CHAPTER 6: STORMWATER TREATMENT AREAS – STATUS OF RESEARCH AND MONITORING TO OPTIMIZE EFFECTIVENESS OF NUTRIENT REMOVAL AND ANNUAL REPORT ON OPERATIONAL COMPLIANCE

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SUMMARY

The biotic integrity of the Everglades is endangered from a variety of impacts, including nutrient enrichment of the surface water. Everglades periphyton and plant communities are known to be sensitive to phosphorus (P) availability. Reducing the amount of total phosphorus (TP) being delivered to the Everglades in agricultural runoff is central to the District's restoration program, which includes building a system of large treatment wetlands referred to as Stormwater Treatment Areas (STAs). The Everglades Forever Act requires the District to initiate a research and monitoring program to optimize the nutrient removal performance of the STAs. The STA Optimization Research and Monitoring Program described in this section of the Everglades Consolidated Report will provide the information necessary to fulfill this mandate. This research program consists of: (1) practical experience gained from operating the Everglades Nutrient Removal (ENR) Project and analyzing ENR Project performance data; (2) experiments conducted in the ENR Project test cells; (3) analysis of data from other wetlands; and (4) simulation of nutrient removal efficiency under different operating scenarios using a wetland nutrient fate and transport model, the Wetland Water Quality Model, being developed by the District.

The ENR Project was a 1,545 hectare (ha) treatment wetland built by the District on former agricultural land and served as a prototype STA. The project operated independently from August 1994 through April 1999 and has been incorporated into the footprint of STA-1W.

The ENR Project is almost completely vegetated with either emergent, floating or submerged aquatic plants. Cattail is the dominant emergent species and has the greatest coverage, but large areas throughout the project are also colonized by a variety of other plant species. The vegetation that exists today is more species diverse than was envisioned in early conceptual plans and has proven to be dynamic, i.e., the relative abundance of vegetative cover is still changing and some Treatment Cells have actually lost a portion of their cattail coverage. However, changes in the vegetation of the Project have not had an observable impact on the nutrient removal efficiency of the wetland. The time for emergent vegetation to completely fill the test cells varied from 26 to 13 months for the north and south banks of cells, respectively. These data suggest that grow-in rates for the different STAs may be quite variable.

Water budgets were calculated for the entire ENR Project and each individual cell. The combined volume of water from the Inflow and Seepage Return Pumps accounted for 82.7 percent of the total inflow water budget to the ENR Project over the period of record; rainfall and seepage from Water Conservation Area 1 accounted for the remainder of inflow to the system. Average depths in the ENR Project varied from approximately 0.2

to 0.9 meters (m); the western flow-way (Treatment Cells 2 and 4) was consistently 10 to 30 centimeters (cm) deeper than the other cells. Nominal hydraulic retention times for the entire project ranged from 11.5 to 32.3 days with a median value of 21 days. Forty percent of pumped inflow passed through the eastern flow-way, while the remaining 60 percent of flow moved down the western flow-way.

The ENR Project achieved its performance objectives based on an evaluation of 57 months of operational data (August 1994 through April 1999). All 12-month, rolling, flow-weighted TP concentrations at the project outflow were well below the mandated 50 µg/L (= 50 ppb) (cumulative outflow TP concentration = 21 µg/L). All 12-month rolling, TP load reduction estimates (inflow versus outflow) were greater than the 75 percent goal (cumulative total P load reduction = 83 percent). Since the start of operations, the ENR Project has removed 70.7 metric tons of P from Everglades Agricultural Area runoff that otherwise would have been pumped into Water Conservation Area 1 and had a cumulative TP settling rate of 18.4 m/year. Based on these results, from early in the lifespan of the wetland, the STA design settling rate of 10.2 m/year appears to have been a reasonable, possibly conservative estimate. Concentrations of soluble reactive P (SRP), particulate P (PP) and dissolved organic P (DOP) were reduced with varying degrees of efficiency as water moved through the ENR Project; almost all SRP was removed as was some PP, but little or no effect was observed for DOP. Difference in TP removal between the eastern and western flow-ways can be explained, to some extent, by the fact that the western flow-way was loaded more heavily than the other cells but also by real differences in treatment performance. Differences in treatment performance may be related to subtle differences in the species composition or physiological efficiency of the vegetation community in each flow-way or possibly, by the volume of deep groundwater seepage that entered the eastern flow-way from WCA-1.

Results from the ENR Project have validated the premise that treatment wetlands (i.e., STAs) constructed on former agricultural land can effectively remove TP from Everglades Agricultural Area runoff and achieve the interim outflow concentration limit of 50 µg/L specified in the Act. However, due to design limitations, the ENR Project could not be operated in a pulsed-flow mode that fully mimics the magnitude of flows that will occur in the STAs during storm events. Evaluation of treatment efficacy under storm-driven operating conditions will come from test cell research, modeling efforts and operation of the STAs themselves.

On an individual cell basis, Treatment Cell 4 achieved the best treatment performance. These results suggest that SAV/periphyton, the dominant plant community in this cell, was more efficient at removing TP than either the mixed marsh or cattail dominated communities found in the rest of the ENR Project.

The median sediment deposition rate for the entire ENR Project by 1998 was 5.6 mm/year. The upper 5 cm layer of sediment in Treatment Cell 1 has become P enriched; 82 percent of this material in this layer was organic. These data support the contention that the primary P removal mechanism in the ENR Project and the STAs is the deposition and burial of P-rich organic materials in the sediments

Phosphorus uptake rates by periphyton and coontail in short-term experiments increased as P spike concentration was increased. At all spike concentrations, the median uptake rate was always higher with increased irradiance. The uptake rates measured in these experiments more than likely represent luxury uptake and would not be expected to be sustainable over long periods of time. However, these results do illustrate the capacity of one component of the plant community to sequester P on a short-term basis.

Plant tissue decomposition rates differed substantially among species in long-term experiments.

Water lettuce and submerged aquatic vegetation (SAV)/periphyton decomposed quite rapidly, while cattail leaves were the most resistant to decay. Water hyacinth decomposed at an intermediate rate. SAV/periphyton, water hyacinth and water lettuce all lost a substantial amount of tissue P within the first week of incubation. Conversely, cattail lost relatively little of its tissue P content over the same time period.

A study has been initiated to characterize the potential for nutrient release after dryout and reflooding of wetland sediments. This information will enable District managers to better assess the potential impact of dryout on STA performance.

Research is being conducted in the ENR Project test cells to examine how hydrologic conditions (hydraulic residence time and depth) may influence STA performance. Modifications to the test cells needed to conduct these experiments were completed in 1998 and the cells were characterized through preliminary water quality sampling. The first experiments have been initiated.

Data from other wetlands (e.g., the Water Conservation Areas, Iron Bridge and Boney Marsh) have provided the District with insight into the long-term treatment performance that might be expected from subtropical wetlands and were used to help establish design criteria for the ENR Project and STAs.

The Wetland Water Quality Model recently has undergone preliminary calibration tests using data from Water Conservation Area 2A and the ENR Project. While results from the calibration runs for the hydrodynamic submodel have been very encouraging, an evaluation of the water quality submodel output indicated that further developmental work is needed before the full model can accurately simulate all the biological and chemical processes that remove nutrients in wetlands. Additional calibrations are underway.

With few exceptions, effluent from the ENR Project throughout the period of record has been in compliance with Class III water quality standards. However, dissolved oxygen concentrations at the project inflow, outflow and the Water Conservation Area 1 reference site were frequently below the 5 mg/L standard. This pattern is typical of conditions found in productive Everglades marsh habitats.

STA-6, Section 1 is the first component of the District's Everglades Construction Project to be completed. Operation of this facility began in December 1997. STA-6, Section 1 is in compliance with the Stabilization Period criteria established in the operating permit. All monthly mean TP concentrations at the outflow during the first 17 months of operation were below the 50 µg/L interim goal established for the project. Outflow water quality for all other parameters was consistently better than at the inflow. There are no operational data to report at this time for the other STAs.

BACKGROUND AND ISSUES

EVERGLADES IMPACTS AND STORMWATER TREATMENT AREAS

The biotic integrity of the Everglades is endangered from impacts to the system such as urban and agricultural development, disruption of the natural hydroperiod resulting from regional flood-control efforts and the introduction of nutrient-rich agricultural and urban runoff and Lake Okeechobee water releases. A discussion of these impacts and resulting changes in the Everglades ecosystem can be found in the 1999 Everglades Interim Report (see McCormick, et al., 1999; Redfield, et al., 1999; and Sklar, et al., 1999). Everglades periphyton and plant communities are known to be extremely sensitive to phosphorus (P) availability. It is generally accepted by most scientists that excess P is the

nutrient most responsible for the negative ecological impacts occurring in the Everglades. Reducing the amount of total P (TP) being delivered to this system is central to the South Florida Water Management District's (District) Everglades restoration program, which includes building a series of large treatment wetlands referred to as Stormwater Treatment Areas (STAs) (**Figure 6-1**). The Everglades Forever Act (Act) requires the District to initiate a research and monitoring program to provide the information necessary to optimize nutrient removal performance by these treatment systems, specifically the removal of TP. Regional environmental issues and Act requirements pertaining to the STAs are treated more fully in **Chapter 1** of this Report.

DESIGN BASIS FOR THE STORMWATER TREATMENT AREAS

In the late 1980s, the District began to develop a plan for using "flow ways" (i.e., treatment wetlands) to reduce nutrient levels in runoff coming from the Everglades Agricultural Area (EAA; **Figure 6-1**) before this water entered the Everglades (SFWMD 1988, 1989a and b). This concept had its roots in observations of P removal by constructed and natural wetlands in south and central Florida (e.g., Iron Bridge, Orlando Eastern Service Area, Boney Marsh [CH2M Hill, 1991; Kadlec and Newman, 1992; Moustafa et al., 1995], Lake Apopka [Reddy et al. 1982a and b] and the Water Conservation Areas [Walker, 1995]). The research and development program initiated to assess the efficacy of using wetlands built on former agricultural soil to treat EAA runoff became known as the Everglades Nutrient Removal (ENR) Project. Initial design recommendations for this project considered active plant management (e.g., controlled burning, crop harvesting or disking plant biomass back into the soil) as essential to sustaining long-term nutrient removal. However, for a number of practical considerations, this concept was abandoned in favor of allowing the project to be colonized by native plant species (e.g., cattail) that sequestered P through rapid accretion of plant biomass into the peat. This accretion was coupled with a prolonged hydroperiod to minimize sediment drying and subsequent oxidative remobilization of stored nutrients. The nutrient concentration in effluent discharged from peat-based wetlands represents an equilibrium condition between nutrient uptake and removal mechanisms and the flux rate of material out of the sediment into the water column. Other early design goals and considerations for the STAs included a target outflow P concentration of approximately 30 µg/L, 3 feet of freeboard on all perimeter levees, a minimum hydraulic residence time of 5 days and a maximum sustained depth of 3 feet. The rationale and assumptions used to select and apply the STA design model are covered in Kadlec and Newman (1992), Walker (1995) and various STA design documents (e.g., Burns & McDonnell, 1992a, 1993). The history of events leading up to the decision to construct the ENR Project and the basis of design for the ENR Project and the STAs are more fully summarized in SFWMD (1988, 1989a and b, 1991), CH2M Hill (1991) and the references contained therein.

