						
	OCT						
	NOV						
	DEC						
2001	JAN						
	FEB						
	MAR						
	APR						
	MAY						
	JUN						
	JUL						
	AUG						
	SEP						
	OCT						
	NOV						
	DEC						
2002	JAN						
	FEB						
	MAR						
	APR						
	MAY						
	JUN						
	JUL						
	AUG						
	SEP						
	OCT						
	NOV						
	DEC						

- Response of the PSTA periphyton and sparse macrophyte plant communities to a range of inlet TP concentrations and flow rates
- Management issues related to maintaining periphyton dominance over emergent and submerged aquatic macrophytes
- Soil pre-treatment options and effectiveness
- Effects/benefits of placing multiple PSTA cells in series
- Benefits/liabilities of high current velocities and winds on PSTAs
- Effects of long-term soil accretion on PSTA performance and engineering design

Additional information related to some of these topics will continue to be gathered from the District's Field-Scale PSTA demonstration project currently underway. A plan to use the District's STA 1-W Test Cells to quantify the effects of cells-in-series, pulsed inlet loading, and combination of PSTA with other natural wetland treatment technologies (emergent and submerged macrophytes) has recently been developed. Use of the PSTA portable mesocosms might be the best research platform to test alternative management techniques and soil amendments.

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

As a land-intensive treatment option, the PSTA technology offers a potentially high level of operational flexibility and resilience to natural perturbations. Large water volumes can be stored within the footprint of the proposed PSTA during high rainfall events. Effects of this storage on performance are not known. Higher input TP loads can be assimilated to some extent due to relatively long residence times, and response to low TP loads is not expected to be a problem. Unlike other supplemental technologies, such as emergent and submerged macrophyte dominated STAs, the PSTA system is currently expected to recover relatively quickly from dessication occurring from drought. Fairly rapid recovery (approximately 2 weeks) was demonstrated during an early summer dry-out test and reflects the possible ability of the periphyton to be fully dessicated and recover its P-removal ability within a period of hours or days following rewetting. While this P uptake may start rapidly upon rewetting, optimal treatment performance of the PSTA will likely require an initial period of holding water without release.

Because they have less potential fuel, PSTAs are not as likely to carry a wildfire as are macrophyte-dominated STAs following a drought. High winds are known to mobilize some periphyton, resulting in the apparent potential for movement and washout of periphyton biomass during extreme weather events. However, the concept of periphyton growing in an open matrix of sparse macrophytes appears to be relatively immune to high biomass export.

4.3.7.8 Residual Solids Management

Forecast modeling described in the final PSTA report indicated that periphyton/ accreted solids harvesting was unlikely to contribute to a significant increase in TP load reduction. Periphyton harvesting would also result in an unmanageable amount of wet biomass needing disposal. For this reason, there is no side stream or residual management envisioned for this technology. The PSTA sizing and costs estimated in this report are based on 0 biomass harvesting and export.

4.3.8 Summary of Full-Scale PSTA Implementation Issues

Engineered PSTAs have only been studied during a 3-year research and demonstration period and only at a relatively small scale (mesocosms and Test Cells with areas ranging from 65 to 22,000 ft^2). Larger-scale (5 acre) PSTA demonstration cells are in an early operational stage, and are on-going at the time of the STSOC analysis. Assessment of the cost and reliability of full-scale PSTAs intended to treat very large volumes of stormwater runoff is based on this existing database, model simulations, and cost and construction assumptions described in this report. These estimates of system design and performance are subject to considerable uncertainty until additional information is gathered and analyzed. Thus, while the information generated during the study period has dramatically increased our understanding of the engineerability of PSTAs, and the data have supported the preliminary STSOC analysis, it is premature to conclude that sufficient information is in hand to support detailed design and technology application full-scale.

Results to date for performance of PSTAs for post-STA TP load reduction are promising. TP mass reduction rates are dependent on TP load and are as high as or higher than removal rates of other natural wetland-based technologies. In addition, PSTAs offer the potential to achieve lower TP outflow concentrations than emergent macrophyte STAs and wetlands dominated by SAV and have the ability to recover relatively quickly following drought. They are not subject to fire or significant impairment from hurricanes or other foreseeable natural disasters. They are not likely to create an ecological imbalance in adjacent aquatic environments.

PSTAs do have limitations for full-scale application for TP load reduction. Land area requirements estimated by the STSOC analysis are large, requiring many thousands of acres to meet low TP concentration targets downstream from the existing STAs. Area estimates for PSTAs are subject to the uncertainty described above, and additional research on effects of pulsing, infiltration, cells-in-series design, and antecedent soil conditions on TP-removal performance is sorely needed.

