# Chapter 4B: STA Optimization

The Everglades Forever Act requires the South Florida Water Management District (District or SFWMD) to optimize nutrient removal performance of the Stormwater Treatment Areas (STAs). The STA Optimization Research and Monitoring Program consists of a number of individual research studies designed to assist the District in meeting this mandate. A description of this program and results from earlier STA optimization experiments and analyses are provided in previous Everglades Consolidated Reports (ECRs) (Chimney and Moustafa, 1999; Chimney et al., 2000; Nungesser et al., 2001). The objective of this section of Chapter 4 is to present new findings and analyses completed since last year's report and update ongoing studies that have generated sufficient new information, including STA optimization experiments conducted in the test cells, the Marsh Dryout Study, the STA-5 Dryout Study and development of the Dynamic Stormwater Treatment Area (DMSTA) water quality model. Evaluations of overall STA performance, including calculation of TP load and concentration reductions, are presented in Section 4A of this chapter. This section also contains an analysis of nutrient reduction in each of the treatment cells that comprised the old Everglades Nutrient Removal Project (ENRP), which is now part of STA-1 West (STA-1W) (discussion below). Similar cell-by-cell analyses of ENRP performance have been presented in previous ECRs.

All the experiments described in this chapter have been conducted in small-scale systems, either the STA-1W test cells or enclosures (mesocosms). Small experimental units are commonly used in modern ecological research. Small systems afford the researcher with many advantages that include, but are not limited to: (1) comparatively low cost and logistical simplicity relative to field studies; (2) using experimental manipulations that cannot be duplicated at full scale; (3) a level of control over environmental factors and spatial heterogeneity not possible in the field; (4) the ability to replicate treatments and employ experimental designs that are compatible with inferential statistics; and (5) experiments that can be conducted quickly and are easily repeated (Lamberti and Steinman, 1993; Drake et al., 1996; Lawton, 1996). However, use of small systems is predicated on the assumption that they contain sufficient physical and biogeochemical complexity to adequately mimic the functioning of larger ecosystems. Without the context of appropriate field studies, small-scale experiments are suspect as being irrelevant, since they might distort or exclude important features of communities and ecosystems (Carpenter, 1996). Insightful research is likely to consider a range of different scales (Levin, 1992), while the results of small-scale experiments are prompted and verified by results of larger field programs (Frost et al., 1988). The District acknowledges that the test cells and mesocosms are not perfect analogs of the STAs. Data collected in these experiments may suffer from effects attributable to antecedent soil conditions, vegetation grow-in phenomenon, low water velocities, short duration of the experiments or other factors. The test cells and mesocosms are not unique in this respect; all small experimental systems are potentially subject to scaling and enclosure artifacts. Nevertheless, results from the STA Optimization experiments can provide the District with useful insights into STA performance issues. In addition, data collected from the test cells and mesocosms will be valuable in calibrating the DMSTA for use in future design applications.

# ENRP WATER QUALITY MONITORING

## CONSTRUCTION CHANGES

The ENRP was a 1,545 hectares (3,819 acres) treatment wetland that served as a prototype STA (Chimney et al., 2000) and has since been incorporated into the footprint of STA-1W (**Figure 4B-1**). The construction of STA-1W involved making modifications to the existing ENRP infrastructure and building a number of new water control structures. Two new treatment cells (Cells 5A and 5B) were added to the wetland, which enlarged its effective treatment area to 2,699 hectares (6,670 acres), a 75-percent increase over the old ENRP. Surface inflow now comes from the S5A pump station and enters STA-1W through two lift gates at the G-302 structure. Some of this flow moves westward into Cell 5A through a series of culverts in the G-304 levee, while the remaining water enters the old ENRP cells through two lift gates at G-303. The G-250 pump station now handles only seepage-return water from Cells 5A and 5B. To accommodate increased flow into STA-1W, the levee separating the old Buffer Cell and Cell 1 was degraded, combining these cells, and culverts were added to levees in the old ENRP's western flow way (G-255 and the G-254 levee separating Cells 2 and 4). Outflow from Cells 3 and 4 still exits the wetland through the G-251 pump station. The seepage return canal outside the perimeter levee was enlarged and now conveys water leaving Cell 5B through the G-306 levee southward to a new outflow pump station (G-310). G-310 also has the capacity to handle excess water from Cells 3 and 4 during storm events, when water will be released from these cells into the new discharge canal via gates (G-258, G-259, G-308 and G-309) in the perimeter levee. A more complete description of the layout and operation of the old ENRP is provided in Chimney et al., 2000; of STA-1W, in the STA-1W Operation Plan (SFWMD, 2001).

## DATA COLLECTION AND ANALYSIS

Previous ECRs have included separate water and P budgets for the entire ENRP and each of the interior cells (Chimney et al., 2000; Nungesser et al., 2001). This year's report presents updated budgets for those STA-1W treatment cells that comprised the old ENRP (Cells 1, 2, 3 and 4). The Buffer Cell has been incorporated into Cell 1. Cells 5A and 5B began discharging water in Summer 2000. However, most of this water was routed through the G-250 pump station into Cells 1 through 4. Installation of equipment needed to monitor inflow and outflow water quality in Cells 5A and 5B has been delayed. The new outflow pump station (G-310) became operational in October 2000, but due to the drought, pumped relatively little water this year. Complete water and P budgets for Cells 5A and 5B will be included in next year's ECR. Calculation methodology followed Chimney et al., 2000. Where necessary, algorithms were modified to account for STA-1W construction activities and to reflect new information regarding system hydrology. Budgets for prior years have been recalculated to reflect this new information.

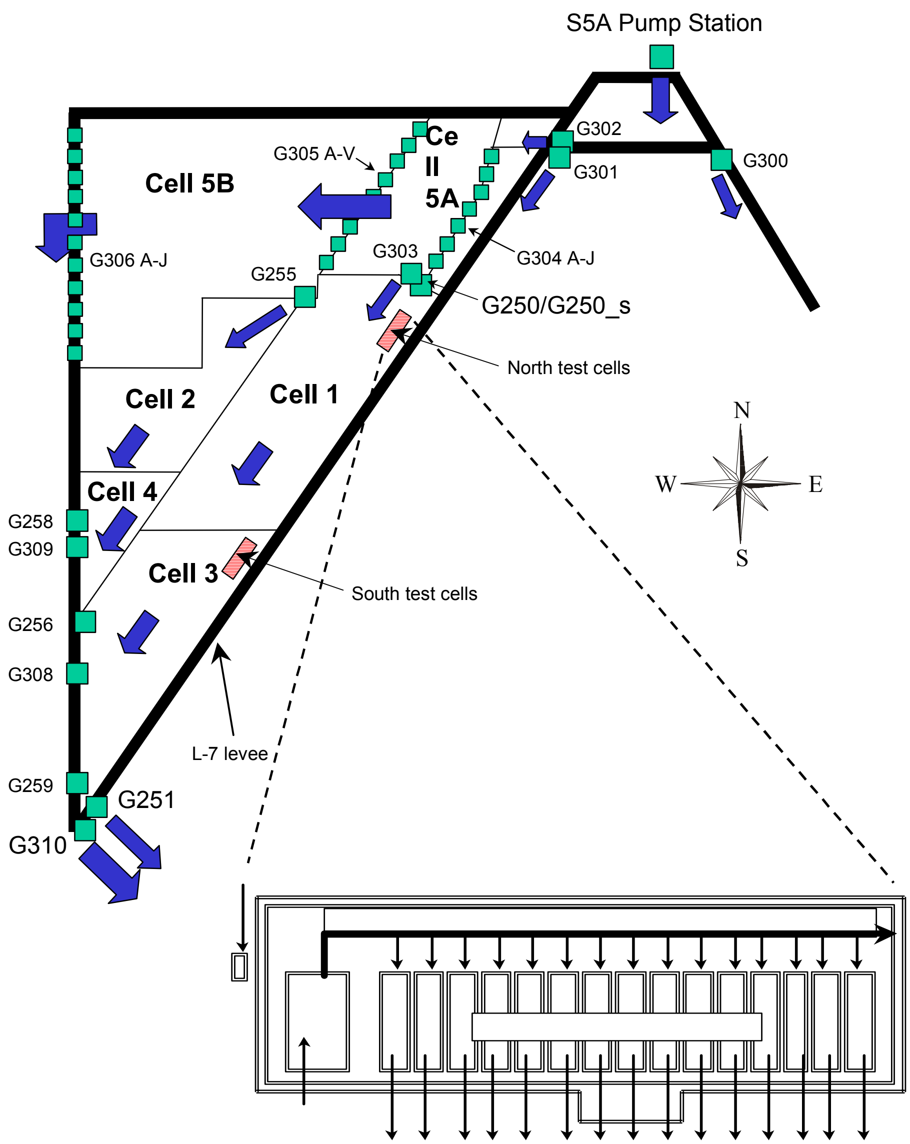


**Figure 4B-1.** Map of Stormwater Treatment Area 1-West showing location of the test cells. Arrows indicate direction of flow. The old Everglades Nutrient Removal Project was comprised of Cells 1, 2, 3 and 4.

Construction of STA-1W resulted in a number of hydrologic changes in what was the old ENRP. The surface area of Cell 1 increased as a consequence of combining it with the old Buffer Cell in March 1999. Also, Cell 1 now receives inflow directly from G-250 and G-303 and has a direct outflow into Cell 2 (G-255). Instrumentation to monitor discharge through the G-303 gates was not operational when it went into service in July 1999. Flow through this structure from July 1999 through March 2000 was computed using estimates of head- and tail-water elevations derived from regressions with other nearby stage recorders. Flow was estimated by similar means at other structures in the old ENRP where monitoring was disrupted by construction activities. During construction of the new discharge canal along the western perimeter of STA-1W, seepage was pumped from the excavation back through G-258 and G-259 into Cells 3 and 4. These structures, therefore, acted temporally as inflow points to STA-1W.

Other changes were made to water and P budgets based on new information or a re-evaluation of previous assumptions. The U.S. Geological Survey (USGS) recently quantified groundwater movement in treatment cells that comprised the old ENRP (Choi and Harvey, 2000) and derived improved empirical equations to model seepage flow. The District has adopted their approach, and recomputed groundwater discharge and recharge in STA-1W accordingly. The median TP concentration in shallow wells along the L-7 levee (sampled quarterly) was used to compute nutrient loads in all groundwater that entered STA-1W from WCA-1. The same TP concentration was used to estimate the nutrient load that entered STA-1W through G-258 and G-259. Cell-specific geometric means of surface inflow and outflow TP concentrations were used to estimate mass lost from STA-1W through groundwater outflow along the west and north sections of the perimeter levee. Flow-weighted TP concentrations at the S5A Pump Station were used as estimates of nutrient levels at G-303. The District discontinued monitoring of dry deposition at the ENRP in October 1997. The mean monthly TP load over the first two years of the project (no evidence of seasonal effects was found to justify a more complicated approach) was used to estimate the contribution of dry deposition to the nutrient budget in succeeding months.

## RESULTS

### Water Budgets

Inflow and outflow components of water budgets for the old ENRP and its treatment cells are summarized in **Figure 4B-2**. Individual values for the water budget components are listed in **Appendix 4B-1**. Water budgets have been calculated based on water years running from May 1 through April 30 of the next calendar year.

*ENRP*: The annual average inflow represented by pumped flow was approximately 86 percent, and rainfall and evapotranspiration (ET) are usually similar in quantity. However, in the most recent water year, pumped inflow was 84 percent of inflow, and the total rainfall was only 63 percent that of ET. Total annual inflow during this water year was 158.8 $hm^3$ (1 $hm^3$ = 1,000,000 $m^3$), one of the lowest 12-month totals recorded for this system, reflecting the severe drought experienced in South Florida during the past year. Outflow pumping was also lower than in any previous water year, representing only 662 percent of total outflow. Nearly a third of outflow was lost as groundwater, while ET accounted for another 16 percent of outflow. While overall error for the ENRP water budget has consistently remained at or below 5 percent, this year's error term was much larger at 18 percent, which was attributed to the impact of construction on STA-1W hydrology. The net error term for the six-year period, 3 percent, was exceptionally low for a wetland water budget.