STORMWATER TREATMENT AREA OPTIMIZATION RESEARCH PROGRAM

The STA Optimization Research and Monitoring Program described herein is mandated by the Act and will assist the District to develop an operational strategy that maximizes performance of the STAs independent of other technologies. Information is being compiled from four distinct research efforts:

- Practical experience gained from operating the ENR Project and analysis of ENR Project performance data;
- Experiments conducted in the ENR Project test cells;
- Analysis of data from other treatment wetlands, especially those located in South and Central Florida; and
- Simulation of nutrient removal under different operating scenarios using a wetland nutrient

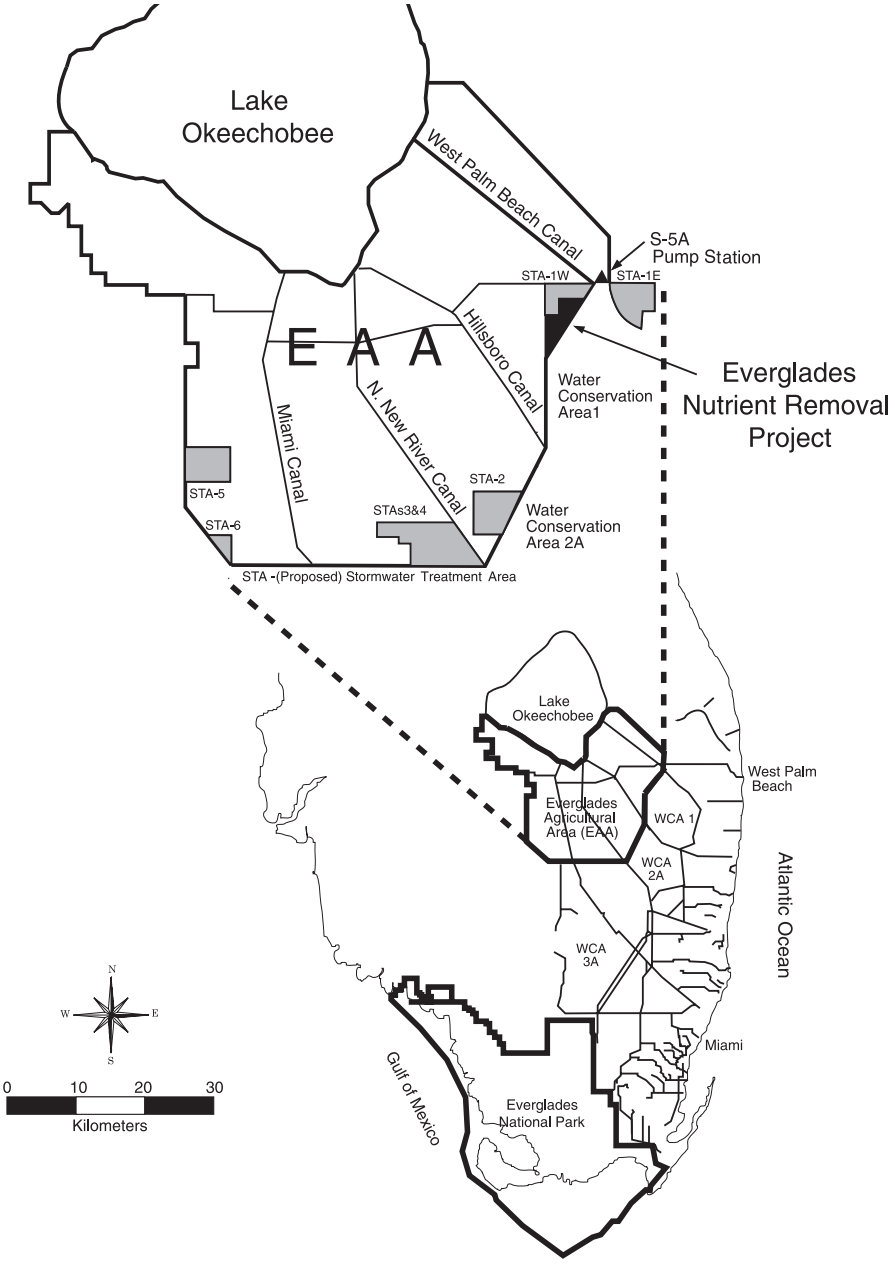

Figure 6-1. Location of the Everglades Nutrient Removal Project in relation to the Everglades Agricultural Area and the Stormwater Treatment Areas in South Florida.

fate and transport model, the Wetland Water Quality Model, currently being developed by the District.

An annotated list of the research and monitoring activities conducted by the District to support this research program is provided in the 1999 Everglades Interim Report (see Table 6-2 in Chimney and Moustafa, 1999). Sampling locations associated with these efforts are identified in **Figure 6-2**.

CHAPTER OBJECTIVES

The objectives of this chapter in the Everglades Consolidated Report (Report) are to (a) summarize key findings from on-going research and monitoring efforts relative to P removal performance and/or compliance with water Class III quality standards; and (b) provide a report on the operational performance of the STAs. This chapter is organized around these efforts, as was the chapter on STA Optimization Research in the 1999 Everglades Interim Report (Chimney and Moustafa, 1999). In large measure, much of the information that follows is cumulative in nature and represents an update of our ongoing research and monitoring activities. The District has adopted an annual reporting period or "water year" which runs from May 1 through April 30 of the following calendar year for this and all future Reports. Note that this differs from the August 1 through July 31 "operational year" used in Chimney and Moustafa (1999). The period of record for ENR Project operations covered in this Report extends from August 1994 through April 1999, which encompasses 57 months or 4.75 years.

EVERGLADES NUTRIENT REMOVAL PROJECT – A PROTOTYPE STA

SITE DESCRIPTION

The ENR Project was a 1,545 hectare (ha) (3,819 acres) treatment wetland built by the District on land previously farmed for sugar cane, corn and rice. The project site is located 25 kilometers (15.5 miles) west of the city of West Palm Beach in Palm Beach County, FL, bordering the northwestern corner of Water Conservation Area 1 (WCA-1) (26^{o} 38' N and 80^{o} 25' W). The ENR Project served as a prototype STA and has been incorporated into the footprint of STA-1West (STA-1W; **Figures 6-1** and **6-2**). With the issuance of the STA-1W NPDES [#FL0177962-001] and Everglades Forever Act [#503074709] operating permits in May 1999, and completion of key water control structures shortly thereafter, the ENR Project ceased to exist as a separate entity from both a regulatory and operations perspective. The operational and reporting requirements of FDEP operating permit #502232569 for the ENR Project have been superceded by these new permits.

The ENR Project was built in two phases: Phase I was completed in July 1989 with flooding of the first 384 hectares (ha) (950 acres). Phase II included building containment levees, pump stations and other major structural elements from June 1991 through September 1993. Delays associated with obtaining discharge permits prevented the District from initiating flow-through operations until August 1994. Additional site information for the ENR Project can be found in Goforth, et al., (1994), Guardo, et al., (1995) and Chimney and Moustafa (1999).

The ENR Project is operated as a once-through treatment system and has the capacity to process up to 60 percent of the annual runoff that would otherwise be pumped directly into WCA-1 via the S-5A pump station (Chimney and Moustafa, 1999). It was anticipated that the project would be operated with a range of water depths between 30 and 91 centimeters (cm) and a hydraulic retention time (HRT) of at least 10 to 13 days (Burns & McDonnell, 1989; CH2M Hill, 1991; SFWMD, 1991).

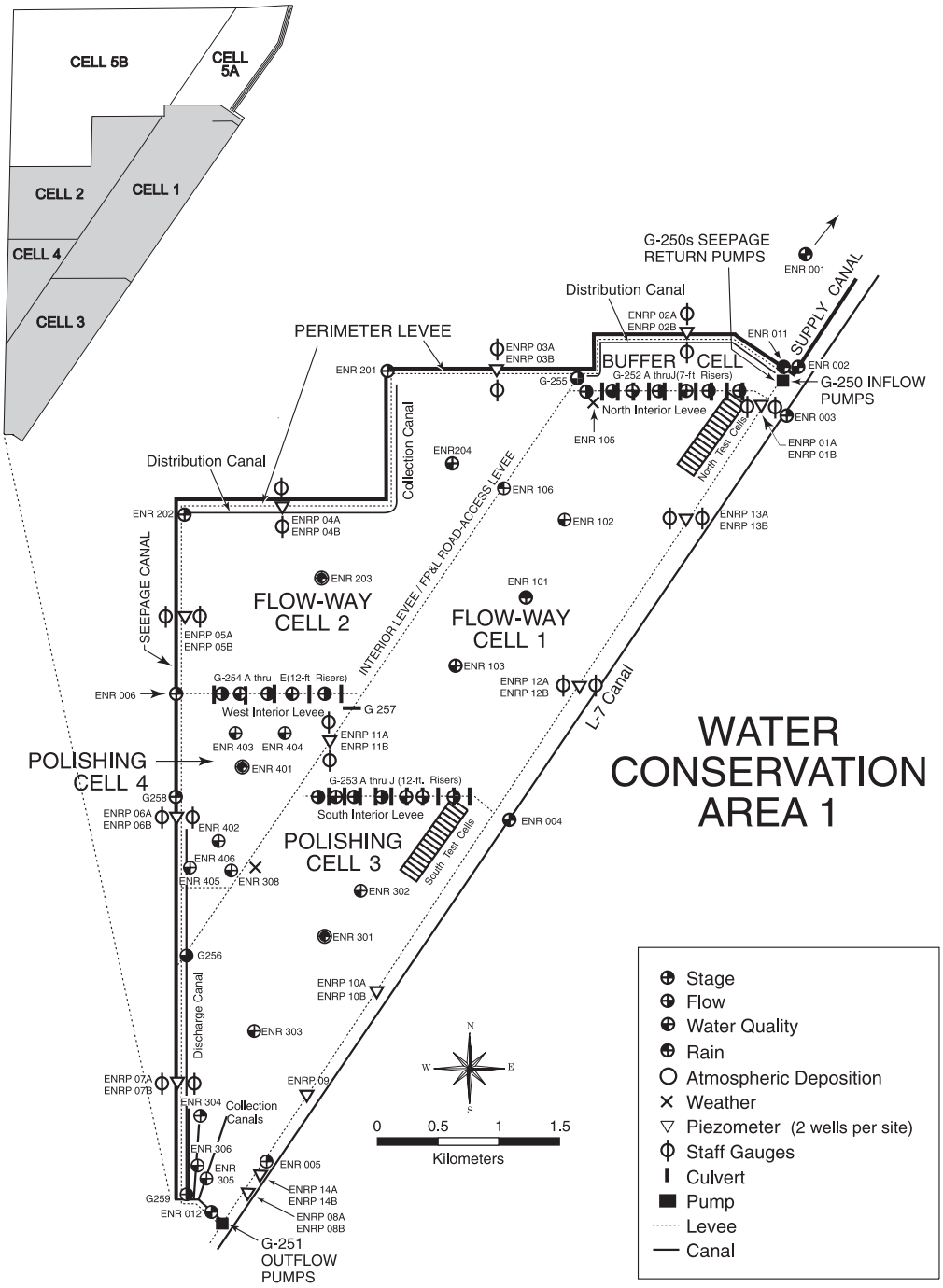

Figure 6-2. Site plan for the Everglades Nutrient Removal Project showing the location of stage, flow and water quality monitoring sites. Insert shows the boundaries of the Everglades Nutrient Removal Project within the footprint of STA 1-West.