In addition to their relatively large footprint, PSTAs will require an undetermined amount of plant management and/or alteration of pre-existing soil conditions. Placement of relatively inert soils to cover agricultural lands with high antecedent concentrations of available P may not be practical on a large

scale. However, it is clear from the existing research that, at least during the early operational phase, relatively small amounts of available soil P will offset P-removal potential of any of the natural wetland treatment technologies near background TP concentrations. An additional effect of these elevated soil TP levels for PSTA is their apparent stimulatory effect on colonization and growth of emergent macrophytes that may out-compete the desired calcareous periphyton plant communities. While we have not yet identified how to optimize PSTA design and operations on peat substrates, the reality is that this is the system that prevails in the natural Everglades. Further research on peat-based PSTAs is strongly recommended in spite of the early results obtained to date.

Since there are few potential tools available to the regulator who wishes to achieve very low TP standards and Everglades protection, it is prudent to continue to refine knowledge of PSTA design and the potential of PSTAs for TP control. Their best use might be in conjunction with other "pre-treatment" technologies, such as emergent macrophyte STAs or SAV wetlands. Whether as stand alone or integrated treatment units, PSTAs offer the potential to help achieve the environmental goals in the Everglades of South Florida.

4.4 Summary of PSTA Sustainability

A 2-year period of operation can not fully evaluate PSTA sustainability. The PSTA Forecast Model provides a tool to predict future performance beyond the research timeframe; however, the accuracy of such predictions is significantly limited by the operational data. Based on the model, the ability of PSTA to provide removal of TP from agricultural drainage waters does not improve or decline with system age. The PSTA Forecast Model predicts a background TP concentration of approximately 3 to 5 µg/L based on rainfall inputs alone. The model extrapolates that 10 µg/L outflow concentrations can be achieved under some loading conditions and based on relatively large footprint areas. The estimated PSTA area needed to achieve 10 µg/L or lower concentrations is still under evaluation.

Macrophytes will likely need management in a full-scale PSTA. The amount of macrophyte management will depend on the range of inflow TP concentrations. More management will be needed with high inflow TP and less with low inflow TP. Macrophyte management is most likely to be in the form of herbicide application, water level control, and system dryout.

The biological community is expected to continue to capture, cycle, and accrete P as long as there is volume in a treatment cell

The PSTA Forecast Model predicts a background TP concentration of approximately 3 to 5 µg/L based on rainfall inputs alone. The model extrapolates that 10 µg/L outflow concentrations can be achieved under some loading conditions and based on relatively large footprint areas.

for sediment accretion. The current research project did not accurately define that net accretion rate, but it appears to be less than an average of approximately 5 cm/yr. Assuming a conservative accretion rate of 2.5 cm/yr, this would result in the accumulation of approximately 1.25 m of new soils in a 50-year project life. This rate of soil formation will require inclusion of a comparable embankment height to contain water during the project's life. There is considerable uncertainty concerning the actual rate of soil accumulation in a PSTA undergoing periodic dry outs.

Finally, a PSTA *per se* is not expected to create unfavorable water quality conditions in downstream waters. Water quality changes, such as reduction of TP concentrations and slight shifts in concentrations of calcium, alkalinity, color, DO, and pH, are not likely to cause any harm to adjacent Everglades ecosystems. However, because of the large footprint of this technology, harmful anthropogenic chemicals (potentially including herbicides, metals, and TP), if present in pre-existing soils, could leach into the water column of a PSTA or any other "green" technology and create water quality problems. Site selection and preliminary soil sampling to quantify antecedent conditions will be a key factor in implementation and sustainability of a full-scale PSTA.

SECTION 5

Remaining PSTA Research Issues

5.1 Introduction

During the past 3 years, the PSTA Research and Demonstration Project has identified the key issues related to determining the feasibility of full-scale design and performance of PSTAs, and has addressed those issues within the practical limitations of allocated time and funding. That research agenda was constantly updated throughout the 3-year project with consultation from the District's scientific and engineering staff and based on detailed review of experimental treatments and data by a distinguished outside Scientific Review Panel (SRP).

Research is currently continuing at a larger, field-scale with the use of four 5-acre PSTA cells located near STA-2. This effort will help to better define issues related to alternative soil preparation techniques, groundwater exchange rates, and increased flow velocities. However, many issues related to the overall project goals will not be fully addressed within the confines of this project. This section describes key remaining PSTA research issues for continuing work to better define PSTA long-term performance and costs for TP control.