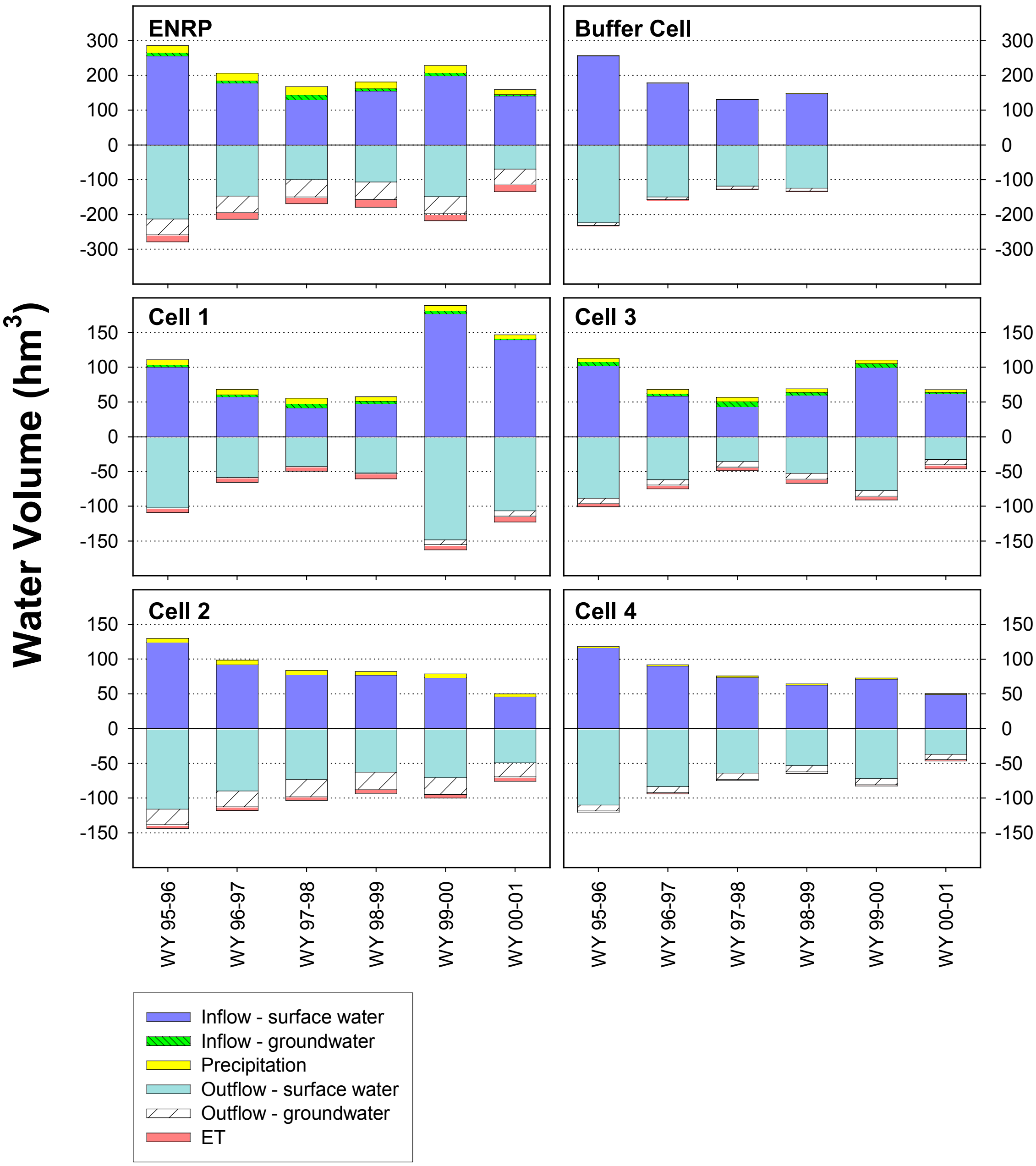


**Figure 4B-2.** Annual water budgets for the old Everglades Nutrient Removal Project calculated for the entire wetland and each treatment cell. Outflow components of each water budget are represented by negative water volumes. One $hm^3$ = 1,000,000 $m^3$.

*Cell 1*: The surface area of Cell 1 increased by 133 acres (54 ha) when it was combined with the Buffer Cell. Correspondingly, its inflow water load has approximately doubled (**Figure 4B-2**), as it now receives all inflow from G-250 and G-303, the major inflow source to the ENRP. Surface water inflow this year was less than the past year's but is still substantially greater than in prior years. Evapotranspiration was nearly double that of rainfall because of the severe regional drought. Annual water budget error terms have been much larger during the last two years (13 and 18 percent) compared to previous years (-4 to 8 percent).

*Cell 2*: Reduced inflow to Cell 2 was attributed to the regional drought (**Figure 4B-2**). Ninety-four percent of inflow was through G-255, and the remainder was from rainfall. Flow through G-254 into Cell 4 accounted for 73 percent of outflow, 5 percent from ET, and the remaining 22 percent was from groundwater seepage. The water budget for Cell 2 continues to indicate greater losses than from measured volumes. Error in the Cell 2 water budget was high, averaging -21 percent for the six-year period. In the past year, it increased to nearly 50 percent. It is possible that activities associated with construction of the new discharge canal outside the perimeter levee increased groundwater losses from the ENRP.

*Cell 3*: Variation in annual inflow and outflow to Cell 3 followed the same temporal pattern seen in Cell 1(**Figure 4B-2**). Flow through the G-253 levee accounted for 88 percent of the total inflow for the entire POR, while seepage into the cell from the L-7 levee and Water Conservation Area (WCA) 1 and rainfall both accounted for 6 percent. Outflow was higher for groundwater than inflow: 11 percent for the total period. Total water budget error was 33 percent last year, nearly double that of previous years.

*Cell 4*: Last year's inflow was slightly lower than in previous years (**Figure 4B-2**). Error in the Cell 4 water budget averaged -2 percent over the entire project, but was higher during the construction of STA-1W (14 and 9 percent).

## Phosphorus Budgets

*ENRP*: The ENRP has continued to perform well relative to P retention during the last year, even with impacts associated with STA-1W construction and the drought (**Figure 4B-3**). Individual values for the total phosphorus budget components are listed in **Appendix 4B-2**. Surface inflow TP accounted for 94 percent of the total inflow load, with dry deposition contributing the remaining TP. Most of the TP (98 percent) that left the ENRP flowed through the G-251 pump station. Annual mean TP outflow concentrations at this site have ranged between 19 and 27 µg/L (**Figure 4B-4**), while annual inflow concentrations have varied between 63 µg/L during the drought (WY00-01) to 123 µg/L during the period of heavy construction in STA-1W (WY99-00).

*Cell 1*: Cell 1 has retained 36 percent of its incoming TP load (**Figure 4B-3**) over the entire POR. Less than 5 percent of inflow TP was from sources other than surface inflow through the G-252 levee, the G-250 pump station or G-303 gates. Before the last two water years, Cell 1's annual mean outflow TP concentration ranged between 29 and 45 µg/L (**Figure 4B-4**). During the construction of STA-1W, outflow concentrations increased to 72 µg/L and remained around this concentration for the last water year, as well.

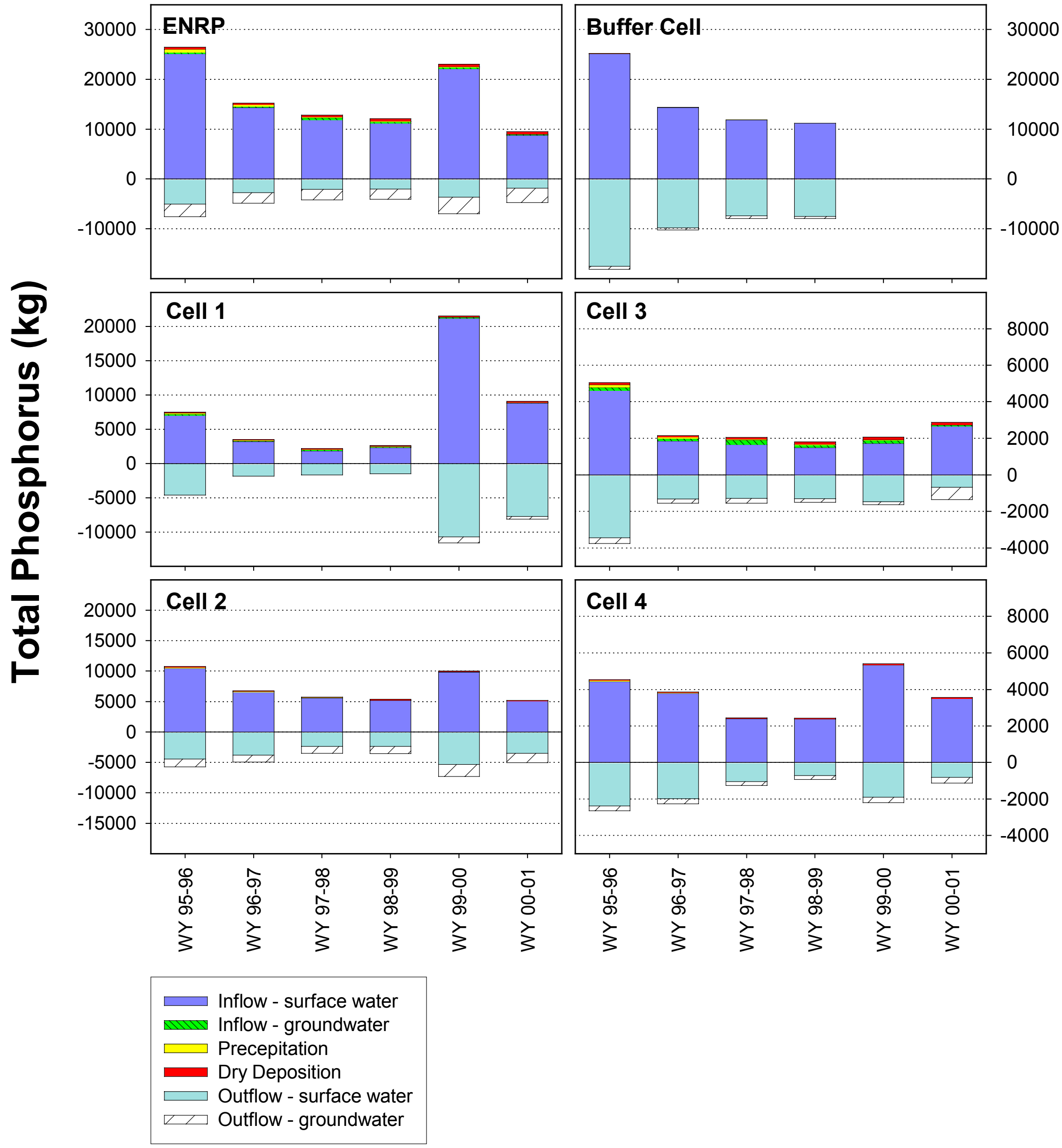


**Figure 4B-3**. Annual total phosphorus budgets for the old Everglades Nutrient Removal Project calculated for the entire wetland and each treatment cell. Outflow components of each TP budget are represented by negative values.

*Cell 2*: Cell 2 retained 32 percent of inflow TP. Nearly all the inflow TP load entered through G-255. More than a quarter of the TP leaving Cell 2 was entrained in seepage (**Figure 4B-3**). Cell 2's annual mean outflow TP concentrations increased markedly in the last two years, a pattern similar to that seen in Cell 1 (**Figure 4B-4**). This change may have been related to either STA-1W construction activities or the drought.

*Cell 3*: Cell 3 retained 30 percent of the inflow TP load (**Figure 4B-3**) over its six years of operation. A relatively greater portion of the inflow mass came from groundwater, precipitation and dry deposition (13 percent compared to the other treatment cells). Although annual TP concentrations in surface water that entered Cell 3 from Cell 1 were high in the last two years (section above), the corresponding mean outflow concentrations from Cell 3 were the lowest values (19 and 21 µg/L) observed during the POR (**Figure 4B-4**). This treatment cell obviously can absorb higher levels of TP than it had received previously.

*Cell 4*: Cell 4 has an overall TP retention rate of 53 percent for the six-year operational period (**Figure 4B-3**). Nearly all its TP input has been in surface water that entered through the G-254 levee. Although it has the smallest surface area, the area-weighted TP retention rate in Cell 4 is higher (1.3 $g/m^2$-yr) than in the other treatment cells (0.2-0.5 $g/m^2$-yr), except for the old Buffer Cell (7.6 $g/m^2$-yr). Annual mean outflow TP concentrations from Cell 4 increased slightly during the last two years to levels greater than 20 µg/L (**Figure 4B-4**). This change paralleled similar increases in mean outflow TP levels observed in Cells 1 and 2 and reversed the downward trend in TP concentrations in Cell 4 over the previous three years. In fact, mean outflow TP concentrations from Cell 4 during the past two years (27 and 22 µg/L) were slightly higher than corresponding mean TP levels exiting Cell 3.