The primary source of inflow water to the ENR Project is the S-5A basin (595.7 square kilometers), which drains the northeastern portion of the EAA (**Figure 6-1**). Water is delivered to the ENR Project's Inflow Pump Station (G250) via a supply canal that is connected to the West Palm Beach Canal. Water is pumped through the Inflow Pump Station, which has six axial-flow electric pumps with a combined capacity of 17 m^3/sec (600 cfs), into the Buffer Cell (54 ha). From the Buffer Cell, water is distributed via gravity flow to two parallel treatment trains separated by an interior levee (**Figure 6-2**). The eastern flow-way is comprised of Treatment Cells 1 (527 ha) and 3 (404 ha). The western flow-way is comprised of Treatment Cells 2 (413 ha) and 4 (147 ha). Flow moves from Treatment Cell 1 to 3 and from Treatment Cell 2 to 4 through culverts in separating levees. Effluent from Treatment Cell 4 is discharged into a canal, which is separated from Treatment Cell 3 by a levee. The western flow-way (560 ha) is 40 percent smaller than the eastern flow-way (931 ha). Treatment Cells 1 and 3 have an aspect ratio (length to width) of approximately 3:1, while the aspect ratio of Treatment Cells 2 and 4 is about 2:1. The Buffer Cell provides hydraulic dampening of inflow water velocities, allows for independent water delivery to each treatment train, and promotes initial treatment of inflow water (e.g., removal of much of the suspended particulate load from the inflow water). It was anticipated during design that 67 percent of the water pumped into the Buffer Cell would enter the eastern flow-way via ten 72-inch culverts in the G252 levee, while the remaining 33 percent of the flow would enter the western flow-way via five 72-inch culverts at the G255 structure. A distribution canal was built along the north side of the Buffer Cell to assist in conveying water from the Inflow Pump Station to G255. Treatment Cells 1 and 2 were intended to remove the majority of the nutrient load entering the ENR Project (the Buffer Cell also acts in this capacity), while Treatment Cells 3 and 4 would achieve final polishing of the water to reduce nutrient concentrations to target levels. Water is discharged from the ENR Project into WCA-1 at the Outflow Pump Station (G251), which uses six axial-flow electric pumps with a combined capacity of 12.7 m^3/sec (450 cfs) to pump the discharge over the L-7 levee. A perimeter canal collects groundwater seepage along the western and northern boundaries of the ENR Project and returns it to Seepage Return Pumps (three axial-flow electric pumps with a combined capacity of 5.7 m^3/sec [200 cfs]) located in separate bays at the Inflow Pump Station, where the seepage is pumped back into the Buffer Cell.

Treatment Cells 1 and 2 and the Buffer Cell have been allowed to revegetate naturally. The dominant emergent macrophyte in each cell is cattail (*Typha domingensis* Pers. and *T. latifolia* L.). The plant community in Treatment Cell 3 is a mixture of naturally recruited cattail and areas (131 ha) that were planted with wetland species common to south Florida and is referred to in this Report as a "mixed-marsh" plant community. Species that were planted included arrowhead (*Sagittaria latifolia* Willd. and *S. lancifolia* L.), spikerush (*Eleocharis interstincta* [Vahl] Roemer & Schultes), maidencane (*Panicum hemitomon* Schultes), pickerelweed (*Pontederia cordata* L.) and sawgrass (*Cladium jamaicense* Crantz). Treatment Cell 4 has been actively maintained as a submerged aquatic vegetation (SAV)/periphyton community dominated by coontail (*Ceratophyllum demersum* L.) and southern naiad (*Najas quadalupensis* [Spreng.] Magnus), with lesser quantities of pondweed (*Potamogeton* sp.), through periodic and selective use of herbicides to remove emergent and floating macrophytes. Areas in Treatment Cells 1, 2 and 3 that were not initially colonized by emergent species during project construction now support dense stands of SAV (principally *C. demersum* and *N. quadalupensis* with lesser quantities of hydrilla, *Hydrilla verticillata* [L.f.] Royle, and the macroalga *Chara* sp.). Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) and water lettuce (*Pistia stratiotes* L.) were first observed in northern areas of the project during construction (S. Newman, SFWMD, pers. obs.) and are becoming an increasingly important component of the plant community (SFWMD, 1995a, 1996, 1997, 1998a, 1999).

As summarized in Chimney and Moustafa (1999), the original ENR Project performance goal, removal of 25 mt P/yr, was predicated on the amount of land available (1,497 ha) and an expected TP removal rate of 1.67 g P/m^2/yr. Subsequent performance expectations for the Project focused more on achieving an effluent concentration of 50 µg/L (note that P concentration units expressed as µg/L are equivalent to parts per billion [ppb]) rather than removing a specific mass of TP. Assuming the same inflow TP concentrations and hydraulic loading rates, slightly lower TP removal rates than the original estimate would be required to meet the outflow concentration target, i.e., only 1.30 to 1.42 g P/m^2/yr (Chimney and Moustafa, 1999). The primary performance objective for the ENR Project mandated by the FDEP operating permit was to reduce the amount of TP discharged from the Outflow Pump station into WCA-1 up to 75 percent relative to the inflow TP load. A secondary performance objective, also mandated by the FDEP operating permit, was to discharge water with an annual, flow-weighted TP concentration no greater than 50 µg/L (see the Glossary in **Chapter 1** for a definition of flow-weighted concentration). The new operating permits require that effluent from STA-1W continues to meet an annual, flow-weighted TP concentration limit of 50 µg/L.

VEGETATION COVERAGE

Data collection and analysis

A vegetation monitoring program has been conducted in the ENR Project pursuant to requirements of Florida Department of Environmental Protection (FDEP) operating permit for this facility. (Note: the new STA-1W National Pollution Discharge Elimination System (NPDES) and Everglades Forever Act permits do not require continuance of this monitoring program). The intent of this monitoring program was to document both spatial and temporal changes that occurred in the plant community within the treatment cells. Aerial photographs of the entire site were taken routinely at a scale of 1:6,000 using high-contrast infrared film. The ENR Project was initially photographed quarterly from October 1993 to October 1994 but in 1995, the overflight schedule was changed to semi-annual. The photographs acquired from each overflight (approximately 40 overlapping, separate images) were digitized to generate electronic images. These images were then rectified to known geographic markers to produce a composite image suitable for use as a GIS background image. Vegetation was classified into 21 distinct "coverage types" (**Table 6-1**) through an interpretation of the photographs and verified by ground-truth surveys conducted after each overflight. Subsequently, a map was generated for each overflight on which the different vegetation coverage types were color-coded. The minimum mapping unit was established by superimposing a grid scaled to represent blocks of 25m x 25m (625m^2) over the background image. The coverage type assigned to each grid block represented the dominant species within that grid element. Changes in the areal extent of each vegetation coverage type within the treatment cells have been documented over time. Analysis of vegetation coverage in the Buffer Cell was added to the monitoring program in November 1995.

The 21 vegetation coverage types identified in the ENR Project have been arranged into the following major groups for analysis and discussion in this Report:

- Cattail;
- Floating macrophytes: includes areas dominated by mats of *E. crassipes* and *P. stratiotes*;
- Open water/submerged aquatic vegetation (SAV): with one exception, it was impossible to differentiate on the aerial photographs between open water areas without SAV from areas with SAV just under the water's surface, which is why regions in the ENR Project without emergent or floating plants were generally classified as "open water/submerged vegetation". The exception were situations in which SAV had "topped out," that is, SAV extended to the water's surface and was usually covered with a dense growth of periphyton. These areas

Table 6-1. Summary of areal coverage of individual vegetation types and major vegetation groups in the Everglades Nutrient Removal Project Buffer and Treatment Cells derived from photographic overflight data collected November 1998. Boldface coverage values indicate dominant individual vegetation types.

	Cell 1		Cell 2		Cell 3		Cell 4		Buffer Cell	
Vegetation Coverage Types	ha	%	ha	%	ha	%	ha	%	ha	%
Open Water/Submersed Vegetation	235.5	44.86	193.7	46.74	45.0	11.06	22.6	15.43	3.6	6.63
Cattail (*Typha* spp.)	161.3	30.73	189.9	45.83	188.7	46.38	6.4	4.36	23.4	43.60
Sawgrass (*Cladium jamaicense*)	31.9	6.08		0.00	21.0	5.16		0.00	1.1	1.96
Primrose Willow (*Ludwigia* sp.)		0.00		0.00	4.9	1.21		0.00		0.00
Willow (*Salix* sp.)	4.0	0.76	0.1	0.02	10.7	2.63		0.00	1.1	1.96
Floating macrophytes	26.5	5.05	26.7	6.44	5.8	1.42	0.4	0.30	22.0	40.89
Bulrush (*Scirpus californicus*)		0.00		0.00		0.00		0.00		0.00
Fern-emergent mix	0.5	0.10		0.00		0.00		0.00		0.00
Spikerush (*Eleocharis interstincta*)		0.00		0.00	3.4	0.83	<1.0	0.02		0.00
Pickerelweed (*Pontederia cordata*)		0.00		0.00	11.3	2.77		0.00		0.00
Wild Taro (*Colacasia esculenta*)		0.00		0.00	0.3	0.08		0.00		0.00
Arrowhead (*Sagittaria latifolia*)		0.00		0.00	4.9	1.20		0.00		0.00
Arrowhead (*Sagittaria lancifolia*)		0.00		0.00	2.8	0.70		0.00		0.00
Misc. grasses	1.9	0.36	1.4	0.34	2.9	0.72	0.3	0.20		0.00
Leather Fern (*Acrostichum* sp.)	8.0	1.53		0.00		0.00		0.00		0.00
Smartweed (*Polygonum* sp.)		0.00	0.4	0.09		0.00		0.00	0.4	0.68
Shrub mix	25.0	4.75	1.0	0.23	30.6	7.53		0.00	0.9	1.73
Algae/macrophyte complex		0.00		0.00		0.00	115.7	78.95		0.00
Misc. spp. mix 1	30.3	5.77	1.2	0.29	55.9	13.75	1.1	0.75	1.4	2.56
Misc. spp. mix 2		0.00		0.00	18.5	4.56		0.00		0.00
Misc. spp. mix 3	0.1	0.02		0.00		0.00		0.00		0.00
TOTALS	525.0	100.0	414.4	100.0	406.7	100.0	146.6	100.0	53.7	100.0

	Cell 1		Cell 2		Cell 3		Cell 4		Buffer Cell	
Major Vegetation Groups	ha	%	ha	%	ha	%	ha	%	ha	%
Cattail	161.3	30.73	189.9	45.83	188.7	46.38	6.4	4.36	23.4	43.60
Floating macrophytes	26.5	5.05	26.7	6.44	5.8	1.42	0.4	0.30	22.0	40.89
Other emergent macrophytes[1]	101.7	19.37	4.1	0.98	167.3	41.13	1.4	0.96	4.8	8.89
Open water/SAV[2]	235.5	44.86	193.7	46.74	45.0	11.06	138.4	94.37	3.6	6.63
TOTALS	525.0	100.0	414.4	100.0	406.7	100.0	146.6	100.0	53.7	100.0

[1] Other emergent macrophytes = sawgrass + primrose willow + willow + bulrush + fern-emergent mix + spikerush + pickerelweed + wild taro + arrowhead + misc. grasses + leather fern + smartweed + shrub mix + misc. spp. mix 1 + misc. spp. mix 2 + misc. spp. mix 3

[2] Open water/SAV = open water/submersed vegetation + algae/macrophytes complex

1 hectare = 2.471 acres

were easily identified on the photographs and were classified as "algae/macrophyte complex". These two vegetation coverage types are combined into the open water/SAV group; and

- Other emergent macrophytes: includes all other plants not listed above (see **Table 6-1**).