5.2 Status of Field-Scale PSTA Testing

Exhibit 5-1 schematically illustrates the PSTA Field-Scale demonstration facility layout. Four PSTA cells were constructed in early 2001 from onsite materials. These four cells are each approximately 20,000 m^2 (5 ac). Three of the cells are rectangular at 61 m wide by 317 m long (200 by 1,040 ft) and one cell is sinuous with a length of 951 m (3,120 ft) and a width of 21 m (70 ft). Cells 1 and 2 have approximately 30 cm (12 in of compacted material) of limerock placed over the native peat soils. The relatively shallow peat soils were excavated and removed from Cell 3 to expose the underlying caprock. Native peat soils with no amendments or other pre-treatments comprise the floor of Cell 4. Field-scale construction activities are summarized in Appendix H.

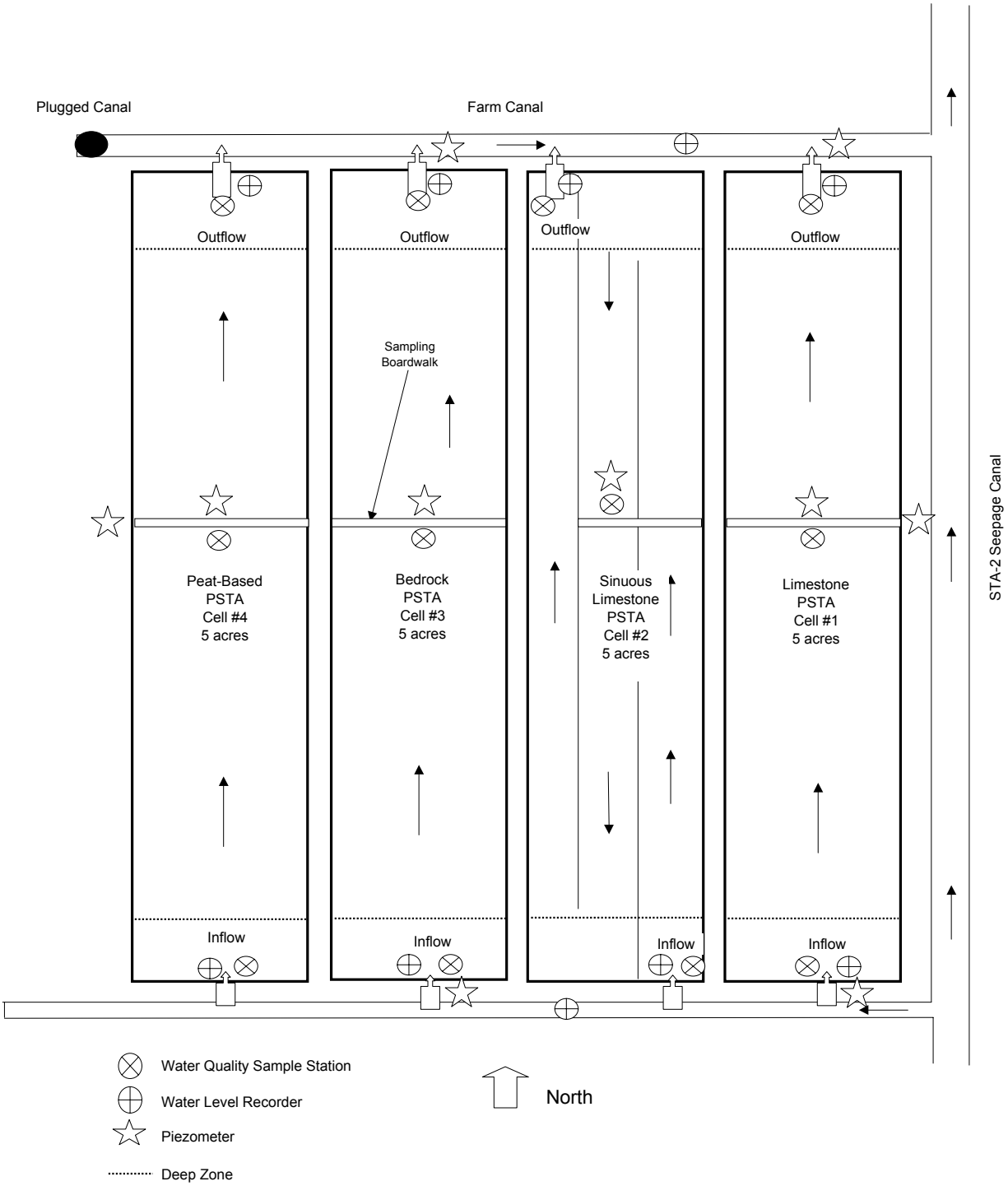


Exhibit 5-1
Schematic of Field-Scale Cells Showing Sampling Locations

Influent water to this facility can be conveyed from two sources: the STA-2 seepage control canal or Cell 3 of STA-2. These water sources can be used independently or by blending. Influent canal water is pumped into the four PSTA cells using diesel pumps, and water flows by gravity from the inlet deep zones to the outlet deep zones, which distribute and collect these flows. Water flows out of each cell through a single outlet weir box equipped with an Agridrain water level control, which consists of 60-cm-wide removable stoplogs. The top stoplog acts as a horizontal overflow weir and controls the water level in the cell as well as being used in conjunction with a water level recorder for outflow quantification. Scaffold-type "boardwalks" are installed across the width of each cell at the center point to allow access for internal sampling. A series of groundwater sampling wells are arranged within and around the PSTA cells to allow monitoring of groundwater TP gains and losses. Low densities of spikerush were planted in bands across the width of each cell. Periphyton colonization was by natural recruitment. Construction of the PSTA Field-Scale demonstration facility was completed in early 2001, and routine operation and monitoring began in July 2001.

Exhibit 5-2 summarizes the analytical sampling plan for the Field-Scale PSTA demonstration. Water stage and flows in the cells will be continuously monitored. Field measurements will be collected weekly as will inflow and outflow P forms. Other important water quality parameters, such as nitrogen and calcium, will be monitored monthly. Biological sampling for periphyton and macrophyte biomass and P storages will be monitored monthly or quarterly. Sediments will be sampled at the start and end of this phase of the Field-Scale project. At the current time, monitoring activities at the Field-Scale Cells are scheduled through December 2002. Clearly, the research benefits of this phase of the project will require continued monitoring over an extended period well beyond December 2002.