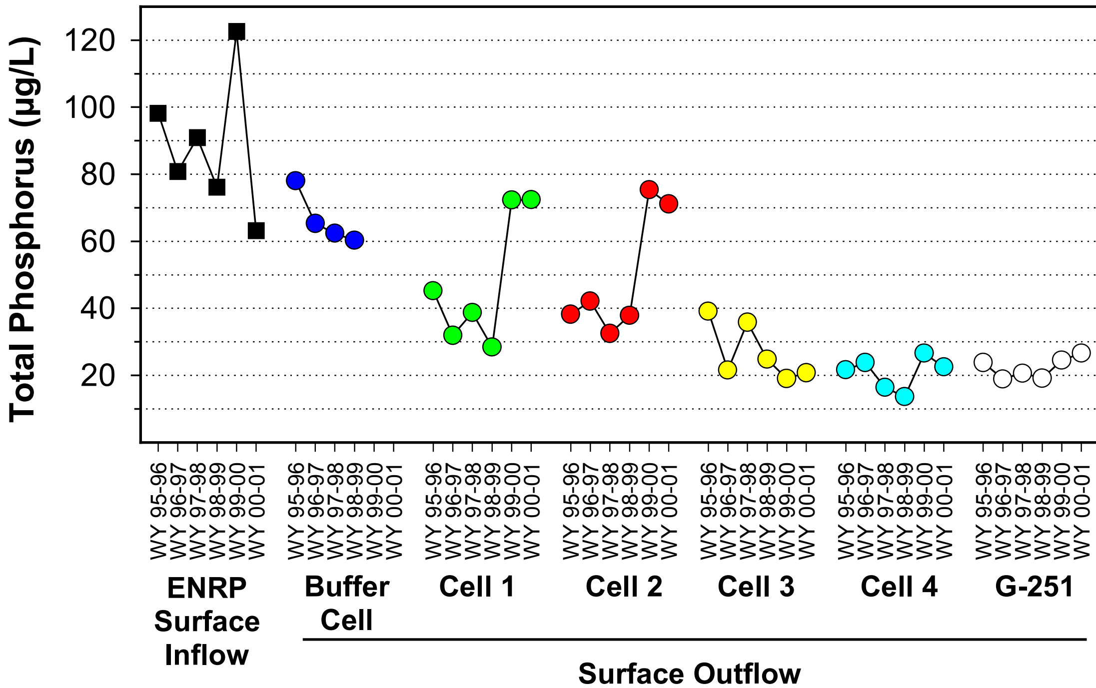


**Figure 4B-4**. Annual flow-weighted mean inflow and outflow total phosphorus concentrations in surface water for treatment cells that comprised the old Everglades Nutrient Removal Project.

# TEST CELLS

## DATA COLLECTION AND ANALYSIS

The District is conducting research in the STA-1W test cells to evaluate the impact that hydrology has on wetland performance as part of the STA Optimization Research Program. These experiments involve hydraulic manipulations that cannot be duplicated in the STAs, such as maintaining steady flows and depths for a prescribed period of time. This is because the timing and delivery of water to the STAs is a function of rainfall events and subsequent flood control discharges from the drainage basin that cannot be controlled to the degree needed for these experiments.

The test cells are small rectangular wetlands, each 0.2 ha in size, that are hydrologically isolated from each other. They are arranged into two groups of 15 cells: one group is located in Cell 1 and the other group in Cell 3 of STA-1W (**Figure 4B-1**). Ten test cells, six at the north site and four at the south site, are being used for this research. Vegetation in the test cells consists primarily of dense stands of cattail (*Typha sp.)* mixed with incidental populations of submerged aquatic vegetation and periphyton. The District elected to perform this research in cattail-dominated systems that developed on a volunteer basis, because it is anticipated that this community type will also dominate the STAs. A more complete description of the test cells and general design of the experiments being conducted in them is provided in previous ECRs (Chimney et al., 2000; Nungesser et al., 2001). The status of STA Optimization experiments scheduled for the test cells is provided in **Table 4B-1**. The treatment efficacy of wetlands dominated by SAV and periphyton is being evaluated in other District-sponsored research projects (**Chapter 4C**).

One series of experiments was designed to document the effect that changing hydraulic loading rate (HLR) has on P removal (**Table 4B-1**). All test cells used in these experiments were operated initially at a HLR of 2.6 cm/d and a depth of 0.6 m to provide baseline performance data. These starting conditions were within the range of the STA conceptual design criteria ($1.6 \leq$ HLR $\leq 3.0$ cm/d; 0.2 m $\leq$ operating depth $\leq$ 1.4 m; Burns & McDonnell, 1994) and operating guidelines currently used for the STAs. Two test cells at each location acted as controls and were maintained at the initial HLR throughout the experiments. The HLR to two north test cells and one south test cell was then decreased by 50 percent in step-wise fashion every 15 weeks, ending with an HLR of 0.3 cm/d (low-HLR experiments). Concurrently, the HLR in the remaining north and south test cells was doubled approximately every 15 weeks, ending with a maximum HLR of 18.5 cm/d (high-HLR experiments). Depth was held constant at 0.6 m in all test cells throughout these experiments. At a constant depth, HLR is inversely related to the nominal HRT, i.e., increasing the HLR decreases nominal HRT, and decreasing HLR increases nominal HRT. In order to determine actual HRTs, lithium (Li) tracer experiments were conducted in five test cells at different HLRs.

**Table 4B-1.** Schedule of experiment start dates, mean hydraulic loading rates, and nominal depths for STA Optimization research experiments conducted in the STA-1W test cells.

| Exp # | Exp Type[a] | North Test Cells | South Test Cells | HLR (cm/d) Low | Control | High | Depth (m) |
|---|---|---|---|---|---|---|---|
| 1 | H/L | May 19, 1999 | November 2, 1999 | 1.2 | 2.6 | 4.8 | 0.60 |
| 2 | H/L | September 1, 1999 | February 14, 2000 | 0.7 | 2.6 | 10.4 | 0.60 |
| 3 | H/L | February 14, 2000 | July 3, 2000[b] | 0.3 | 2.6 | 18.5 | 0.60 |
| 4 | D | October 2, 2000 | October 18, 2000 | - | 2.6 | - | 0.15 |
| 5 | P | October 2, 2000 | October 18, 2000 | - | Pulsed | - | 0.60 |
| 6 | D | April 1, 2001 | April 12, 2001 | - | 2.6 | - | 1.20 |
| 7 | P | April 1, 2001 | April 12, 2001 | | Pulsed | | 0.60 |

[a]H/L = high and low hydraulic loading rate (HLR) experiment; D = depth experiment; P = pulsed-HLR experiment.

[b]The 0.3 cm/d HLR experiment was not conducted in the south test cells. See text for details.

After the low- and high-HLR experiments were concluded, all test cells were returned to the initial HLR and depth conditions for a period of time before initiating water depth and pulsed-HLR experiments (**Table 4B-1**). Two north test cells and one south test cell were used for water depth experiments (low depth = 0.15 m; high depth = 1.2 m) and operated at a constant HLR (2.6 cm/d). The remaining test cells are assigned to the pulsed-HLR experiment. The HLR in the pulsed-HLR experiment changes weekly and will vary from 0.05 to 15.27 cm/d. The flow pattern developed for this experiment was based on a 10-year period of record for the STA-2 Basin. Both the water-depth and pulsed-HLR experiments will run for one year.

## RESULTS

The low- and high-HLR experiments have been concluded (**Table 4B-1**). These data were collected to help answer two questions central to the STA Optimization Research Program: (1) what is the impact of prolonged increases in hydraulic loading on treatment performance, such as may occur after large storm events, and (2) what are the limits to STAs' treatment performance? The high-HLR experiments directly addressed the first question, while the low-HLR experiments attempted to address the second. Results from these experiments can only be extrapolated to full-scale wetlands with the same type of vegetation, i.e., cattail-dominated communities, and are subject to the scaling artifacts discussed earlier.

Wetland treatment performance, as measured by outlet TP concentration, is inversely related with TP loading (Kadlec, 1999). Theoretically, decreasing the TP load to a given wetland should result in greater TP concentration reduction until the limit of treatment performance for that wetland (the C* or background concentration) is reached. Given a fixed inflow water volume and inflow TP mass, TP loading can be decreased by increasing wetland surface area. Ideally, an experiment intended to investigate the limits of STA treatment performance, relative to STA size, would use wetlands of various sizes that simultaneously receive the same inflow water volume and TP mass. However, the test cells were all the same size and this experiment could not be performed. The District's approach was to lower the test cell HLR to reduce TP loading. The District equated the reduction of HLR to an equivalent increase in wetland surface area. For example, assuming a uniform inflow TP concentration, decreasing the test cell HLR by one-half would result in the same reduction in TP loading as doubling wetland surface area at a fixed inflow water volume.

## Low-HLR Experiments

Decreasing HLR resulted in, at best, small improvements in TP removal. The mean outflow TP concentrations at the north control and low-HLR test cells were almost identical in the first experiment (35 versus 31 µg/L, respectively); differences between control and experimental cells in the second experiment were larger (46 versus 33 µg/L, respectively) as shown in **Figure 4B-5**. However, neither difference in TP concentration was statistically significant. In addition, there was no statistically significant improvement in outflow TP concentrations between north control and lowest-HLR experiment or in any of the experiments conducted at the south test cells. The lowest HLR (0.3 cm/d) was often equal to or less than the daily evapotranspiration rate in the ENRP (annual range approximately 0.1 to 0.7 cm/d). As a consequence, water was discharged from the test cells at this HLR only when the inflow water volume was augmented by rainfall. The District did not conduct the 0.3 cm/d HLR experiment in the south test cells because this discharge pattern was judged to be atypical of routine STA operation.

Kadlec (1999) recommends that analyses of P retention in wetlands should not be applied over time periods shorter than three nominal HRTs. This is because a parcel of water entering a wetland can be widely dispersed as it transits the system and discharged at time intervals ranging from < 1 HRT to ≥ 3 HRTs. The first and second low-HLR experiments in the north test cells ran for 102 and 110 d, respectively, at nominal HRTs of approximately 56 and 96 d, respectively. Neither experiment satisfied Kadlec's duration criteria. However, the increase in inflow TP concentration during the second experiment (**Figure 4B-5**) was almost proportionate to the decrease in HLR. As a result, TP loading during both experiments was quite similar (1.150 and 1.126 mg $P/m^2/d$). Both data sets were reevaluated as a single run of 212 d with a mean HRT ≅ 71 d. This "combined" experiment met Kadlec's criteria of three HRTs and had flow-weighted outflow TP concentrations from the control and experimental test cells of 41 and 32 µg/L, respectively. Reductions in TP loading to the experimental cells, relative to the controls, was equivalent to changes that would have resulted by enlarging wetland surface area by a factor of 2.8. The combined experiment did not reduce outflow TP concentrations beyond that observed in the STAs.

## High-HLR Experiments

The mean outflow TP concentrations at the north control and high-HLR test cells were almost identical in the first high-HLR experiment (35 versus 40 µg/L, respectively) in which HLR was increased by a factor of 1.8 (**Figure 4B-5**). The next two step increases in HLR (10.4 and 18.5 cm/d) resulted in reduced treatment performance, signified by markedly higher mean outflow TP concentrations relative to the controls, though only the difference in the last experiment was statistically significant. However, even at the highest HLR there was a measurable reduction in TP concentration from inlet to outlet. There were no statistically significant differences in mean outflow TP concentrations between control and high-HLR test cells in any of the experiments conducted at the south test cells. The HLRs in these experiments resulted in nominal HRTs of 14.0, 6.5 and 3.6 d, respectively. The duration of these experiments (15 weeks) ranged from approximately eight to 29 times the HRT, and far exceeded Kadlec's (1999) minimum time period recommendation. Nevertheless, our results remain subject to the other scaling and enclosure artifacts discussed previously.