The "misc. spp. mix 1", "misc. spp. mix 2", and "misc. spp. mix 3" vegetation coverage types are different mixtures of emergent and/or upland grass and shrub species too heterogeneous to be designated more specifically.

The establishment and growth of floating and emergent vegetation in the ENR Project test cells

were documented using the same aerial photographs described above, but was a separate effort from the vegetation monitoring program described above. The test cells were mapped using a minimum mapping unit of approximately 1 m^2. Test cell vegetation coverage types were distinguished simply as "vegetated" (i.e., all floating + emergent plant species) versus "no vegetation." Because the test cell maps were usually prepared some time after the original aerial photographs were taken, it was not possible to ground-truth maps accurately and consistently to identify coverage types. The test cells underwent two periods of vegetation establishment, first when the test cells were initially constructed in 1993 and second after modifications were completed in 1998 (see the Test Cell section in this chapter for more details on test cell modifications). Mapping vegetation in the test cells provided District scientists with the opportunity to track the development of plant community in these small constructed wetlands from the time when they were first constructed, something that was missed with mapping of the larger ENR Project. These data have been used to estimate the time needed for emergent vegetation to become established in the STAs.

Status of vegetation research and monitoring

Thirteen photographic overflights of the ENR Project were conducted prior to the expiration of the FDEP operating permit in May 1999. Overflights occurred in October 1993; February, May and October 1994; May and November 1995; April and November 1996; May and October 1997; April and November 1998; and April 1999. Data from the first 12 overflights were available for this Report; data from the last overflight have not been submitted to the District as of this writing. Annual reports on the status of the vegetation are provided in SFWMD 1995a, 1996, 1997, 1998a and 1999. Vegetation maps for first 12 overflights are included in SFWMD, 1999. As of November 1998, 55.2, 53.3, 88.9 and 93.4 percent of the surface area in Treatment Cells 1, 2 and 3, and the Buffer Cell, respectively, was vegetated with either emergent or floating aquatic macrophytes (**Table 6-1**). In contrast, only 5.6 percent of the surface area in Treatment Cell 4 was covered by these vegetation types. Much of the remaining area in Treatment Cells 1, 2, and 3 has been colonized by SAV. Cattail was the dominant emergent macrophyte throughout the ENR Project (**Figure 6-3**). Sawgrass, willow, floating macrophytes, pickerelweed and coverage types composed of a shrub mix and miscellaneous species also were notable components of the vegetation community in Treatment Cells 1, 2 or 3, while Treatment Cell 4 has been maintained as a SAV/periphyton habitat. The Buffer Cell had approximately equal proportions of cattail and floating macrophytes. The sawgrass identified in Treatment Cells 1 and 3 was restricted to the right-of-way easement under a Florida Power and Light transmission line running along the eastern boundary of the project.

Cattail achieved its maximum areal coverage in Treatment Cell 1 by May 1995 (227.6 ha) and in Treatment Cell 2 by November 1995 (341.9 ha; **Figure 6-3** and SFWMD, 1996). Cattail coverage then decreased during the last half of 1995 and all of 1996 in Treatment Cell 1 and throughout 1996 and 1997 and into 1998 in Treatment Cell 2. The loss of cattail coverage was attributed to strong windstorms, which uprooted large cattail mats in areas with a mean water depth of at least 0.5 m (**Figure 6-4**). These floating cattail islands gradually disintegrated over time as wind moved them around the treatment cells. The change in cattail coverage in Treatment Cells 1 and 2 generally decreased during periods associated with increasing cumulative depth-days (depth-days = number of days in the month times average monthly depth) (**Figure 6-5**) . These relationships, however, were weak and only the regression for Treatment Cell 2 was statistically significant. While the spread of cattail throughout Treatment Cell 3 also has slowed markedly from the rate observed in 1994 and 1995 (**Figure 6-3**), it has not yet reached a steady state. To date, Treatment Cell 3 has not experienced any loss of cattail coverage. Mean water depth in this cell seldom exceeded 0.5 m (**Figure 6-4**). There was a weak, but statistically nonsignificant, posi-

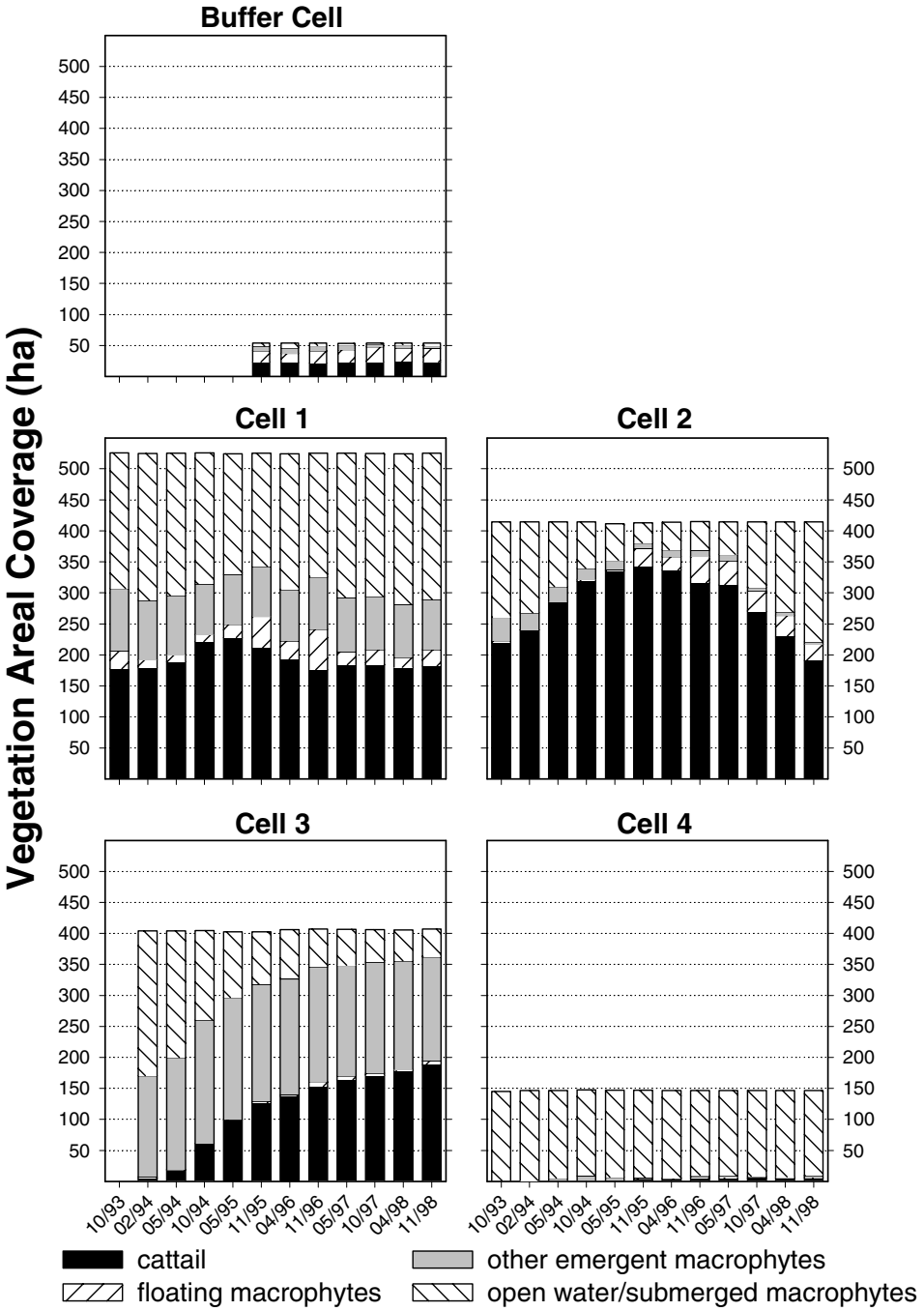

Figure 6-3. Comparison of areal coverage (ha) of cattail, other emergent macrophytes, floating macrophytes and open water/submerged macrophytes in the Everglades Nutrient Removal Project Buffer Cell and Treatment Cells 1, 2, 3, and 4 from October 1993 through November 1999.

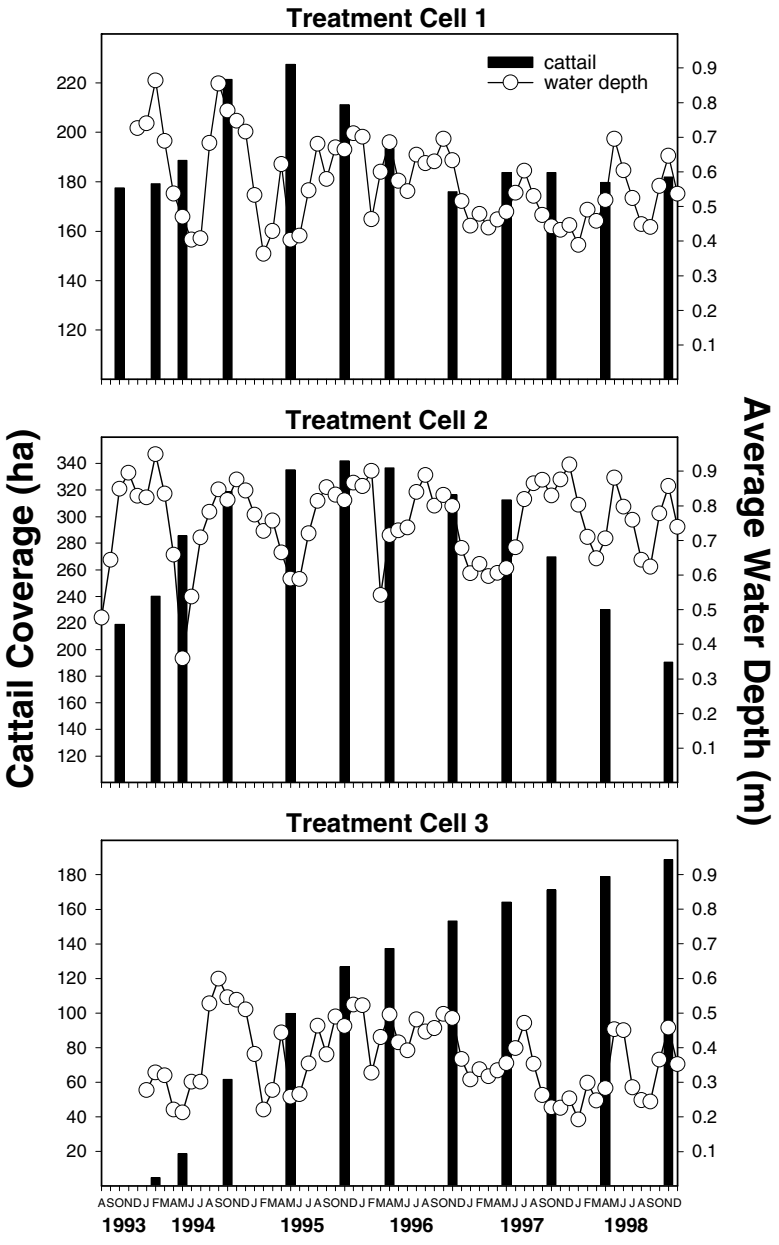

Figure 6-4. Comparison of areal coverage of cattail (ha) with monthly average water depth (m) in Everglades Nutrient Removal Project Treatment Cells 1, 2, and 3 from August 1993 through December 1998. See Figure 6-3 for comparison of cattail coverage with coverage of the other major vegetation groups in each cell. Treatment Cell 1 = 526 ha; Treatment Cell 2 = 413 ha; Treatment Cell 3 = 404 ha.