5.3 PSTA Plant Community Establishment and Control

A key issue requiring additional study is the most effective means of controlling establishment and succession of the periphyton-dominated plant community in a PSTA. While it is clear that it is not feasible to control specific algal species in the periphyton, a desire may exist to control the periphyton community type (e.g., blue-green calcitic-dominated rather than green filamentous). At this point, we do not know with certainty which type of periphyton assemblage is best for P removal and over what water P concentration range. It is also not known how to manage the plant community so one type of periphyton dominates the community biomass. Studies by others have suggested that the potential benefits of iterative dryout periods as a means of encouraging dominance by calcitic algal forms, but no definitive demonstration of this approach has been published.

EXHIBIT 5-2

Proposed Field-Scale Cell Sampling Frequency

Parameter	Sampling Locations and Frequency					
	Piezometers	Inflow Canal	Inflow	1/2	Outflow	Outflow Canal
Field Meter Readings						
Flow	na	na	Pump	na	calc	na
Water Stage	W	C(I)	W	C(I)	W	C(I)
Water temperature	W	W	W	C(I)	W	na
Dissolved oxygen	na	W	W	C(I)	W	na
pH	W	W	W	C(I)	W	na
Conductivity	W	W	W	C(I)	W	na
Total Dissolved Solids (note a)	W	W	W	C(I)	W	na
Turbidity (note a)	W	W	W	C(I)	W	na
PAR	na	na	na	M	na	na
Water Quality Analyses						
Phosphorus (P) Series						
Total P	M	NS	W	M	W	NS
Dissolved Reactive P	NS	NS	W	M	W	NS
Total Dissolved P	NS	NS	W	M	W	NS
Nitrogen (N) Series						
Total N	NS	NS	M	Q	M	NS
Ammonia N	NS	NS	M	Q	M	NS
Total Kjeldahl N	NS	NS	M	Q	M	NS
Nitrate+nitrite N	NS	NS	M	Q	M	NS
Total suspended solids	NS	NS	M	Q	M	NS
Total organic carbon	NS	NS	M	Q	M	NS
Calcium	NS	NS	M	Q	M	NS
Alkalinity	NS	NS	M	Q	M	NS
Chlorides	M	NS	M	Q	M	NS
Biological Analyses						
Periphyton Cover	NS	NS	NS	M	NS	NS
Macrophyte Cover	NS	NS	NS	M	NS	NS
Periphyton Dominant Species	NS	NS	NS	Q	NS	NS
Biomass (AFDW)	NS	NS	NS	M	NS	NS
Calcium	NS	NS	NS	M	NS	NS
Cholorophyll *a* , *b* , *c* , phaeophytin	NS	NS	NS	M	NS	NS
Phosphorus (P) Series						
Total P	NS	NS	NS	M	NS	NS
Total Inorganic P	NS	NS	NS	M	NS	NS
Non-reactive P	NS	NS	NS	Q	NS	NS
Total Kjeldahl N	NS	NS	NS	Q	NS	NS
Accretion (Net Organic/Inorganic)	NS	NS	NS	Q	NS	NS
Sediments (Start and End)						
Phosphorus (P) Series						
Total P	NS	NS	NS	S/E	NS	NS
Total Inorganic P	NS	NS	NS	S/E	NS	NS
Non-reactive P	NS	NS	NS	S/E	NS	NS
Phosphorus Sorption/Desorption	NS	NS		S/E		NS
Total kjeldahl N	NS	NS	NS	S/E	NS	NS
Total organic carbon	NS	NS	NS	S/E	NS	NS
Bulk density	NS	NS	NS	S/E	NS	NS
Solids (percent)	NS	NS	NS	S/E	NS	NS
System-Level Parameters						
Gross primary productivity	NS	NS		C(I)		NS
Net primary productivity	NS	NS		C(I)		NS
Community respiration	NS	NS		C(I)		NS