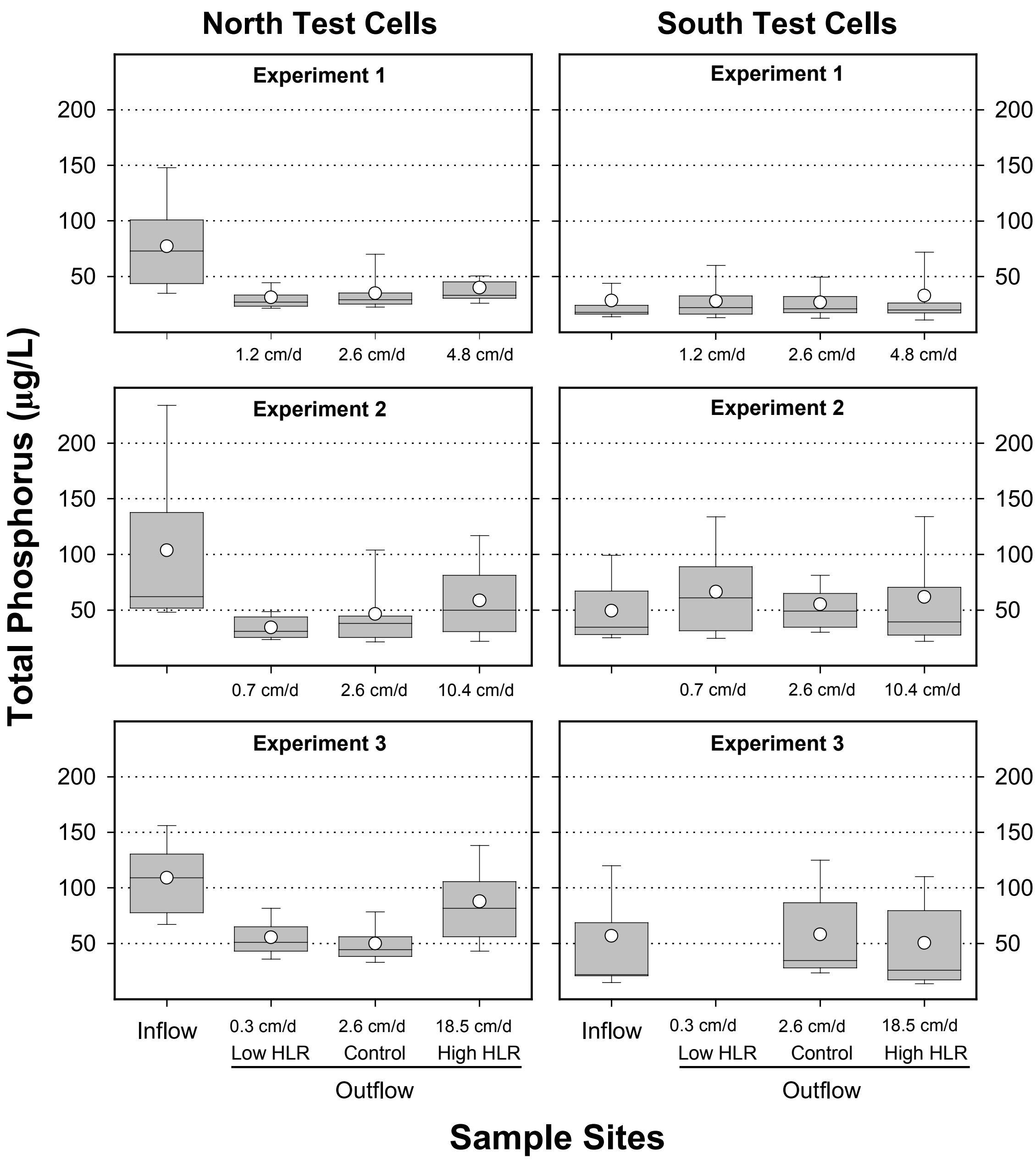


**Figure 4B-5.** Summary of weekly inflow and outflow total phosphorus concentrations for hydraulic loading rate experiments conducted in STA-1W test cells. Open circles represent mean concentrations. Top and bottom of box = 75$^{th}$ and 25$^{th}$ percentile of the data distribution, respectively; mid-line in box = 50$^{th}$ percentile; ends of whiskers = 10$^{th}$ and 90$^{th}$ percentiles, respectively. The 0.3cm/d HLR experiment was not conducted in the south test cells. See text for details.

## Hydraulic Tracer Studies

Uneven flow patterns through a treatment wetland, i.e. short-circuiting, can result in hydraulic inefficiency and might reduce the system's ability to remove nutrients and other constituents (Reed et al., 1995; Persson et al., 1999). Hydraulic tracer studies are the most effective means to quantify the degree of wetland short-circuiting. We conducted a number of tracer studies using lithium (Li) in five STA Optimization test cells between May 1, 2000 and August 22, 2000 as part of the HLR experiments (these studies were independent of other tracer tests in the test cells associated with Advanced Treatment Technology projects (**Chapter 4C**). The objective was to determine the actual HRT in the test cells during these experiments and compare this value against the nominal HRT computed from HLRs and test-cell geometry. Tracer spikes were prepared by diluting lithium chloride (LiCl) brine solution (78,457 mg/L as Li) to an approximate concentration of 350 µg Li/L. The tracer spike was added to each test cell over a period of two minutes by pouring it into the inlet distribution system. Automated samplers were deployed at the outlet of each test cell and programmed to collect 250-mL samples at varying time intervals starting with introduction of the tracer. Samples were preserved with nitric acid (pH ≤ 2). Test cell outflow rates were measured daily as described above. Grab samples collected at the G-251 outflow pump station during the course of another test cell tracer study verified that discharge from the test cells did not raise the background concentration of Li in STA-1W.

The tracer study data were interpreted following the gamma distribution method summarized by Kadlec (2001). Each hydraulic tracer study was typically run for a period three times the nominal HRT to ensure adequate recover of the Li spike. However, because relatively little of the tracer was recovered in the time allotted to each of the low-HLR experiments (15 weeks; HRTs in these experiments ranged from 46.2 to 201.5 d), results from the control and the high-HLR experiment test cells only were analyzed. All the test cells exhibited similar hydraulic properties (**Table 4B-2**) and residence time distribution (RTD) curves. When the RTD curves were plotted in a dimensionless form to allow for comparison, the curves of the four test cells were similar (**Figure 4B-6**). The number of tanks-in-series resulting from this analysis ranged from 4.4 to 7.4 tanks, indicating that the test cells can be accurately modeled as plug-flow reactors. In general, the mean HRTs based on the tracer data were larger than nominal HRTs computed using the HLR and test-cell geometry. The corresponding volumetric efficiencies (measured HRT/nominal HRT) were greater than 100 percent, indicating that the test cells were not hydraulically short-circuited.

**Table 4B-2.** Summary of lithium tracer studies performed at the STA Optimization STA-1W North (N) and South (S) Test Cell Facilities. Tracer tests began May 1, 2001.

| Parameter | N-Control | S-Control | N-High | S-High |
|---|---|---|---|---|
| Average volume ($m^3$) | 1449.3 | 1449.3 | 1449.3 | 1449.3 |
| Average flow ($m^3$/d) | 56.2 | 64.5 | 474.7 | 246.0 |
| Nominal HRT (d) | 25.8 | 22.5 | 3.0 | 5.9 |
| Mean HRT, $\tau$ (d) | 33.5 | 29.6 | 2.4 | 7.6 |
| Number of tanks (N) | 6.6 | 7.4 | 7.2 | 4.4 |
| Volumetric efficiency (%) | 130 | 132 | 80 | 129 |
| Mass recovery (%) | 49 | 68 | 93 | 84 |

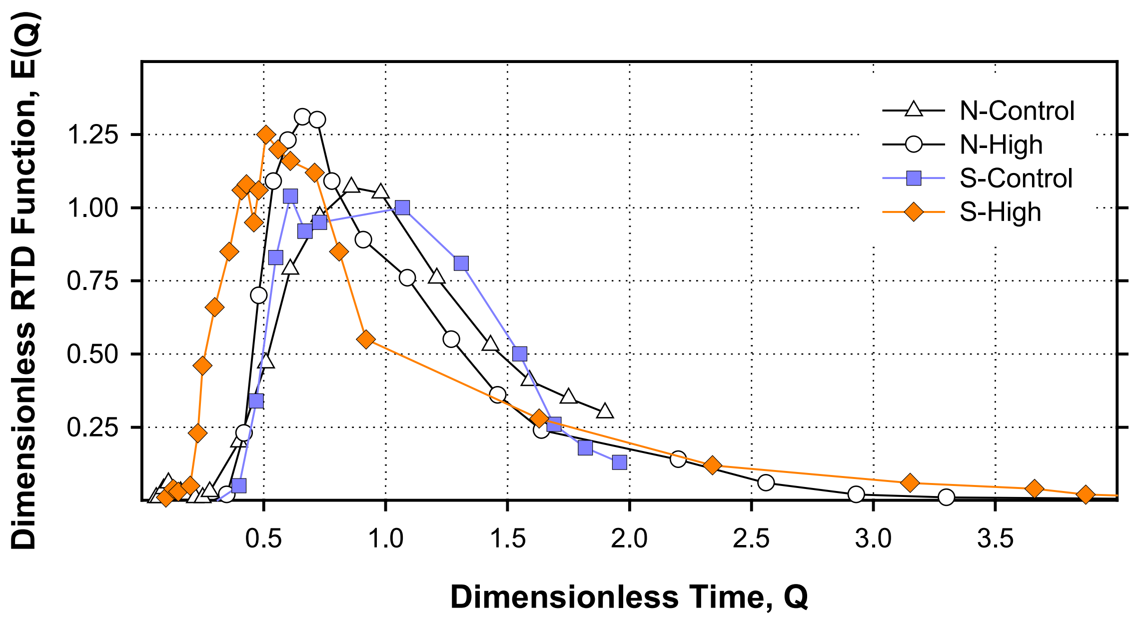


**Figure 4B-6.** Residence time distribution curves for the north and south test cells generated using the Gamma distribution method. Tracer data were collected during HLR experiments conducted from May 1 through August 22, 2000.

### Water-Depth and Pulsed-HLR Experiments

The water-depth and pulsed-HLR experiments were initiated in both the south and north test cells in October 2000 (**Table 4B-1**). Fieldwork is scheduled for completion in November 2001. Analyses and interpretation of data from these experiments will be presented in next year's ECR.

### Management Implications

Lowering the HLR in the north test cell to values less than the STA design criteria (1.6 to 3.0 cm/d) and, thereby, reducing TP loading, did not significantly improve reduction in mean outflow TP concentrations. The changes in TP loading in these experiments, including the combined experiment, were equivalent to more than doubling the surface area at a constant HLR. These results suggest that increasing surface area in cattail-dominated portions of the STAs would provide little improvement in treatment performance beyond that already realized within the existing footprints. In addition, none of the low-HLR experiments achieved a mean outflow TP concentration of <30 μg/L, a level of performance that has been exceeded by the existing STAs. Conversely, an approximate doubling of the test cell baseline HLR (2.6 to 4.8 cm/d) produced relatively little change in mean outflow TP concentrations. However, a marked increase in mean outflow TP levels occurred at a four-fold HLR increase. The high-HLR experiments identified a region of sustained hydraulic loading between 4.8 and 10.4 cm/d within which treatment performance in cattail-dominated wetlands may be expected to decline. Again, it must be emphasized that extrapolating from the HLR experiments to the STAs should be restricted to forecasting the performance of similar vegetation communities.

## FUTURE RESEARCH

Forecasts of STA performance based on this work need to be verified against actual STA performance data. Keep in mind, however, that the unifying principle behind all these experiments was to examine wetland response at the extremes of STA operating conditions. Verification will be possible only when extreme hydrologic conditions are experienced by the STAs. Comparisons between our predictions and actual STA performance will be made in future ECRs as the requisite data become available.

The District, the Department and the Department of the Interior are discussing plans for conducting follow-on experiments using all 30 test cells after the current STA Optimization and Advanced Treatment Technology experiments (**Chapter 4C**) are concluded. These proposed experiments would attempt to increase wetland treatment efficiency beyond that already documented in the STAs and test cells by using emergent macrophyte, SAV and periphyton-dominated cells in various treatment-train combinations.

Harvesting plant biomass has been suggested to the District on several occasions as one possible way to enhance STA treatment performance. The presumptive benefits include direct removal of nutrients, enhancement of plant growth rates, and avoidance of plant senescence or light/space limitation. Removing plants is generally regarded as an inefficient method of nutrient removal (Wieder et al., 1989) and is not recommended in free surface water treatment wetlands (Reed et al., 1995). The aboveground standing stock of plant biomass in emergent macrophyte-dominated wetlands typically accounts for only a small percentage (<10 percent) of P storage in the system (Vymazal, 1999, 2001), the primary P storage compartments being the below ground plant biomass and the litter layer. Kadlec and Knight (1996) cite potential changes in wetland ecological functioning as a reason that plant harvesting "should be avoided when possible." For example, harvesting the aboveground biomass of emergent macrophytes would also remove the periphyton, bacteria and fungi attached to the stems and leaves. Because the microbial community is largely responsible for removing P directly from the water column in wetlands (Reddy et al., 1999), harvesting stands of emergent macrophytes would likely reduce, not enhance, treatment performance. The District investigated whether harvesting SAV would stimulate growth and thereby enhance P removal in a mesocosm experiment (DBEL, 1999). Harvested mesocosms had reduced P retention (outflow TP concentrations almost doubled) for approximately two months immediately after plant removal compared to unharvested controls. Harvested mesocosms performed no better after their SAV standing crops recovered to pre-harvest levels than did the unharvested controls. No indication was found in this experiment that harvesting improved P removal. The recommendations and results outlined above do not necessarily preclude that periodic plant harvesting may be beneficial in maintaining consistent P retention after many years or decades of STA operation. However, it is uncertain how such long-term benefits can be demonstrated in short-term experiments.

# MARSH DRYOUT STUDY

Operational guidelines for the STAs specify keeping these wetlands hydrated at all times, with a minimum water level of 15 cm (0.5 ft). However, it was recognized that during droughts all or part of an STA might dry out. Most STAs have organic soils that, if dried and exposed to the atmosphere, will oxidize and release nutrients back to the water column upon reflooding. The magnitude of nutrient release will be influenced by factors that control soil oxidation, including composition of the organic material and climatic conditions, such as soil temperature and duration of the dryout (Reddy, 1983; Olila, et al., 1997). To better understand the potential impact of dryout on STA performance, the District initiated the Marsh Dryout Study (MDOS) in February 1999 to quantify the effects of nutrient loading, seasonality and composition of the vegetation community on P flux from dried wetland sediments upon rehydration. It is thought that the MDOS will reasonably predict what will occur in the STAs under similar hydrologic conditions.