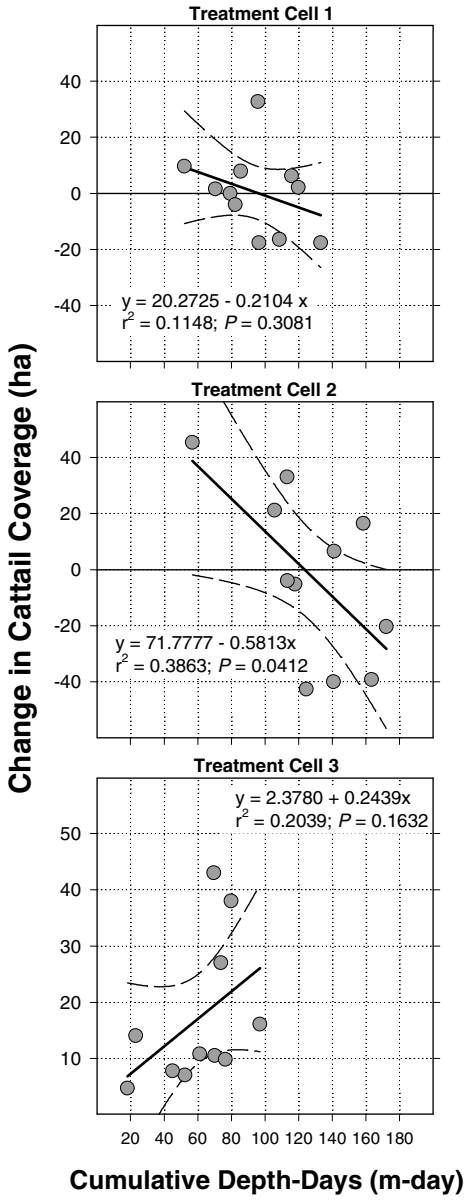

Figure 6-5. Change in cattail areal coverage (ha) between photographic overflights relative to cumulative depth-days (m-day) during the same time intervals in Everglades Nutrient Removal Project Treatment Cells 1, 2, and 3 from August 1993 through December 1998. Heavy solid line represents best linear fit to the data; dashed line represents 95% confidence interval around regression line. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

tive correlation between change in cattail coverage and cumulative depth-days for this cell (**Figure 6-5**). Cattail now has to compete for space and light with floating and submerged macrophytes, which may slow or inhibit altogether the expansion of existing cattail stands and reinvasion into areas of the ENR Project once occupied by this species.

Because 131 of 404 ha in Treatment Cell 3 were planted, it has a more diverse plant community than the other cells (**Table 6-1**). The District has allowed its plant community to develop in a natural manner. As noted above, Treatment Cell 4 has been actively managed to control the spread of emergent and floating vegetation through selective use of herbicides. The District will continue to maintain Treatment Cell 4 as a SAV/periphyton habitat in order to be able to compare the treatment performance of this type of wetland habitat against the mixed-marsh plant community established in Treatment Cell 3.

The conceptual model originally developed for operation of the ENR Project and the STAs was predicated on a wetland plant community which when fully developed would closely resemble that found in nutrient impacted areas of the WCAs, i.e., a community almost entirely dominated by dense cattail stands (SFWMD, 1989a). The vegetation community that has developed in the ENR Project is considerably more diverse (see **Table 6-1**). Notably, it was not anticipated during project design that large stands of SAV with associated periphyton would develop nor that the composition of the plant community would be as dynamic as it has proven to be, especially the loss of cattail in Treatment Cells 1 and 2. As of November 1998, cattail occupied only 40.1 percent of the combined surface area in Treatment Cells 1, 2, and 3, (reduced from a maximum of 50.7 percent in November 1995), while 35.2 percent of the combined surface area in these cells was occupied by SAV. It is thought unlikely that this community composition will change appreciably in the near future. Despite these differences and the observed changes in the plant community, the ENR Project has met or exceeded all mandated performance objectives throughout its operational history (see P mass balance budget in this chapter). This suggests that other plant species (e.g., SAV and floating macrophytes and/or periphyton) are also important in removing nutrients from the water and that successful performance of the STAs may not necessarily depend upon a plant community dominated by cattail.

The growth of vegetation in the test cells has been quantified as changes in relative vegetation coverage (**Figure 6-6**) and fit to a generalized logistic growth model (Odum, 1971; Krebs, 1972) using the SAS Model procedure (SAS/ETS Version 6.12; SAS Institute, Inc. Cary, NC):

$$N_t = \frac{K}{1 + e^{(a - rt)}} \qquad (6.1)$$

where:

N_t = population size, i.e., relative vegetation coverage at time *t*;

K = carrying capacity of the environment, i.e., the maximum relative vegetation coverage;

a = constant of integration, defines the position of the curve relative to the origin;

r = intrinsic rate of increase in relative vegetation coverage; and

t = time interval (month);

The value of K was set at 1.0, i.e., complete relative vegetation coverage. There were insufficient post-modification coverage data available for this Report to fit a growth model.

The rate of vegetation establishment differed markedly between pre-modified north and south test cells (**Figure 6-6**). The north test cells required

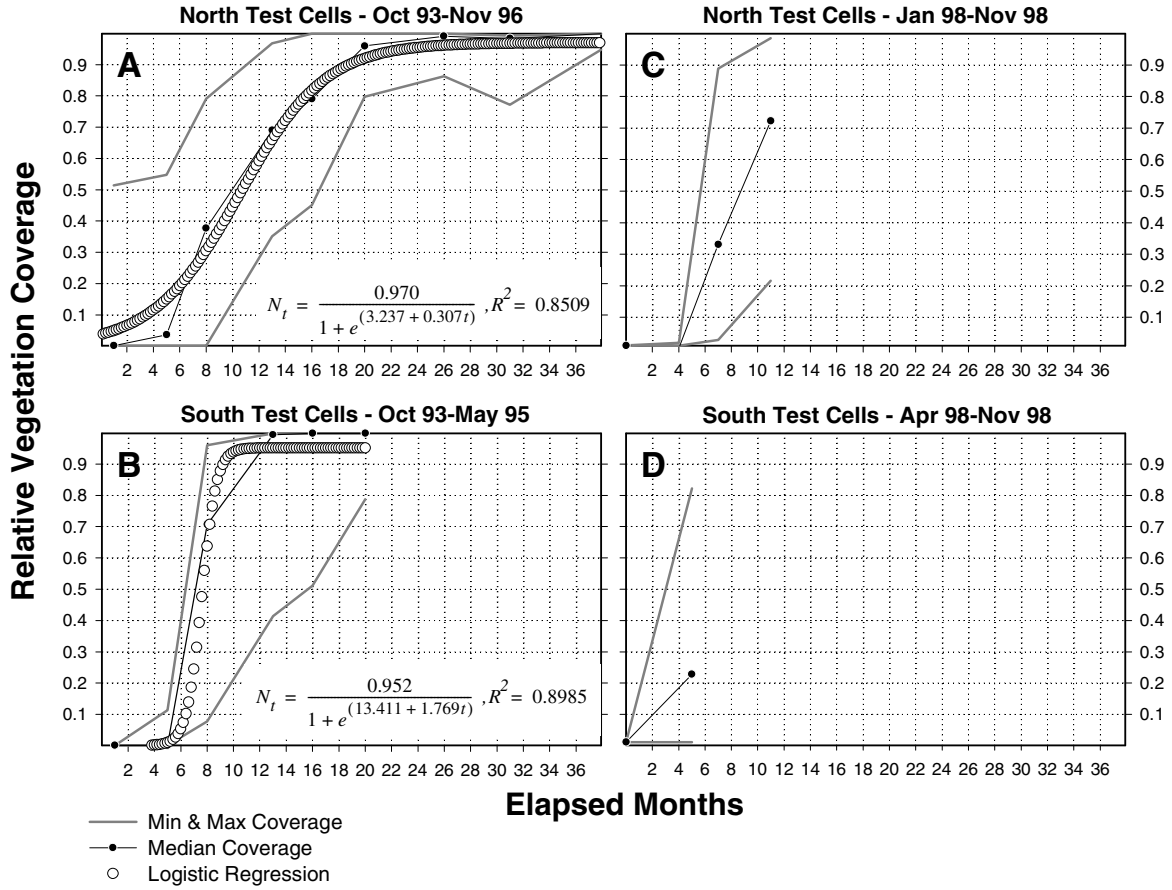

Figure 6-6. Growth of emergent and floating vegetation in the Everglades Nutrient Removal Project test cells presented as relative vegetation coverage. Panels A and B = summary of minimum, maximum and median coverage values for the north and south test cells, respectively, prior to test cell modifications; Panels C and D = summary of minimum, maximum and median coverage values for the north and south test cells, respectively, after test cell modifications.

10 and 26 months to achieve a median vegetation coverage of 50 and >99 percent, respectively, while the south test cell reached the same median coverage levels in only seven and 13 months, respectively. The value of r in the growth equation derived for the south test cells (1.769) reflected a much faster growth rate compared to the constant derived for the north test cells (r = 0.307). Note that there was considerable variation around median coverage values as both the north and south test cells were filling in (compare minimum and maximum coverage values). Although analysis of the post-modification data is not yet complete, it appears that vegetation in both the north and south test cells is growing at rates similar to that observed in the pre-modified south test cells. These data suggest that grow-in rates for the different STAs may be quite variable.

HYDROLOGY

Data Collection and Analysis

Separate water budgets were computed for the entire ENR Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4 based on daily estimates of inflows, outflows and change in storage capacity using a water mass balance equation of the general form:

$$I - O = \Delta S + r \qquad (6.2)$$

where:

I = inflow water volume to the system (m^3);

O = outflow water volume from the system (m^3);

ΔS = change in storage capacity within the system (m^3); and

r = remainders to the water budget (m^3).