Notes:

note a = presumes Hydrolab sensor available
W = weekly
M = monthly
Q = quarterly
(D) = sampled by District
C(I) = continuous with instrument

NS = not sampled
S/E - start and end of study phase
na = not applicable
Assumes number of piezometers = 12
Assumes number of mesocosms = 4

A related issue is the effect of macrophytes on TP removal performance and periphyton dominance. The effect of different macrophyte groups (e.g., submerged versus emergent), macrophyte species (e.g., spikerush versus cattails), and macrophyte biomass density and shading on long-term TP removal performance has not been fully documented by the research to-date. A better understanding is needed of how to control the densities of these various macrophyte assemblages to provide optimal cover so that periphyton dominance is maintained.

Many large and small research efforts could be designed and undertaken to investigate this issue of PSTA plant community management thoroughly. The list of ideas below is provided to identify other prospective study topics that would have value for better understanding PSTA design and operations issues.

- Porta-PSTA research platform
  - Combined effects of TP, DRP, and calcium on periphyton community structure (e.g., effects of P fractions and loads as well as total calcium)
  - Effects of flow velocity on periphyton community structure and export (e.g., variable speed re-circulation pumps to regulate flow velocities)
  - Effects of different macrophyte groups and species on periphyton biomass (e.g., test major SAV and emergent species including hydrilla, southern naiad, chara, bladderwort, spikerush, sawgrass, and cattails)
  - Effects of differing soil types on macrophyte and periphyton colonization (e.g., various sources of peat and sand soils)
  - Methods for controlling macrophyte colonization and succession (e.g., pre-emergent herbicides, herbicide application rates, mechanical harvesting, water depth control, soil seed bank sterilization, etc.)
- Test Cell research platform
  - Synoptic community structure sampling from inlet to outlet to relate community succession and structure to the gradient of P concentrations and forms
  - Macrophyte management at a larger scale (e.g., herbicide application techniques, both pre-emergent and post-emergent)

5.4 PSTA Optimization on Soils with High Antecedent P Levels

The PSTA research conducted during Phases 1 and 2 has illustrated the consequences of labile P in antecedent soils. It appears likely that soils providing a source of available P will impair PSTA performance during a significant startup period. In addition, antecedent storages of available P in soils promote the colonization of macrophytes that compete with periphyton for available sunlight. It may

be impractical to establish a PSTA on peat-based soils without amending those soils in some way to sequester any existing labile P. Several such soil amendments/pre-treatments tested in the current research project include:

- Covering peat soils with shellrock, sand, and limerock
- Adding hydrated lime to peat soils
- Rinsing sand soils with a dilute solution of hydrochloric acid to remove available P

While some form of these treatments might be technically feasible on a larger scale, it is not clear at this time that any of these treatments will be cost-effective. Additional research should be conducted at the Porta-PSTA scale to more fully evaluate the effectiveness and cost of various types of soil amendments on PSTA performance. Suggested Porta-PSTA research efforts are outlined below:

- Test various forms of calcium (lime, hydrated lime, crushed limestone, etc.), lime addition rates, and methods for lime addition (broadcast, flood, roto-till, etc.)
- Test different depths of limerock and shellrock addition over peat soils
- Test various types of native soils (farmed versus non-farmed soils; soils from areas adjacent to existing cattail-based STAs)
- Test various types of sandy soils and methods of trapping antecedent labile P concentrations

5.5 PSTA Cells in Series

Multiple cells-in-series may enhance treatment performance of any type of wetland plant community treatment system (Kadlec, 2001b). Enhanced performance results from improved hydraulics that better simulate plug-flow conditions and the optimization of first-order removal processes that depend on concentration. The PSTA mesocosms have hydraulics between plug flow and completely mixed, and on the basis of tracer studies conducted as part of this study may be described hydraulically as from 1.2 to 2.7 TIS during Phase 1 to 3.8 to 4.1 TIS during Phase 2 (see Kadlec, 2001a and Appendix F).

The cells-in-series concept may be tested in the ENR Test Cells as part of a second phase of testing of integrated treatment processes. This concept could be easily tested on a smaller scale by linking a number of Porta-PSTA tanks in series and documenting performance. It will be important to make future improvements to the PSTA Forecast Model to allow future evaluation of the effects of optimizing system hydraulics.

5.6 PSTA Performance at High Inlet P Loads

Because natural calcareous periphyton communities are known to occur at low P water concentrations, the PSTA concept has been considered only as a final polishing step (post-STA application) and not for use at the front-end of a P management project. While this concept may be logical, it has not been thoroughly tested in the EAA. Algal-turf scrubber technology has been shown to be effective for trapping P at much higher inlet concentrations and loads than those tested as part of this program (Addy et al., 1993; Craggs, 2000; Hydromentia, 2000). Even if PSTA will not find use at the beginning of a treatment train, it would be helpful to understand their performance response along a more complete gradient of P concentrations and loads. Results summarized in this report indicate that P removal rate was increasing up to the highest loading rates tested. Research on the effects of inlet P loading on PSTA performance could be conducted by moving Porta-PSTA mesocosms to the north research site in the ENR.

5.7 PSTA Performance under Variable Hydraulic Loads

Hydraulic theory and wetland data analysis indicate that average treatment performance may be altered under variable inlet loads compared to steady operation (Kadlec, 2000). Performance may be reduced under highly variable loads, such as those resulting from stormwater inputs. The PSTA concept has not been tested under a regime of widely variable loads, both from varying inlet concentrations and flows.

Ongoing development of future Test Cell research is being designed to provide a test of the effect of variable loading on PSTA performance. This type of research could also be conducted at the Porta-PSTA mesocosm scale.

5.8 Review of Long-Term PSTA Datasets

The District's PSTA Research and Demonstration Project conducted operational monitoring for 2 years, which is the longest time span of any PSTA research effort to-date. However, water flow and quality data exist from other periphyton-dominated sites, such as the Water Conservation Areas, the C-111 Basin, and ENP. All of these locations have been "operational" for many more years than the District's PSTA research systems. Some of the data from these periphyton-dominated ecosystems could be examined to estimate PSTA performance in a mature plant community and for a longer time period. Also, ecological data exist for some of these systems that may provide insight into the natural peri

phyton and macrophyte succession in these areas and how that plant community development relates to soil chemistry and P loads.

5.9 Summary of PSTA Research Needs

While considerable knowledge has been gained as a result of the District's PSTA Research and Demonstration Project, much more remains to be learned. This section highlighted some of the most important unresolved research topics. Answers to these questions would help optimize PSTA design and increase the cost-effectiveness of this technology.

Key remaining PSTA research issues include:

- Factors that affect plant community establishment and management
- Available options and effects of soil amendments
- Benefits of placing PSTA cells in series
- PSTA performance as a function of high inlet TP concentrations and loads
- PSTA performance under highly variable hydraulic loads

Each of these issues could be further evaluated at the Porta-PSTA research platform scale, and additional relevant PSTA research is being planned for the ENR Test Cells. These planned or potential field research efforts should be combined with a thorough literature and data review relevant to P removal performance and ecological development of naturally occurring periphyton-dominated plant communities in the greater Everglades area.

PSTAs appear to have substantive potential for being a part of the approach for modifying the existing STAs to achieve compliance with the anticipated TP criterion of 10 ppb. Additional investigations are needed to better address sustainability issues, and refine how to apply the cumulative PSTA knowledgebase toward full-scale design and optimization.

SECTION 6

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