## DATA COLLECTION AND ANALYSIS

The MDOS was conducted in mesocosms located at two sites in STA-1W (12 mesocosms at each site). One site (north) received post-BMP water with a high TP load (average = 0.89 $g/m^2$-yr), while the other site (south) received post-STA water with much lower TP levels (average = 0.22 $g/m^2$-yr). The experimental design for this study was a 2x2 factorial with vegetation type and flooding regime as treatments. Vegetation type consisted of either emergent macrophytes (*Typha* spp.) that were planted in half of the mesocosms, or a volunteer *Chara* sp./periphyton community that became established in the remaining unplanted mesocosms. Mesocosms were inundated throughout the entire study (controls) or were intermittently dried out and reflooded. The mean P content (± 1 standard deviation) of the soil used to fill these mesocosms was 229 ± 27 mg/kg. Each dryout period lasted approximately one month. Water quality was monitored at the inlet and outlet of each mesocosm. All experiments were run in triplicate at both sites. Work was initiated at the north mesocosms in March 1999 and at the south mesocosms in March 2000. The MDOS is described in greater detail in the 2001 ECR (Nungesser et al., 2001).

This report presents MDOS data collected from March 2000 through March 2001 and represents second-year results from the north site and first-year results from the south site. This period included two dryouts: April to May 2000 and September to October 2000. Results from the first-year MDOS experiments at the north site are presented in Nungesser et al., 2001. The MDOS ended in March 2001.

The MDOS mesocosms always exhibited a release of sediment P upon reflood after a dryout. This resulted in markedly higher TP concentrations for a period of time in effluent from the experimental mesocosms compared to the control tanks. Each MDOS experiment has been divided into separate time periods or "study phases" for the purpose of data analysis and evaluation. The period of time from drawdown in the experimental mesocosms to the point after rehydration, when effluent TP concentrations in these tanks returned to levels comparable to the control mesocosms, is called "reflood." The time periods between reflood phases are called "interim" phases and were characterized by equivalent TP concentrations in the effluent from both experimental and control mesocosms.

## RESULTS

Summary statistics for constituent effluent concentrations and mass for each study phase during the second year of the MDOS are presented in **Appendices 4B-3** through **4B-6** for both the north and south sites. Inflow TP concentrations in control mesocosms at the north site averaged 85 µg/L, while outflow concentrations averaged 28 and 27 µg/L for emergent and submerged mesocosms, respectively. South-site control tanks had markedly lower average inflow TP (23 µg/L) and outflow concentrations (16 and 13 µg/L for emergent and submerged mesocosms, respectively). There were statistically significant differences between inflow and outflow particulate P (PP) and soluble reactive P (SRP) concentrations in control mesocosms at both the north and south sites. However, no significant differences were detected for dissolved organic phosphorus (DOP) (**Figure 4B-7**).

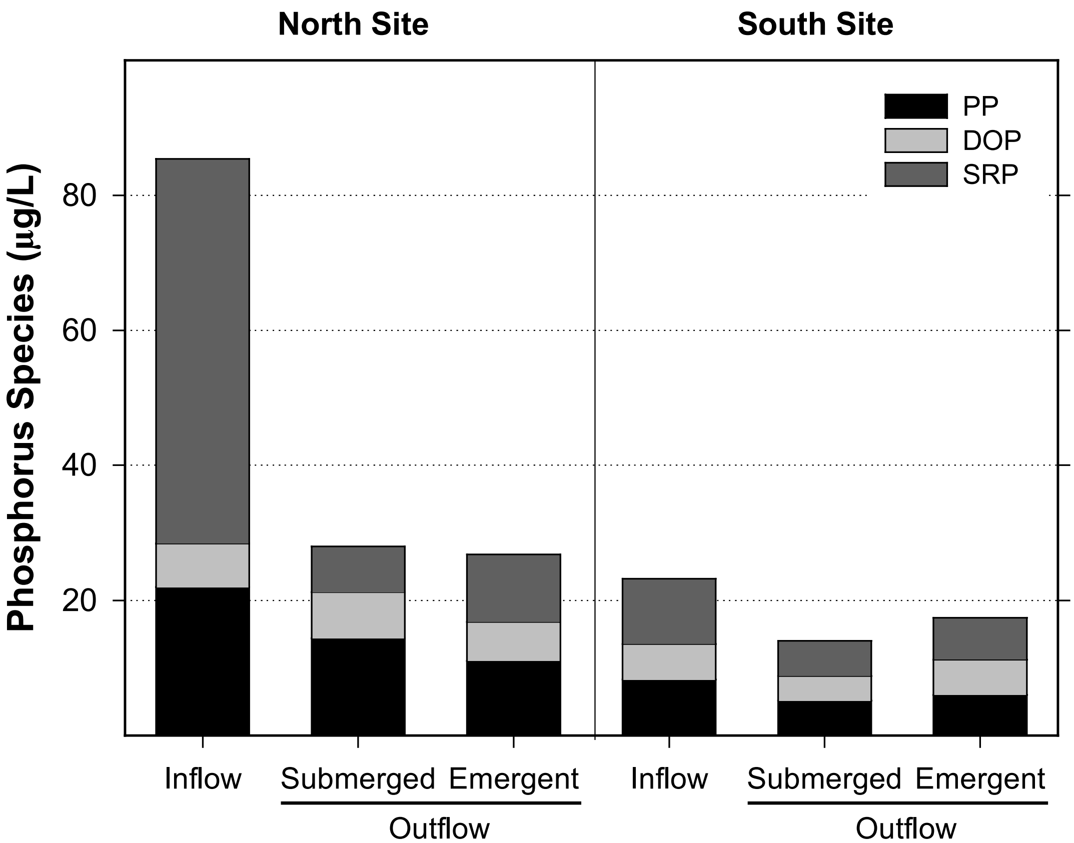


**Figure 4B-7.** Average inflow and outflow concentrations of phosphorus species in control mesocosm during experiments conducted at the North and South Marsh Dry-Out Study sites arranged by vegetation type. Phosphorus concentrations were averaged over the entire study period (North = two years; South = one year). PP = Particulate phosphorus; DOP = Dissolved organic phosphorus; SRP = Soluble reactive phosphorus (refer to Glossary of Technical Terms at the end of this Report).

Reflooding of both vegetation types at the north site resulted in a rapid three-to-four fold increase in outflow TP concentrations relative to control levels, while the south site experienced only a one-to-two fold increase after reflood. In addition, outflow TP concentrations were elevated from only five to 11 days at the south site, compared to 25 to 39 days at the north site. These differences may be related to lower P loading, and possibly higher P limitation, at the south site. It might be that under conditions of P limitation, much of the P released into the water column after rehydration is quickly reabsorbed by the vegetation, thereby decreasing the net P release. The plant community in both the *Typha* and *Chara* treatments persisted throughout the dryout experiments. Although the standing crop of *Chara* died back when dried, the community quickly reconstituted itself when rehydrated.

## North Site

Although dryouts in both the wet and dry season increased P levels in the water column after reflood, the dry-season dryout resulted in a greater average TP (108 µg/L) concentration than did that of the wet season (80 µg/L) (**Figure 4B-8**). The greater increase during the dry season is likely due to increased SRP release. Olila et al., 1997, found that oxidation of newly accreted peat material resulted in conversion of organic P into labile forms, which are readily released into the water column. During the dry season, the SRP concentrations released after reflooding were, on average, two times higher than levels measured after reflood during the wet season. The dryout treatment mesocosms released from 44 to 336 percent more TP compared to the control mesocosms during the experimental periods.

Differences in vegetation type did not have a significant effect ($t = 0.48$; $p = 0.64$) on the mean TP concentration in the water column after reflood. However, differences were detected for some P fractions. Submerged treatments exported significantly more PP after reflood ($t = -4.36$; $p = 0.001$), which was attributed to the rapid breakdown of fragile plant material (*Chara* and periphyton mat). Emergent treatments released significantly more SRP after reflood compared to submerged treatments ($t = 2.34$; $p = 0.04$). No significant differences in DOP concentrations were found between vegetation treatments ($t = -0.46$; $p = 0.65$).

## South Site

The dry-season dryout produced a slightly higher average TP concentration (31 µg/L) after reflood compared to that of the wet season (22 µg/L) (**Figure 4B-9**). Average outflow TP levels during the dry season reflood were higher than the average TP inflow concentration (28 µg/L) for that time period, while the wet season average TP levels remained below the average inflow TP concentrations (23 µg/L). Interestingly, despite the fact that the all the dryout treatment mesocosms experienced an increase in outflow TP concentration after reflooding, these tanks actually exported 8 to 43 percent less TP mass during the experimental periods compared to the control mesocosms. The amount of excess TP released upon reflooding in these tanks did not compensate for the mass of TP released by the controls during the dryout periods.

As at the north site, vegetation type did not have a significant impact on P flux after reflood. Emergent treatments experienced a slightly greater, though not statistically significant ($t = 1.238$; $p = 0.24$), increase in TP than the submergent treatments compared to controls during dryouts in both seasons. Additionally, there is no significant difference between P fractions of both treatment types.

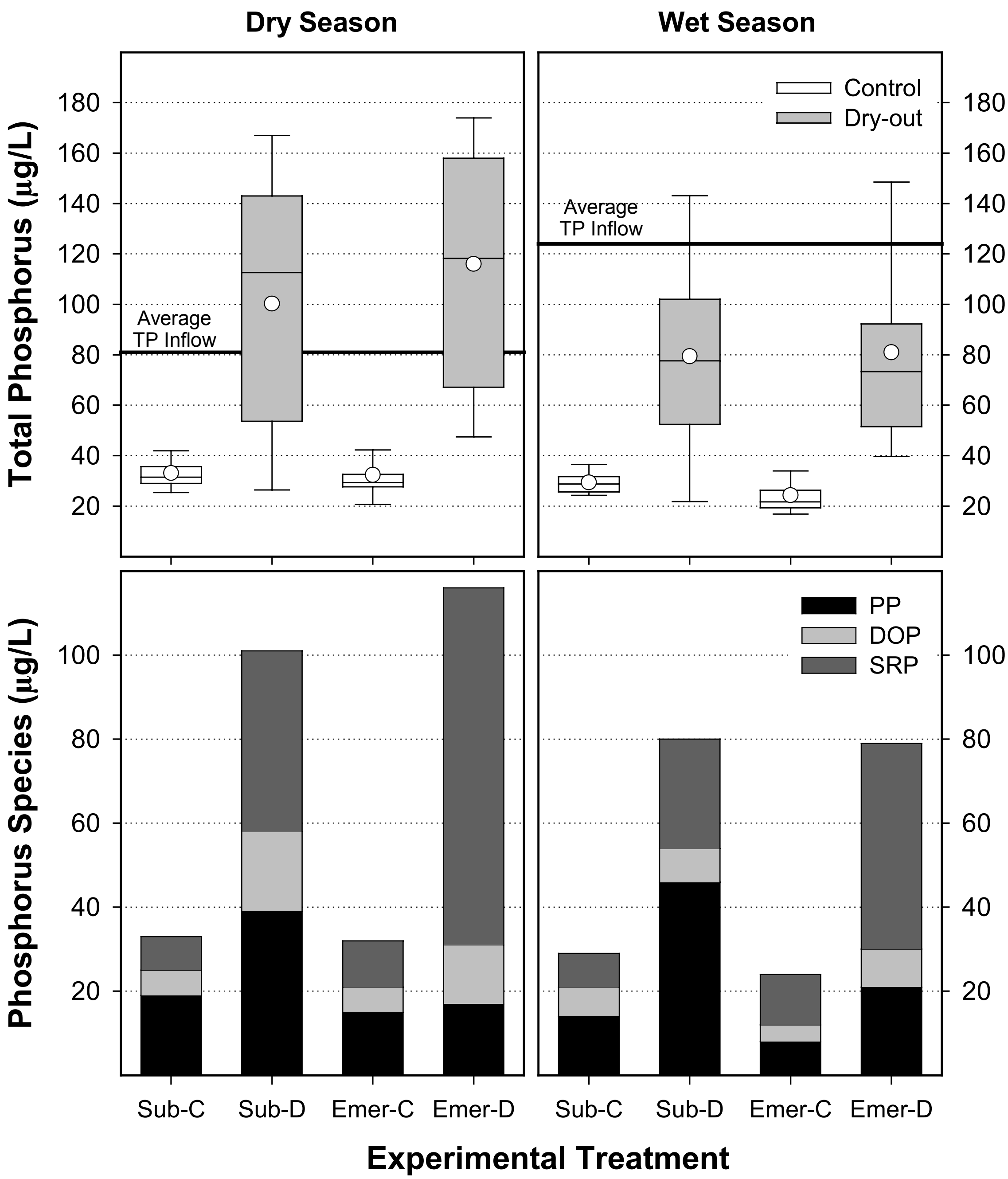


**Figure 4B-8**. Summary of phosphorus concentrations from mesocosm experiments conducted at the North Marsh Dryout Study site during the second year of the study arranged by season, flooding regime and vegetation type. Upper panels = weekly effluent TP concentrations; Lower panels = average effluent concentrations of phosphorus species. Sub = Submerged; Emer = Emergent; C = Control; D = Dryout.