Remainders in each water budget represent water unaccounted for after all inflows and outflows are balanced against the change in storage. Remainders may include measurement errors in water budget terms and/or unmeasured sources of water (Abtew and Mullen, 1997; Abtew and Downey, 1998) and were computed by rearranging terms in **Equation 6.2**:

$$r = I - (O + \Delta S) \qquad (6.3)$$

A positive water budget remainder indicates inflow that exceeds outflow + storage capacity. Conversely, a negative remainder results from outflow + storage capacity exceeding inflow.

The water budget for the entire ENR Project included (a) daily flow measurements at the Inflow (G250), Seepage Return (G250s) and Outflow Pumps (G251); (b) total daily rainfall measured at a network of automated, tipping-bucket gauges located throughout the project (Abtew and Cadogan, 1995; Abtew et al., 1995b); (c) daily estimates of surficial and deep groundwater seepage entering the wetland from WCA-1 along the L-7 levee (Guardo and Prymas, 1998; Guardo, 1999); and (d) continuous evapotranspiration (ET) measurements made at three automated lysimeters or regression equations derived from these data that predicted ET based on meteorological conditions (Abtew and Obeysekera, 1995; Abtew, 1996). Flow at the pump stations was computed from a flow-rating curve developed for each station based on pump revolutions and expressed as a delivery rate (m^3/sec) converted to a daily volume. The water budget for the entire project was computed from the following expression:

$$\Delta S + r = [V_{250} + V_{250s} + V_{ss} + V_{ds} + V_r] - [V_{251} + V_{258} + V_{259} + V_s + V_{ET}] \qquad (6.4)$$

where:

V_{250} = inflow water volume from the inflow pumps [structure G250] (m^3);

V_{250s} = inflow water volume from the seepage return pumps [structure G250s] (m^3);

V_{ss} = infiltration water volume from surficial groundwater seepage (m^3);

V_{ds} = infiltration water volume from deep groundwater seepage (m^3);

V_r = rainfall water volume (m^3);

V_{251} = outflow water volume from the outflow pumps [structure G251] (m^3);

V_{258} = outflow water volume through structure G258 (m^3);

V_{259} = outflow water volume through structure G259 (m^3);

V_s = seepage water volume lost from the system (m^3); and

V_{ET} = evapotranspiration water volume lost from the system (m^3)

Flow through the G258 and G259 structures (V_{258} and V_{259}) was based on standard culvert equations calibrated to headwater and tailwater stage differences at each gate. Seepage loss through the ENR Project's perimeter levee (V_s) was based on a levee flow equation developed by Hutcheon Engineers (1996). Rainfall was spatially averaged over the entire ENR Project utilizing Thiessen weighting coefficients developed for each rain gauge station in the network (Abtew and Mullen, 1997) and expressed as a total daily volume:

$$V_r = R \times A \qquad (6.5)$$

where:

R = depth of daily rainfall spatially averaged over the entire ENR Project (m); and

A = surface area of the ENR Project (m^2).

Seepage emerged along the toe of the L-7 levee (**Figure 6-2**) (i.e., surficial seepage [V_{ss}]) and entered the ENR Project through 21 culverts as surface flow. Biweekly discharge measurements were made at each culvert from August 1994 through June 1996, a total of 42 separate measurement events. A regression relationship was developed between the total volume of flow passing through these culverts, the stage in WCA-1, and the difference in stage between WCA-1 and the eastern flow-way of the ENR Project (all stage measurements referenced to m NGVD) (R^2 = 0.932; Guardo, 1999). Daily surficial seepage was calculated using this model and expressed as a delivery rate and converted to a daily volume:

$$Q_{ss} = (0.2158\, W_{WCA})^{1.3121} \times \Delta h^{2.0246} \qquad (6.6)$$

$$V_{ss} = Q_{ss} \times 86400 \qquad (6.7)$$

where:

Q_{ss} = daily surficial seepage entering the ENR Project (m^3/sec);

W_{WCA} = mean daily stage in WCA-1 above 4.57 m NVGD (m); and

Δh = difference in stage between the eastern Treatment Cells of the ENR Project and WCA-1 (m).

Deep groundwater seepage entering the ENR Project from WCA-1 was estimated as a delivery rate following Guardo and Prymas (1998) and converted to a daily volume:

$$Q_{ds} = (0.42 \times W_{WCA})^{3.06} \times (W_{ENR})^{-3.57} \qquad (6.8)$$

$$V_{ds} = Q_{ds} \times 86400 \qquad (6.9)$$

where:

Q_{ds} = daily deep seepage entering the ENR Project (m^3/sec); and

W_{ENR}= mean daily stage in the ENR Project (m NGVD).

The daily change in storage for the ENR Project was computed as the sum of the daily change in storage for the Buffer Cell and Treatment Cells 1, 2, 3, and 4. Storage for each treatment cell was based on average depth and depth-volume regressions (**Table 6-2**). Daily average cell depth was computed as the difference between (a) the average stage computed from daily measurements recorded by a network of automated stage recorders in each cell (**Figure 6-2**) and (b) the average ground elevation for that cell (**Table 6-3**). The storage in the Buffer Cell was computed as the product of the estimated average daily depth and its surface area (**Table 6-3**).

Table 6-2. Depth-volume regressions used to compute daily storage capacity in Everglades Nutrient Removal Project Treatment Cells 1, 2, 3 and 4.

Cell	Regression Equations[a]	R^2
Treatment Cell 1	$Y = 33717362 - 9885978X + 885069X^2 - 23014X^3$	0.99994
Treatment Cell 2	$Y = -11807968 + 1250015x$	0.99999
Treatment Cell 3	$Y = 28708906 - 7846197X + 663580X^2 - 16361X^3$	0.99998
Treatment Cell 4	$Y = -4311760 + 446543X$	0.99999

a. Y = predicted cell storage capacity (m^3); X = average cell depth (ft)

Table 6-3. Surface area, average ground elevation and average water depth for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 in the Everglades Nutrient Removal Project.

Cell	Surface Area (ha)	Average Ground Elevation[a]		Average[b] Depth (m)
		(ft NVGD)	(m NVGD)	
Buffer Cell	53.9	10.3[c]	3.14	0.58
Treatment Cell 1	525.6	10.109	3.08	0.56
Treatment Cell 2	413.4	9.451	2.88	0.76
Treatment Cell 3	404.1	10.379	3.16	0.38
Treatment Cell 4	147.2	9.660	2.94	0.64

a. Average ground elevations in each Treatment Cell derived from an ARC/INFO analysis of topographic survey point data collected from that cell.
b. Average depth based on average ground elevation and average stage in each cell.
c. Average ground elevation in the Buffer Cell is an estimated value.

Individual water budgets for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 were calculated using the following equations:

Buffer Cell:

$$[V_{250} + V_{250s} + V_r] - [V_{252} + V_{255} + V_{ET} + V_s] = \Delta S + r \quad (6.10)$$

Treatment Cell 1:

$$[V_{252} + V_{ss} + V_{ds} + V_r] - [V_{253} + V_{ET}] = \Delta S + r \quad (6.11)$$

Treatment Cell 2:

$$[V_{255} + V_r] - [V_{254} + V_s + V_{ET}] = \Delta S + r \quad (6.12)$$

Treatment Cell 3:

$$[V_{253} + V_{ss} + V_{ds} + V_r] - [(V_{251} - V_{256}) + V_s + V_{ET}] = \Delta S + r \quad (6.13)$$

Treatment Cell 4:

$$[V_{254} + V_r] - [V_{256} + V_{258} + V_s + V_{ET}] = \Delta S + r \quad (6.14)$$

where:

V_{252} = volume of flow through the culverts in the G252 levee (m^3);

V_{255} = volume of flow through the culverts in structure G255 (m^3);

V_{253} = volume of flow through the culverts in the G253 levee (m^3);

V_{254} = volume of flow through the culverts in the G254 levee (m^3);

V_{256} = volume of flow through the culverts in structure G256 (m^3);

The contribution of rainfall to each cell water budget (V_r) was based on the daily rainfall volume for the entire ENR Project prorated for the surface area of each cell (**Table 6-3**). Surficial and deep groundwater seepage (V_{ss} and V_{ds}) into Treatment Cells 1 and 3 were based on the daily volume entering the entire ENR Project (**Equations 6.6** to **6.9**) prorated for the length of the L-7 levee along the eastern boundary of each cell (**Figure 6-2**). Seepage loss from the Buffer Cell and Treatment Cells 2, 3 and 4 (V_s) through the western and northern portions of the perimeter levee was estimated based on: (a) a seepage loss rate developed for the ENR Project perimeter levee (2 cfs/mile of levee/ft. head; Hutcheon Engineers, 1966), (b) the length of the perimeter levee for each cell and (c) the head difference between localized stage in the Seepage Return Canal and in each cell. Flow through culverts in the G252 (10 culverts), G253 (10 culverts), G254 (5 culverts), G255 (5 culverts) and G256 (5 culverts) structures was measured on a continuous basis with ultrasonic velocity meters (UVMs). The UVM database occasionally had missing records due to equipment malfunction or records indicating negative (i.e., reverse) flow for one or more culverts. Given the small head differences that existed between cells, it is unlikely that these negative data reflected actual reverse flow (especially when adjacent culverts had positive flow measurements) and treated negative flow data as errors. Flow through each of the culverted structures was derived by first calculating a mean daily delivery rate based on all culverts with positive or zero flow and then multi-

plying that value by the total number of culverts to produce a daily volume for the entire structure:

$$Q_c = \frac{\sum_{i=1}^{n} q_1, q_2, q_3 \ldots q_i}{n} \qquad (6.15)$$

$$V_c = (Q_c \times N) \times 86400 \qquad (6.16)$$

where:

Q_c = average flow through culverts with positive flow (m^3/sec);

q_i = flow rate through the i^{th} culvert with positive flow (m^3/sec);

n = number of culverts with positive flow;

V_c = volume of flow through the entire structure (m^3); and

N = total number of culverts in the structure.

Nominal hydraulic retention times (HRTs) for the each cell in the ENR Project were calculated using three-month rolling mean storage capacities of the cell (computed using the depth-volume regressions in **Table 6-2** and the cell's three-month rolling average depth) and its three-month rolling average total outflow.

$$\tau_n = \frac{V_j}{Q_j} \qquad (6.17)$$

where:

τ_n = cell's nominal hydraulic residence time (days);

V_j = cell's mean monthly storage capacity (m^3); and

Q_j = cell's monthly average total outflow (m^3/day).

Nominal HRTs were calculated for the entire ENR Project using the average HRT of the eastern and western flow-ways weighted for differences in storage capacity, plus HRT in the buffer Cell:

$$\tau_n = \tau_{buffer} + \frac{[(\tau_{cell1} + \tau_{cell3}) \times (V_{cell1} + V_{cell3})] + [(\tau_{cell2} + \tau_{cell4}) + (V_{cell2} + V_{cell4})]}{(V_{cell1} + V_{cell2} + V_{cell3} + V_{cell4})} \qquad (6.18)$$

where:

τ_{buffer} = Buffer Cell nominal hydraulic residence time (days);

τ_{cell1} = Treatment Cell 1 nominal hydraulic residence time (days);

τ_{cell2} = Treatment Cell 2 nominal hydraulic residence time (days);

τ_{cell3} = Treatment Cell 3 nominal hydraulic residence time (days);

τ_{cell4} = Treatment Cell 4 nominal hydraulic residence time (days);

V_{buffer} = Buffer Cell storage capacity (m^3);

V_{cell1} = Treatment Cell 1 storage capacity (m^3);

V_{cell2} = Treatment Cell 2 storage capacity (m^3);

V_{cell3} = Treatment Cell 3 storage capacity (m^3); and

V_{cell4} = Treatment Cell 4 storage capacity (m^3).

Surface outflow from Treatment Cell 3 was not monitored directly as it is in all the other cells, which complicates calculating a water budget for this cell. Outflow from Treatment Cell 3 was estimated as the difference between the measured

daily flow at the Outflow Pump Station (V_{G251}) and daily outflow from Treatment Cell 4 through structure G256 (V_{256}) (**Figure 6-2**). Hydrologic data have been summarized based on water years that correspond to the reporting period for the Report, that is, dates running from May 1 through April 30 of the following calendar year. Additional information on instrumentation used to collect hydrologic data, water budget computation methodologies and data summaries is provided in Abtew and Cadogan (1995), Abtew et al. (1995a and b), Abtew and Obeysekera (1995), Guardo et al. (1995, 1996), Abtew (1996), Abtew and Mullen (1997), Abtew and Downey (1998), Guardo and Prymas (1998) and Guardo (1999).

Status of hydrology research and monitoring

Monthly average depths in the ENR Project varied from approximately 0.2 to 0.9 m (**Figure 6-7**). Inspection of median depths for each water year revealed that the western flow-way (Treatment Cells 2 and 4) was consistently 10 to 30 cm deeper than the other cells and that median depth decreased rather consistently in the Buffer Cell and Treatment Cells 1 and 3 over this time period. Average monthly storage for the entire ENR Project ranged from 5.5 to 11.4 hm^3 (1 hm^3 = 1,000,000 m^3 or 810.6 acre-feet). Treatment Cells 1 and 2 had, on average, at least twice the storage capacity of the other cells (**Figure 6-8**). Daily total inflows to the ENR Project (Inflow Pumps + Seepage Return Pumps + rainfall + surficial seepage + deep seepage) varied greatly over the period of record (~ 0.03 to 2.68 hm^3) and often changed dramatically within short periods of time (**Figure 6-9**). These changes reflect the highly managed nature of the wetland. No consistent seasonal pattern for daily inflow was detected among water years. Variation in daily total outflow generally followed that observed for total inflow. Comparison of total inflow data indicated that the ENR Project was loaded more heavily during the first two water years compared to the last three years (**Figure 6-10**). Summary statistics for annual inflow and outflow water loads are presented in **Table 6-4**. The eastern flow-way was closed off

Table 6-4. Descriptive statistics for annual estimates of inflow and outflow water loads, inflow and outflow total phosphorus loads, total phosphorus settling rates and nutrient removal performance in the entire Everglades Nutrient Removal Project for water years from May 1995 through April 1999.

	Mean	Min	Max	Std. Dev.
Inflow water volume (hm^3)	219.2	173.6	292.7	51.7
Outflow water volume (hm^3)	212.6	171.5	281.6	50.0
Inflow total phosphorus (kg)	17,018	12,764	26,978	6,757
Outflow total phosphorus (kg)	3,096	2,134	5,189	1,437
Total phosphorus settling rate (m/yr)	23.5	19.6	29.8	4.6
Total phosphorus load reduction (%)	82.1	80.8	83.4	1.3

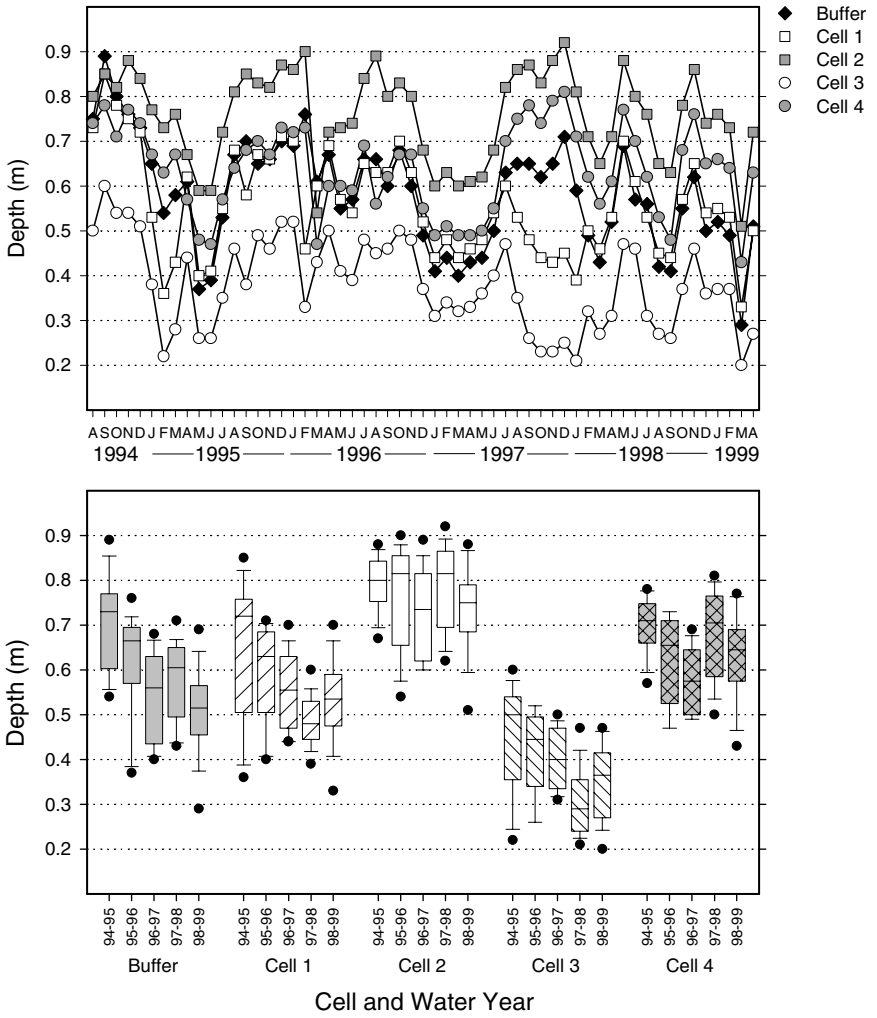

Figure 6-7. Monthly average depth (m) in the Everglades Nutrient Removal Project Buffer Cell and Treatment Cells 1, 2, 3 and 4 from August 1994 through April 1999. Top panel: time series of monthly average depths; Bottom panel: box plots of average monthly depth summarized by cell and water year. Description of box plots: top and bottom of box = 75th and 25th percentile of the data distribution, respectively; mid-line in box = 50th percentile; ends of whiskers = 10th and 90th percentiles; closed circles = observations outside of the 10th and 90th percentiles.

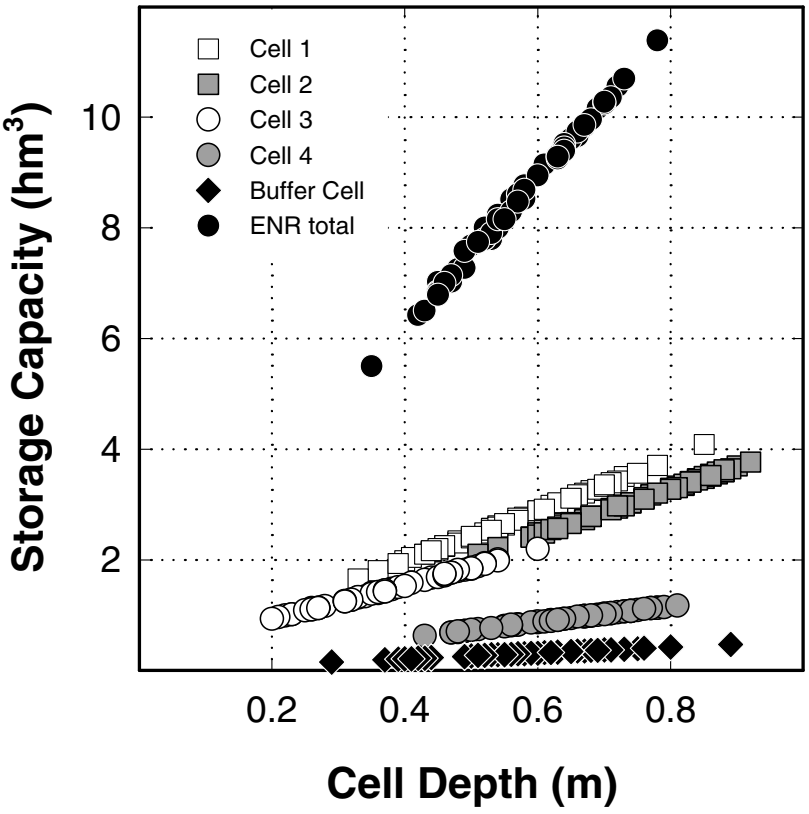

Figure 6-8. Average monthly storage capacity (m^3) in the Everglades Nutrient Removal Project Buffer Cell and Treatment Cells 1, 2, 3 and 4 computed using depth-volume regressions and average monthly depth.

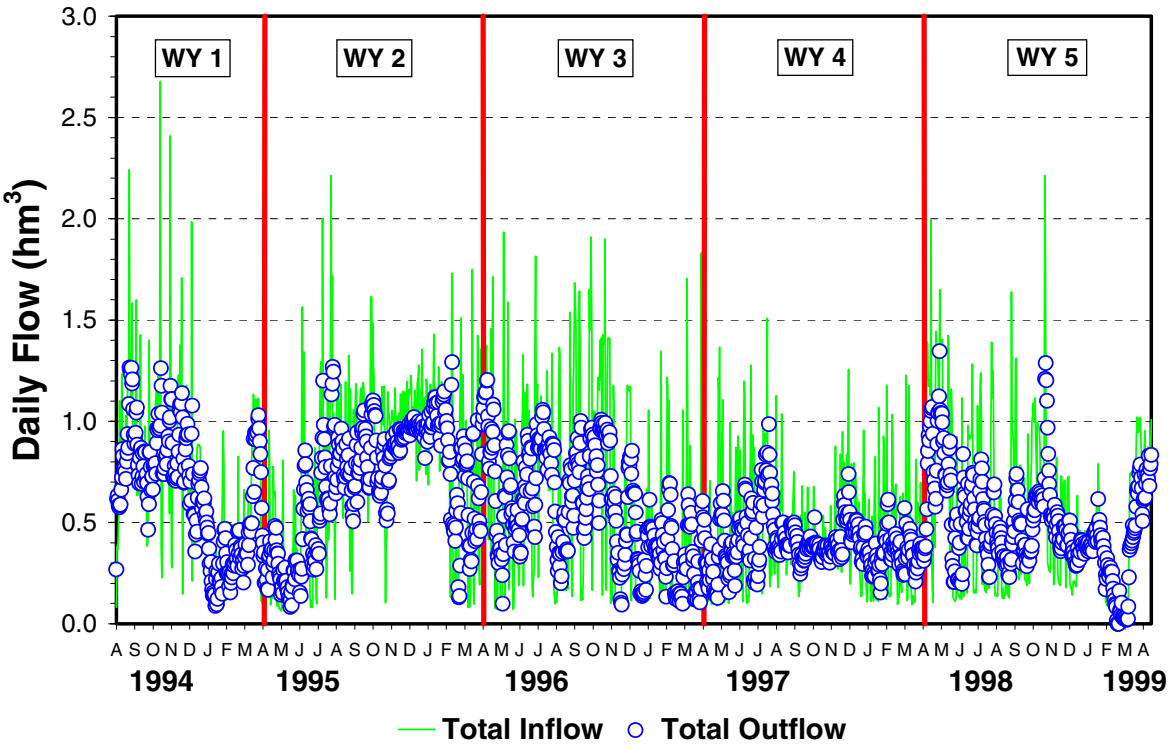

Figure 6-9. Daily total inflow and outflow (hm^3) in the entire Everglades Nutrient Removal Project during the first five water years from August 1994 through April 1999. WY = water year (May 1 to April 30).