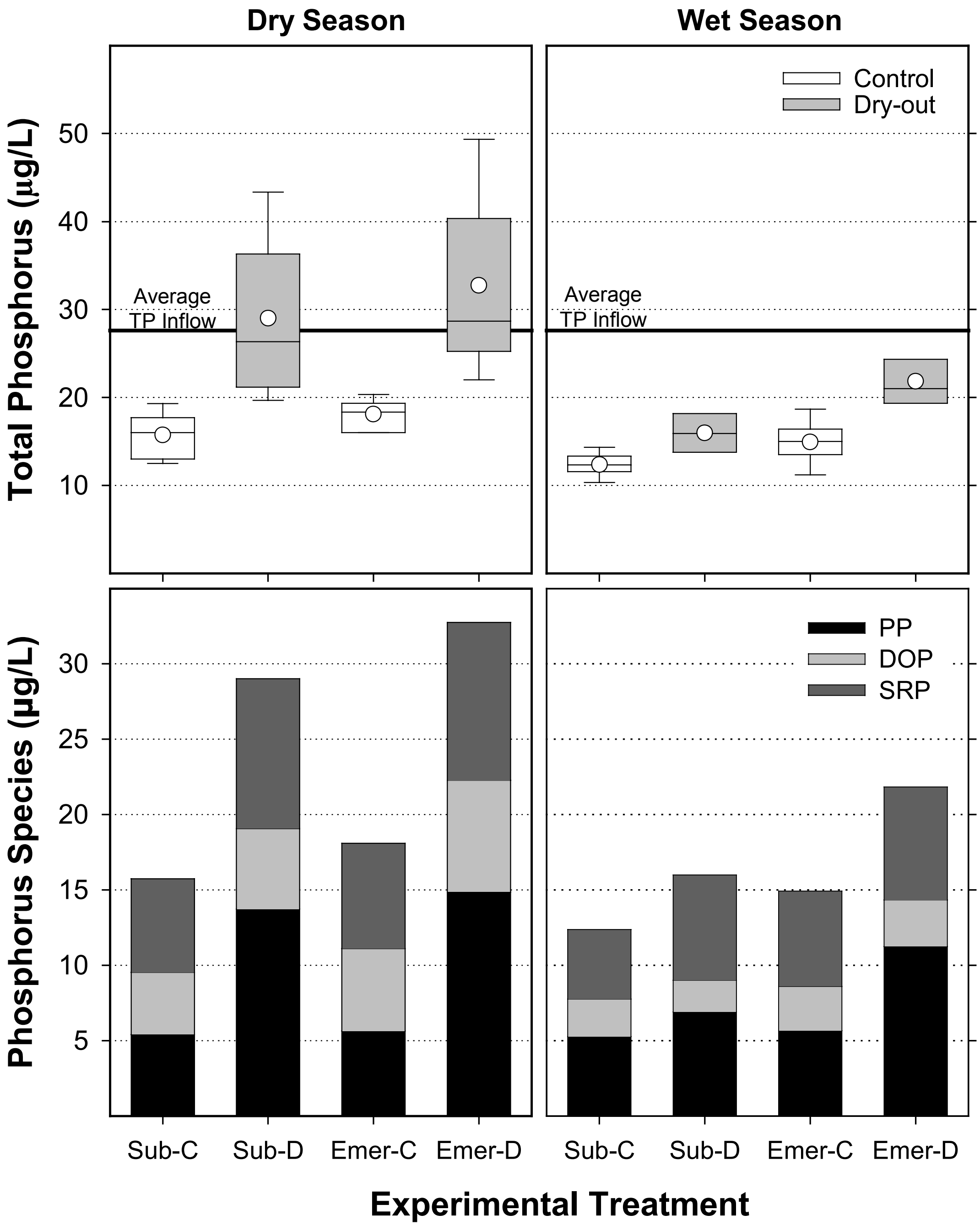


**Figure 4B-9**. Summary of phosphorus concentrations from mesocosm experiments conducted at the South Marsh Dryout Study site arranged by season, flooding regime and vegetation type. Upper panels = weekly effluent TP concentrations; Lower panels = average effluent concentrations of phosphorus species; Sub = Submerged; Emer = Emergent; C = Control; D = Dryout.

## CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Phosphorus retention by organic soils in the MDOS experiments following reflood appeared to depend on prior P loading and intensity of soil oxidation. Though both the north and south MDOS sites released P into the water column following dryout, the highest P release over the longest time interval occurred at the north site during the dry season. As nutrient loading to a system decreased (as at the south site), intensity of oxidation seemed to have diminished influence on P concentration and flux duration. Vegetation type did not significantly influence TP release after reflood, but did have an effect on some P fractions at high TP loading rates. Regardless of the prior level of P loading, most of the P released into the water column after reflood during all dryout events during this study was in the form of PP and SRP. The peak concentration and duration of P releases following reflooding of the mesocosms were wide ranging.

All the dryout treatment mesocosms at the north site experienced a substantially greater export of TP mass following reflood than the control tanks during the experimental periods. Releases of this magnitude could adversely affect the measure of long-term performance in an STA. These results suggest that dryout of the STAs should be avoided when possible.

## FUTURE RESEARCH

South Florida experienced a record drought during the past year, and several of the STAs (STA-2, STA-5 and STA-6) experienced a prolonged dryout. Routine monitoring efforts documented the intensity and duration of P release from each wetland after it was rehydrated (the STAs were reflooded after the cut-off date for including data in this report). These observations will be discussed in the 2003 ECR.

# STA-5 DRYOUT STUDY

STA-5 is located in Hendry County, east of the L-2 borrow canal and west of the Rotenberger Wildlife Management Area (**Figure 1-1**), and is divided into north and south flow-ways, each composed of two treatment cells (**Figure 4A-12**). Refer to the STA-5 Operation Plan (SFWMD, 2000b) and the 2001 ECR for a detailed description of STA-5 operations, and to **Chapter 4A** of the 2002 ECR for performance data.

From startup through January 2001, all treatment cells in STA-5, except for Cell 1B, have dried out twice in response to a severe regional drought. Temporary pumps were used to keep Cell 1B flooded to sustain its submerged aquatic vegetation community. Dryout is operationally defined to occur when the average headwater/tailwater stage in a cell is at or below average ground elevation. STA-5 first dried out in March 2000 and again in mid-May 2000. In response to these events, the District initiated a study to evaluate the potential for nutrient release from dried STA-5 soils upon reflooding.

## HISTORICAL SOIL TYPES AND VEGETATION COVERAGE

A 1946 survey determined that soils in the area of STA-5 were primarily Everglades peat (complete soil differentiation was not performed) at depths ranging from less than 36 to 96 in. (0.9 to 2.4 m) and supported a sawgrass community (**Figure 4B-10**). A subsequent soil survey of Hendry County in 1972/73 found that STA-5 had mostly muck soils (Dania, Gator, Lauderhill, Pahokee, Plantation and Terra Ceia), with smaller amounts of sandy soils (Jupiter Fine and Margate) (**Figure 4B-11**). By the time of the second soil survey, three quarters of Cell 2A and the eastern side of Cell 1A had been farmed (probably for sugar cane), while Cells 1B and 2B remained undisturbed. By the mid-1990s, all four cells had been cultivated for sugarcane, except the western-most sections of Cells 1and 2A, which were used as pastureland for grazing cattle.

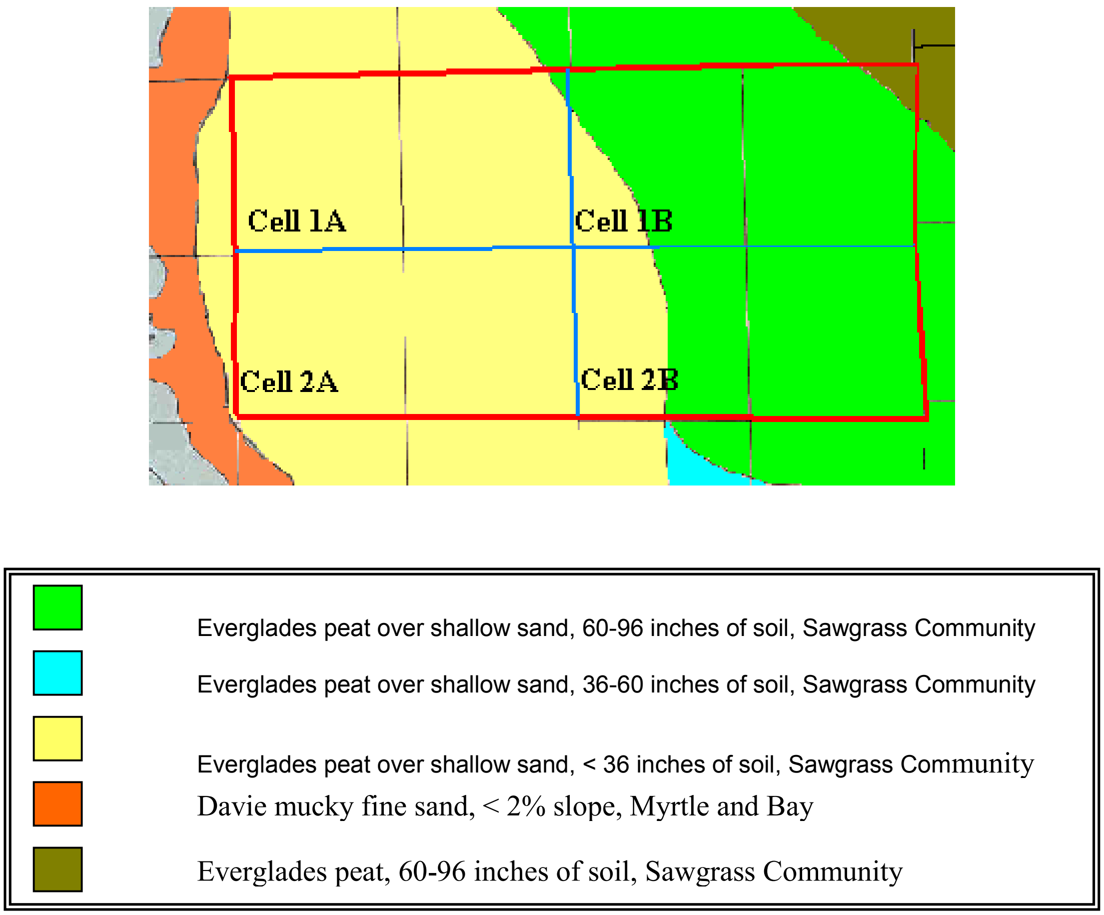


**Figure 4B-10.** Soils map of STA-5 area generated from original 1946 survey conducted by the Soil Conservation Service showing soil types, depth/slope of soil, dominant vegetation communities and the boundaries of present-day STA-5.

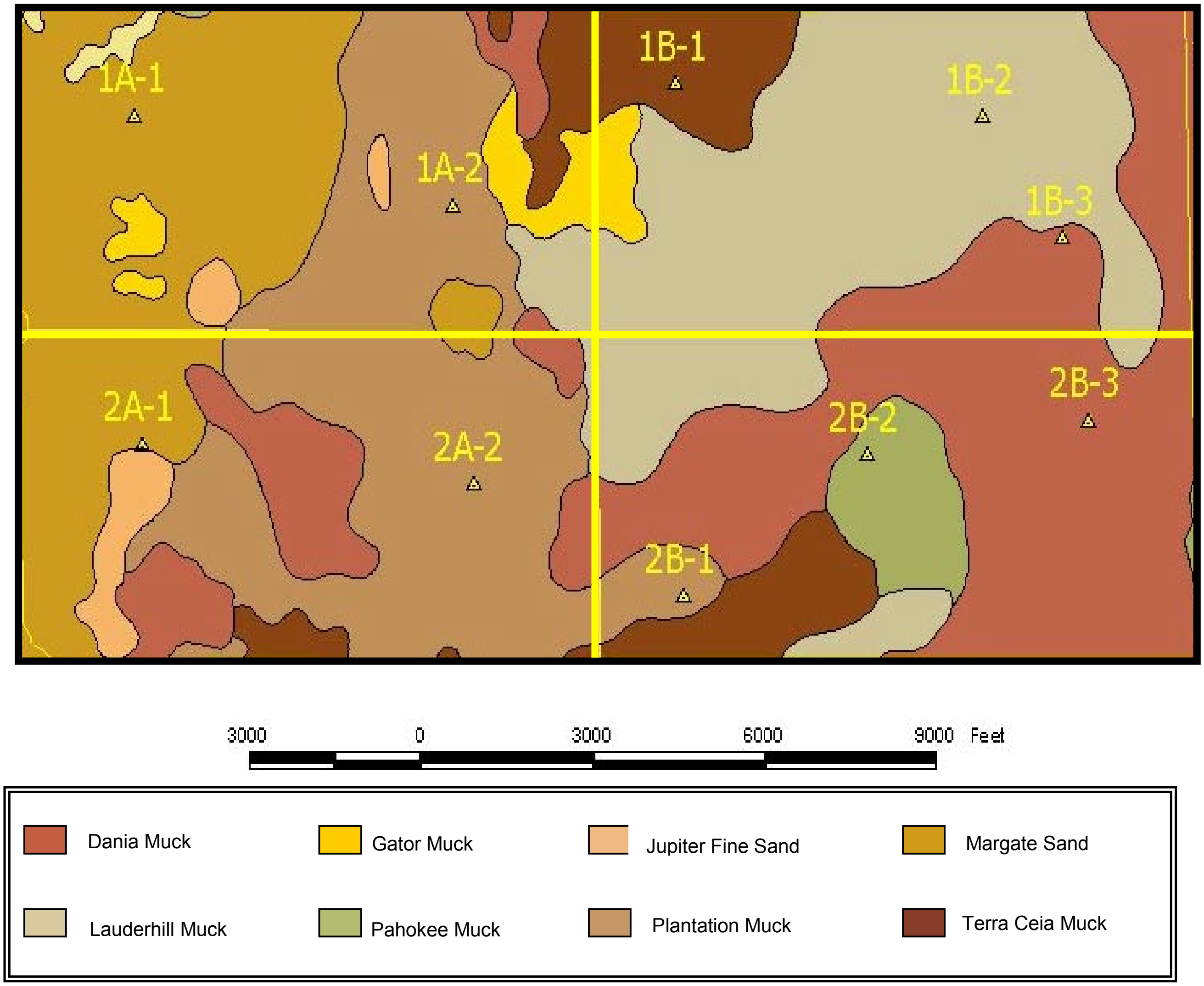


**Figure 4B-11.** Soils map of STA-5 compiled from 1972/1973 survey conducted by the U.S. Department of Agriculture Soil Conservation Service and other copperating agencies. Triangles indicate location of September 2000 soil sampling sites.

## CURRENT SOIL CONDITIONS

In September 2000, the Wetland Biogeochemistry Laboratory at the University of Florida collected 12 30-cm soil cores from 10 sites within STA-5 (**Figure 4B-11**) (triplicate cores at one site) to characterize current soil conditions. Each core was divided into 0-to-10 and 10-to-30 cm sections in the laboratory and analyzed separately for TP, total carbon (TC), total nitrogen (TN) and bulk density. The range of soil nutrient concentrations in STA-5 was comparable to that found in STA-2, but was as much as three times higher than in STA-6 (**Figure 4B-12**). Total P in the surface layer of STA-5 (0 to 10 cm) ranged from 240 mg/kg in Cell 2A to 595 mg/kg in Cell 1B, while mean TP concentrations in the 0 to10 cm and 10 to 30 cm horizons for the entire wetland were 452 and 240 mg/kg, respectively. There were no statistical differences detected in TP concentrations between flow-ways or among treatment cells for either the 0-to-10 or 10-to-30 cm horizons. Mean soil bulk density in STA-5 was moderately higher than in STA-2 and much lower than in STA-6. Both STA-5 and STA-2 have predominantly organic soils, while STA-6 contains mostly mineral soils.

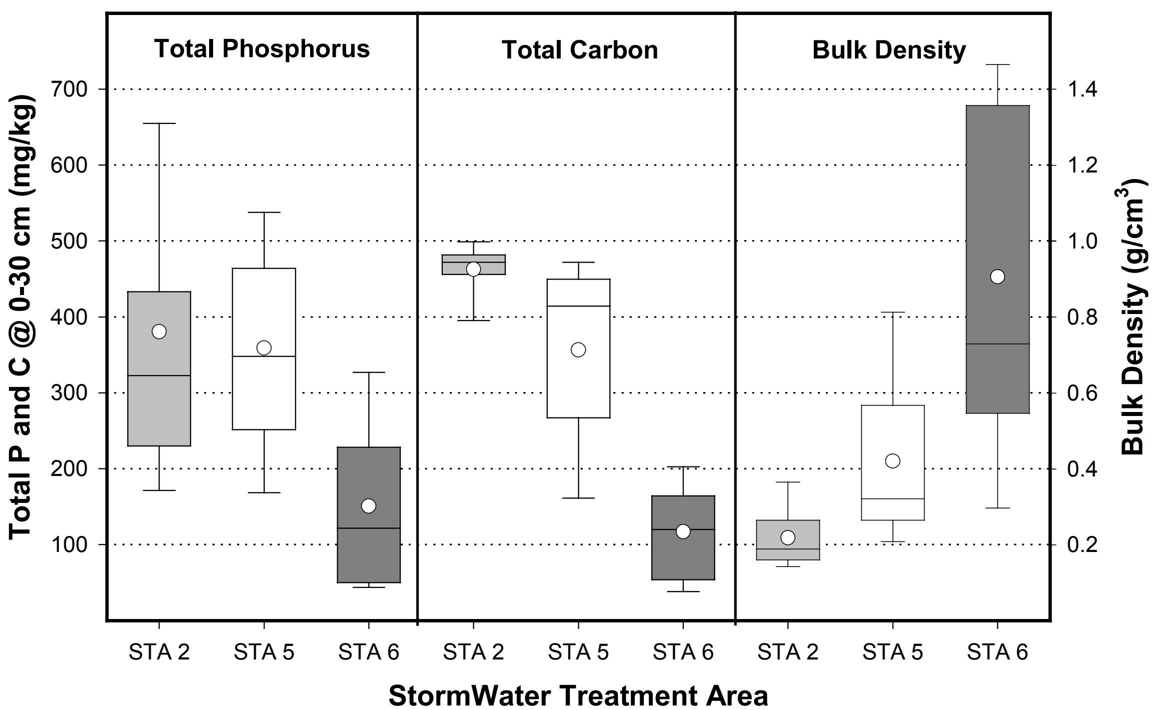


**Figure 4B-12.** Comparison of soil total phosphorous and total nitrogen concentrations and bulk densities measured in 0-30 cm soil cores collected from STA-2, 5 and 6.

## FUTURE RESEARCH

The data suggest that the muck soils in STA-5 have the potential to release a substantial amount of P into the water column following dryout, thereby reducing the overall nutrient retention of the wetland. Increases in P flux from organic soils upon reflood have been documented in the District's Marsh Dryout Study (section above) and in other regional wetlands (Reddy, 1983; Martin et al., 1996; Olila et al., 1997). The effects of dryout on nutrient retention in STA-5 will be evaluated by monitoring changes in water quality (**Table 4B-3**) at inflow and outflow culverts (**Figure 4A-12**), both before and after dryout events.

**Table 4B-3.** Water quality parameters to be monitored at the inflow and outflow culverts of STA-5 to evaluate the impact of dry-out on nutrient retention in the wetland. Grab samples (G) will be collected biweekly. Composite samples from autosamplers (A) will be collected weekly.

| Parameter[a] | Inflow Culverts | | | | Outflow Culverts | | | |
|---|---|---|---|---|---|---|---|---|
| | G342A | G342B | G342C | G342D | G344A | G344B | G344C | G344D |
| TP | A/G | A/G | A/G | A/G | A/G | A/G | A/G | A/G |
| SRP | G | G | G | G | G | G | G | G |
| TDP | G | G | G | G | G | G | G | G |
| TKN | G | G | G | G | G | G | G | G |
| $NH_4$ | G | G | G | G | G | G | G | G |
| $NO_x$ | G | G | G | G | G | G | G | G |
| Cl | G | G | G | G | G | G | G | G |

a

Total phosphorus (TP); soluble reactive phosphorus (SRP); total dissolved phosphorus (TDP); total Kjeldahl nitrogen (TKN); ammonia-nitrogen ($NH_4$); nitrate+nitrite-nitrogen ($NO_x$); chloride (Cl)

# PERFORMANCE EVALUATION OF STA-6, SECTION 1

STA-6, Section 1 (hereafter referred to as STA-6), encompasses 870 acres (352 ha) and is located in the southwestern corner of the Everglades Agricultural Area (EAA) adjacent to the Rotenberger Wildlife Management Area (**Figure 1-1**). Inflow into STA-6 is via a pump station (G-600) with five 100-cfs pumps (**Figure 4A-18**). This pump station is owned by U.S. Sugar Corporation and is operated based on irrigation needs of the upstream basin (a 10,400-acre area owned by U.S. Sugar Corporation). STA-6 is divided into two treatment cells by an interior levee. Cell 3 (245 acres) receives approximately 28 percent of the inflow through a single weir (G-603). Cell 5 (625 acres) receives the remaining inflow through two weirs (G-601and G-602). Both treatment cells have three outflow culverts. For a detailed description of the layout and operation of STA-6, refer to the STA-6 Operation Plan (SFWMD, 1997). Current performance data are presented in **Chapter 4A** of the 2002 ECR.

Since STA-6 began flow-through operations in 1998, outflow TP concentrations have averaged about 25 µg/L, well below the design target of 50 µg/L, despite the fact that the hydraulic load to this wetland has been about three times greater than anticipated. As a result, the mean hydraulic retention time for each treatment cell (Cell 3 = 4.2 days; Cell 5 = 8.8 days) is substantially less than those calculated for STA-1W, which range from 17 to 25 days. In addition to high hydraulic loadings, STA-6 has experienced dryout periods ranging from two to three months each year since it began operation.

## HISTORICAL OPERATIONS, SOIL TYPES AND VEGETATION COVERAGE

Before its conversion to an STA, the STA-6 area was used by the U.S. Sugar Corporation as a stormwater detention area from 1989 to 1997. The system had one inflow point (G-600), and water moved in sheet-flow fashion southward from Cell 5 into Cell 3 through culverts located in the interior levee. In 1997, as part of the Everglades Construction Project, the perimeter levees were heightened and the culverts in the interior levee were closed, thereby creating two separate, parallel flow-ways. The direction of flow is now from west to east, rather than the historical north to south.

The soils in STA-6 are classified as mucks and sands (**Figure 4B-13**). Sediment cores were collected from the interior of the wetland in 1998 and 2000 and analyzed for soil nutrients (including P fractionation), anion/cations, organic content and bulk density (Reddy and Clark, 1998; White and Reddy, 2001). Soil characteristics were variable (**Table 4B-4**), which reflected differences between the upland and hydric soils found throughout the site. All soil types had low P content; mean TP (218 mg/kg), bicarbonate extractable P (7 mg/kg) and HCl extractable P (31 mg/kg) were relatively low, as were potentially mobile P levels of inorganic P (1.3 mg/kg) and TP (3.2 mg/kg). Potentially mobile P accounted for only a small fraction of TP (0.8 percent for Dpi, 2.2 percent for total dissolved P [TDP]). Soil organic matter varied from 4 to 63 percent, and bulk density ranged from 0.18 to 0.81 g/cm$^3$. Mean extractable Ca (11,464 mg/kg) was much higher than extractable Mg (247 mg/kg), Fe (47 mg/kg) and Al (29 mg/kg). However, relative to other soils in the region, STA-6 soils have low Ca levels.

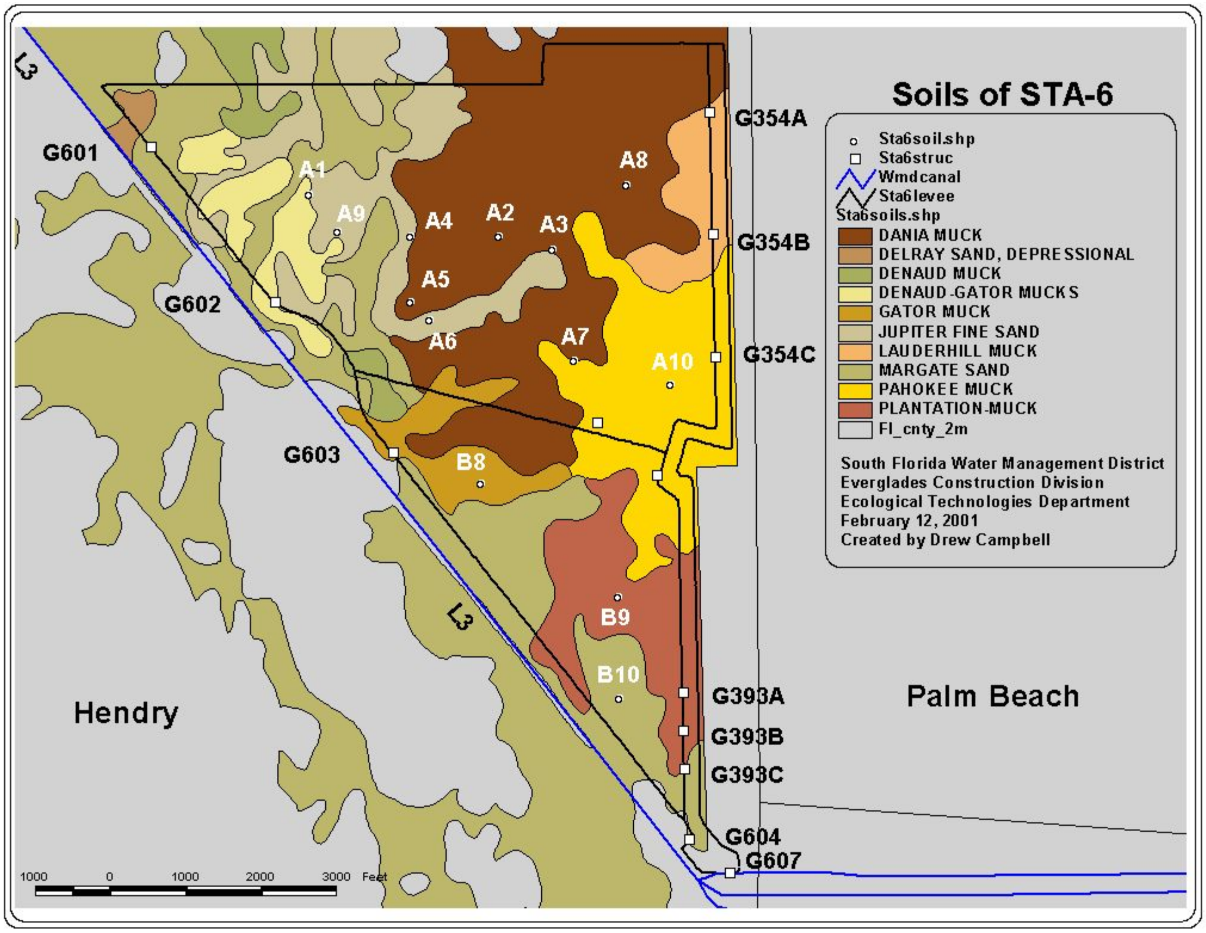


**Figure 4B-13**. Soils map of STA-6 compiled from data collected by USGS showing the location of the District's sediment core sites.

**Table 4B-4.** Summary statistics for parameters measured in soil cores collected from STA-6 in 1998 and 2000.

| Parameter | Date[a] | Cell | Core Section (cm) | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|---|---|
| **Total phosphorus** (g/kg) | 02/98 | Cell 3 | 0-15 | 175 | 158.7 | 76 | 358 |
| | 02/98 | Cell 5 | 0-15 | 215 | 118.1 | 126 | 513 |
| | 10/00 | Cell 5 | 0-10 | 236 | 108.3 | 103 | 435 |
| | 10/00 | Cell 5 | 10-30 | 65 | 34.0 | 35 | 136 |
| **Bulk density** ($g/cm^3$) | 02/98 | Cell 3 | 0-15 | 0.39 | 0.182 | 0.18 | 0.50 |
| | 02/98 | Cell 5 | 0-15 | 0.54 | 0.197 | 0.20 | 0.81 |
| | 10/00 | Cell 5 | 0-10 | 0.52 | 0.181 | 0.26 | 0.78 |
| | 10/00 | Cell 5 | 10-30 | 1.29 | 0.296 | 0.68 | 1.79 |
| **% Ash** | 02/98 | Cell 3 | 0-15 | 33 | 25.6 | 17 | 63 |
| | 02/98 | Cell 5 | 0-15 | 17 | 13.4 | 6 | 51 |
| | 10/00 | Cell 5 | 0-10 | 22 | 10.9 | 9 | 43 |
| | 10/00 | Cell 5 | 10-30 | 7 | 5.3 | 4 | 20 |
| **Total Nitrogen** (g/kg | 10/00 | Cell 5 | 0-10 | 13 | 3.4 | 9 | 20 |
| | 10/00 | Cell 5 | 10-30 | 5 | 2.8 | 3 | 12 |
| **Total Carbon** (g/kg) | 10/00 | Cell 5 | 0-10 | 169 | 48.0 | 116 | 274 |
| | 10/00 | Cell 5 | 10-30 | 65 | 42.8 | 43 | 35 |

[a]Sediment cores were not collected from STA-6 Cell 3 in 2000 due to low water levels and dense vegetation that prevented entry into the cell.

The data suggest that STA-6 soils are stable and should not readily release P into the water column. They may, in fact, act as a nutrient sink. These findings were supported by soil column experiments, where P levels in the overlying water decreased rapidly, indicating removal by the sediments (Reddy and Clark, 1999). No important changes in TP, bulk density or ash content in the upper layer of sediment from treatment Cell 5 were detected between 1998 and 2000 (**Table 4B-4**). Soil cores collected from STA-6, Cell 5 in October 2000 were compared to cores collected at the same time from STA-2 and STA-5 (**Table 4B-5**). STA-6 sediment had markedly lower TP, TN, TC and organic content and higher sediment bulk density than the other STAs. These differences are indicative of the more highly mineralized soil in STA-6.

**Table 4B-5.** Summary statistics for parameters measured in soil cores collected from STA-2, STA-5 and STA-6 in October 2000.

| Parameter | STA | Cell[a] | Core Section (cm) | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|---|---|
| **Total phosphorus** (g/kg) | STA-2 | | 0-10 | 387.1 | 167.6 | 115.2 | 657.0 |
| | STA-2 | | 10-30 | 290.5 | 146.5 | 157.7 | 652.7 |
| | STA-5 | | 0-10 | 461.6 | 95.8 | 239.8 | 595.2 |
| | STA-5 | | 10-30 | 256.3 | 90 | 114.5 | 379.7 |
| | STA-6 | Cell 5 | 0-10 | 236 | 108.3 | 103 | 435 |
| | STA-6 | Cell 5 | 10-30 | 65 | 34.0 | 35 | 136 |
| **Bulk density** ($g/cm^3$) | STA-2 | | 0-10 | 0.21 | 0.07 | 0.12 | 0.39 |
| | STA-2 | | 10-30 | 0.22 | 0.09 | 0.14 | 0.38 |
| | STA-5 | | 0-10 | 0.3 | 0.1 | 0.14 | 0.6 |
| | STA-5 | | 10-30 | 0.5 | 0.3 | 0.22 | 0.92 |
| | STA-6 | Cell 5 | 0-10 | 0.52 | 0.18 | 0.26 | 0.78 |
| | STA-6 | Cell 5 | 10-30 | 1.29 | 0.30 | 0.68 | 1.79 |
| **% Ash** | STA-2 | | 0-10 | 85.5 | 2.7 | 78.3 | 89.0 |
| | STA-2 | | 10-30 | 83.3 | 6.6 | 71.0 | 89.5 |
| | STA-5 | | 0-10 | 71 | 21.2 | 27.3 | 86.7 |
| | STA-5 | | 10-30 | 54 | 29.4 | 11.5 | 86.3 |
| | STA-6 | Cell 5 | 0-10 | 22 | 10.9 | 9 | 43 |
| | STA-6 | Cell 5 | 10-30 | 7 | 5.3 | 4 | 20 |
| **Total Nitrogen** (g/kg) | STA-2 | | 0-10 | 28.3 | 2.8 | 24.3 | 35.3 |
| | STA-2 | | 10-30 | 26.3 | 3.4 | 20.6 | 31.3 |
| | STA-5 | | 0-10 | 27 | 7.5 | 11.9 | 33.4 |
| | STA-5 | | 10-30 | 20.9 | 8.5 | 5.8 | 29.8 |
| | STA-6 | Cell 5 | 0-10 | 13 | 3.4 | 9 | 20 |
| | STA-6 | Cell 5 | 10-30 | 5 | 2.8 | 3 | 12 |
| **Total Carbon** (g/kg) | STA-2 | | 0-10 | 467.2 | 16.9 | 425.3 | 493.7 |
| | STA-2 | | 10-30 | 458.4 | 49.6 | 367.0 | 514.2 |
| | STA-5 | | 0-10 | 391.2 | 105.9 | 167.4 | 481.9 |
| | STA-5 | | 10-30 | 322 | 138.8 | 75.6 | 476.8 |
| | STA-6 | Cell 5 | 0-10 | 169 | 48 | 116 | 274 |
| | STA-6 | Cell 5 | 10-30 | 65 | 42.8 | 43 | 35 |

[a]Sediment cores were not collected from STA-6 Cell 3 in October 2000 due to low water levels and dense vegetation that prevented entry into the cell.

The vegetation communities in STA-6 (**Table 4B-6**) are different from cattail-dominated communities seen in STA-1W. A 1998 survey of STA-6 found that 62 percent of vegetation in Cell 5 was composed of grasses (*Panicum* spp.), while Cell 3 was dominated by sawgrass (45 percent) and a mixture of lowland shrubs (21 percent).

**Table 4B-6.** Composition of the vegetation community in treatment Cells 3 and 5 of STA-6 based on aerial survey data collected August 1998.

| Vegetation Coverage Type | Cell 3 Acres | Cell 5 Acres | Cell 3 % | Cell 5 % |
|---|---|---|---|---|
| Misc. grasses | 4.06 | 387.37 | 1.68 | 62.36 |
| Open water/submerged algae | 7.79 | 90.36 | 3.23 | 14.55 |
| Sawgrass | 109.72 | 7.87 | 45.42 | 1.27 |
| Shrub mix | 51.83 | 2.36 | 21.45 | 0.38 |
| Willow | 15.97 | 12.19 | 6.61 | 1.96 |
| Cattail | 4.55 | 27.56 | 1.88 | 4.44 |
| Floating aquatics | 0.79 | 0.76 | 0.33 | 0.12 |
| Pickerelweed | 0.40 | 2.47 | 0.17 | 0.40 |
| *Sagittaria lancifolia* | 28.48 | 0.00 | 11.78 | 0.00 |
| Misc. mix 1 | 18.02 | 11.57 | 7.46 | 1.86 |
| Misc. mix 2 | 0.00 | 78.55 | 0.00 | 12.65 |
| *TOTALS* | 241.61 | 621.06 | 100.00 | 100.00 |

## FUTURE RESEARCH

Routine water quality monitoring has revealed that STA-6 exports P upon rehydration after a dryout. Future research will focus on reevaluating these data, with emphasis quantifying the mass of P released, the duration of P flux and wetland P removal efficiency during periods of dryout and reflood. In addition to routine weekly flow-proportioned composite samples and biweekly grab samples currently being collected at the pump station (G-600) and outflow weirs (G-354C and G-393B), the District will monitor inflow and outflow P levels at three-day intervals for four to eight weeks after rehydration. To determine if TP concentrations measured at G-600 are representative of levels that enter each treatment cell, autosamplers have been placed at one inflow weir to each cell (G-602 and G-603). The District also plans to monitor the vegetation communities through tissue analysis and density measurements, decomposition rates using cotton strips, and porewater analysis using soil equilibrators.

# STA MODELING EFFORTS

A new water quality model, the Dynamic Model for Stormwater Treatment Areas (DMSTA), is being developed by Drs. William W. Walker and Robert Kadlec under contract to the U.S. Department of the Interior. This model will be used to enhance our understanding of how the STAs function, evaluate alternative long-term water quality strategies for the EPA as part of the Basin Specific Feasibly Studies and improve the management and design of the next generation of STAs that are part of the Comprehensive Everglades Restoration Plan (**Chapter 7**). The District has provided data from the STA Optimization and ATT research programs for model development and calibration.

The size of the STAs was determined using a steady-state design model that employed long-term averages as input for its forcing functions. The DMSTA differs in that it provides a means for simulating the dynamic (time-varying) response of treatment wetlands to changes in environmental and operating conditions, including:

- Variations in flow, load, rain and evapotranspiration
- Effects of various internal structural configurations
- Hydraulic efficiencies
- Impact of cell-aspect ratios, specifically length to width
- Different water depths
- Varying outflow rates
- Different biological communities in the wetlands
- Dryout of the wetlands
- Effect of bypass on STA performance
- Collection and management of seepage.

The base code for the model has been written and is currently being calibrated using a variety of experimental and field-scale wetland data provided by the District and the Department. We anticipate that the current version of the model will be available for distribution by Spring 2002. The development team plans to further refine the model so it simulates the dynamics of STA performance in greater detail, including the addition of feedback loops, a more realistic representation of vegetation dynamics, effects on downstream marsh water quality and soil P concentrations. The model-development team also plans to include sensitivity analyses, uncertainty analyses and new or improved linkages with other compartment models.