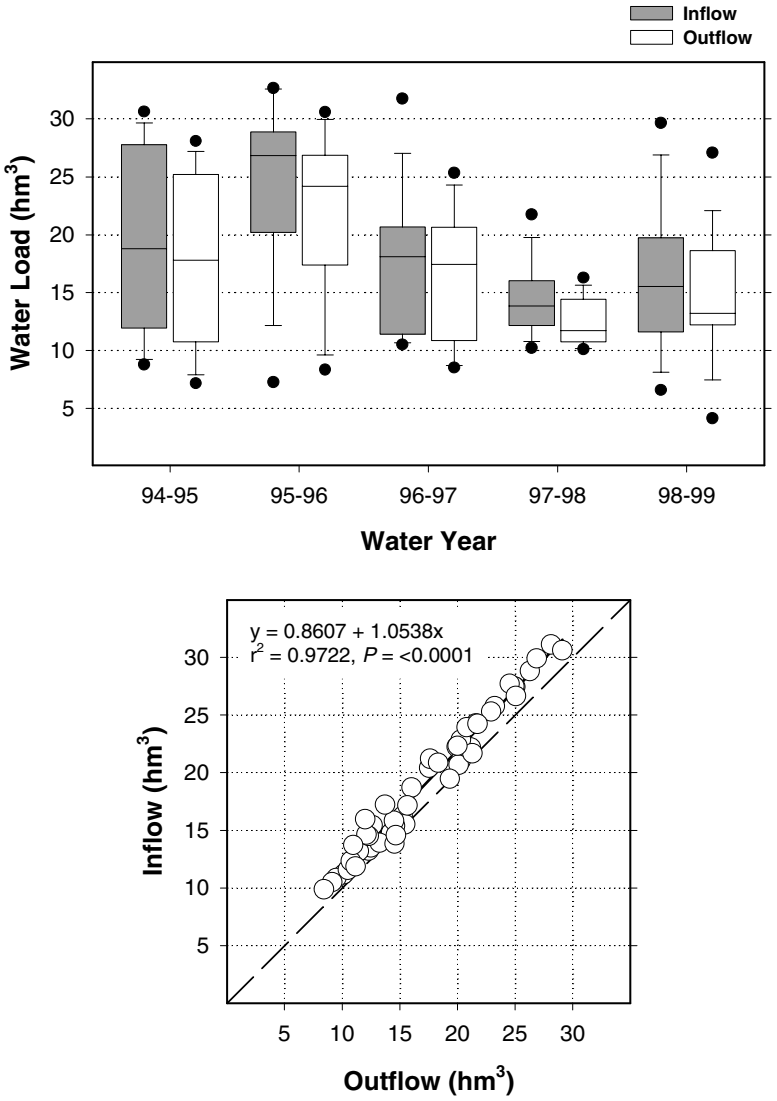

Figure 6-10. Summary of monthly total inflow and outflow water loads (hm^3) for the Everglades Nutrient Removal Project from August 1994 through April 1999. Top panel: box plots of monthly total inflow and outflow water loads (hm^3) summarized by water year; Bottom panel: comparison of rolling 3-month inflow water loads with corresponding total outflow water loads (hm^3). See Figure 6-7 for description of box plots. Heavy solid line represents best linear fit to the data. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

and not operated from July 1997 through January 1998 while the north Test Cells were being modified (see Test Cell Research section). This action decreased the treatment area of the ENR Project by 60% (and consequently its storage capacity) and limited our ability to move water through the project while maintaining target water depths. The reduced variability in monthly water loading in water year 97-98 resulted from reduced pumping activity during this period. Rolling three-month inflow water loads were in good agreement with corresponding outflow water volumes (**Figure 6-10**). The remainder in the water budget for the entire project over the period of record (August 1994 to April 1999) was 3.0 percent (**Table 6-5**). The water loading rate for the Inflow Pumps for the entire period of record (2.6 cm/day; **Table 6-5**) was comparable to ENR Project design assumptions (2.8 and 4.4 cm/day; Chimney and Moustafa, 1999). The combined flow through the Inflow Pumps and the Seepage Return Pumps accounted for 82.7% of the total water volume delivered to the project during the period of record (**Table 6-5**) and comprised most of the inflow water load each month (**Figure 6-11**). Nominal HRTs for the entire ENR Project ranged from 11.5 to 32.3 days, with a median HRT of 20.7 days (**Figure 6-12**). These results were comparable to anticipated HRTs for the project (10-20 days; CH2M Hill, 1991 as cited in Chimney and Moustafa, 1999) and HRTs calculated for the project by Abtew and Mullen (1997), Abtew and Downey (1998) and Guardo (1999).

Figure 6-13 illustrates the direction and volume of all measured and estimated flows used in water budgets for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 for the period May 1995 through April 1999. The network of UVMs installed in the culverts in the ENR Project did not became fully operational until May 1995; hence the period of record for water budgets computed for the Buffer Cell and the Treatment Cells is shorter than the period of record for the entire project, which started with flow-through operations in August 1994 (**Table 6-5**). Accounting for all water volumes within the project, especially flows associated with groundwater seepage, is complex. The primary source of inflow to the entire system from May 1995 through April 1999 was from the Inflow Pump Station (G250; 580.1 hm^3) and the Seepage Return Pumps (G250s; 146.9 hm^3) (**Figure 6-2**). Other inflow sources included surficial and deep groundwater seepage from the adjacent WCA 1 and rainfall. The major outflow from the system was through the Outflow Pump Station (G251; 566.0 hm^3). Other water losses included flow through the G258 and G259 structures into the Seepage Return Canal, seepage out of the western flow-way into this same canal and ET. The net change in storage capacity for the water budgets was quite small compared to the total inflow to each cell (**Table 6-5**). Small changes in storage are expected in a treatment system with pumped inflow, like the ENR Project, that experiences relatively little change in depth over time. It follows then that the magnitude and sign of the water budget remainders were largely a function of differences between inflow and outflow water volumes.

Surface outflow from the Buffer Cell passed through culverts in structures G252 (10 culverts) and G255 (5 culverts). The division of outflow was 249.1 hm^3, or 37.6 percent of total outflow, through G252 into the eastern flow-way (60.2 percent of the total surface area of the ENR Project) and the remaining 374.6 hm^3, or 56.5 percent of total outflow, through G252 into the western flow-way (36.3 percent of the project surface area) (**Table 6-5**). This varied considerably from the design scenario for flow that was based on the number of culverts in each structure (i.e., 66.6 percent of outflow to the eastern flow-way versus 33.3 percent of outflow to the western flow-way). The difference between the observed and expected distribution of water volumes was attributed the hydraulic resistance to flow afforded by the dense vegetation that developed in the Buffer Cell, which forced more water to the west, and to a much smaller extent to periods when flow into the eastern flow-way was purposely restricted by blocking the G252 culverts (e.g., for seepage tests conducted in Treatment Cell 2 from August 12 to September 4, 1996, and during modifications to the north and south banks of test cells from July 17, 1997 to Feb-

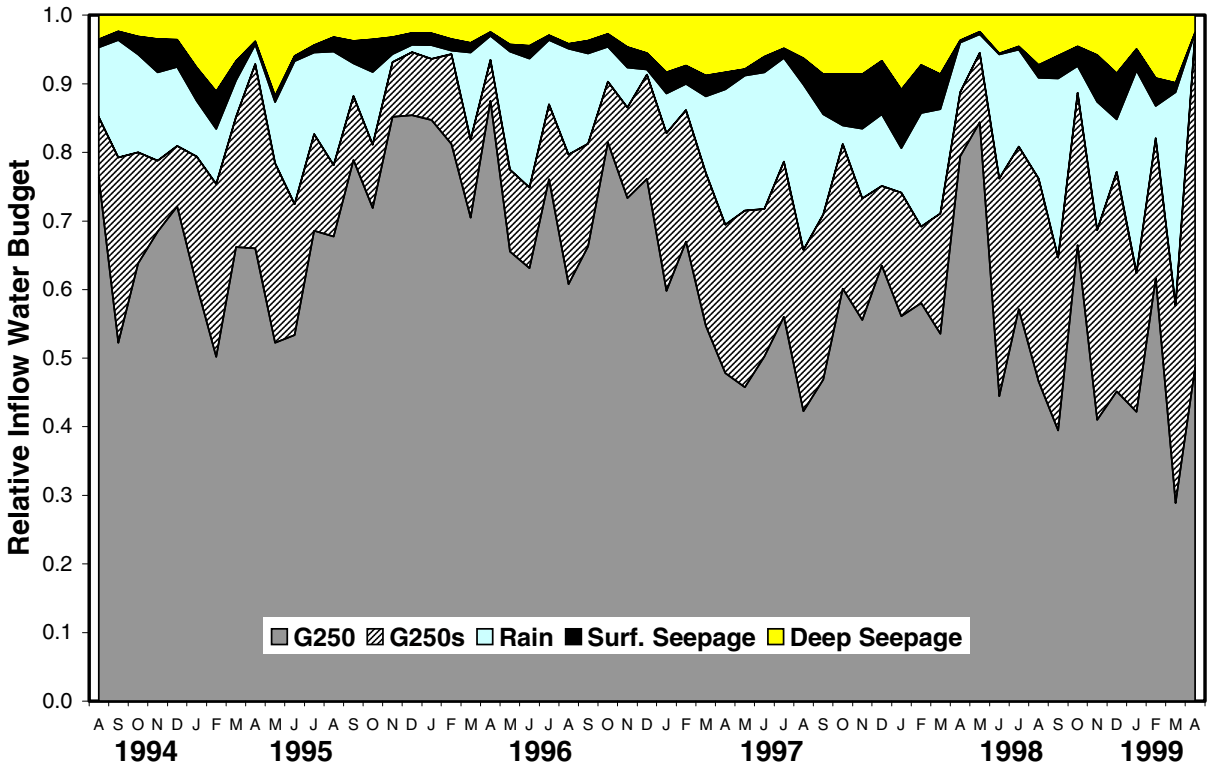

Figure 6-11. Relative monthly inflow water loads to the entire Everglades Nutrient Removal Project associated with the Inflow Pumps (G250), Seepage Return Pumps (G250s), rainfall, L-7 surficial groundwater seepage and L-7 deep groundwater seepage from August 1994 through April 1999.

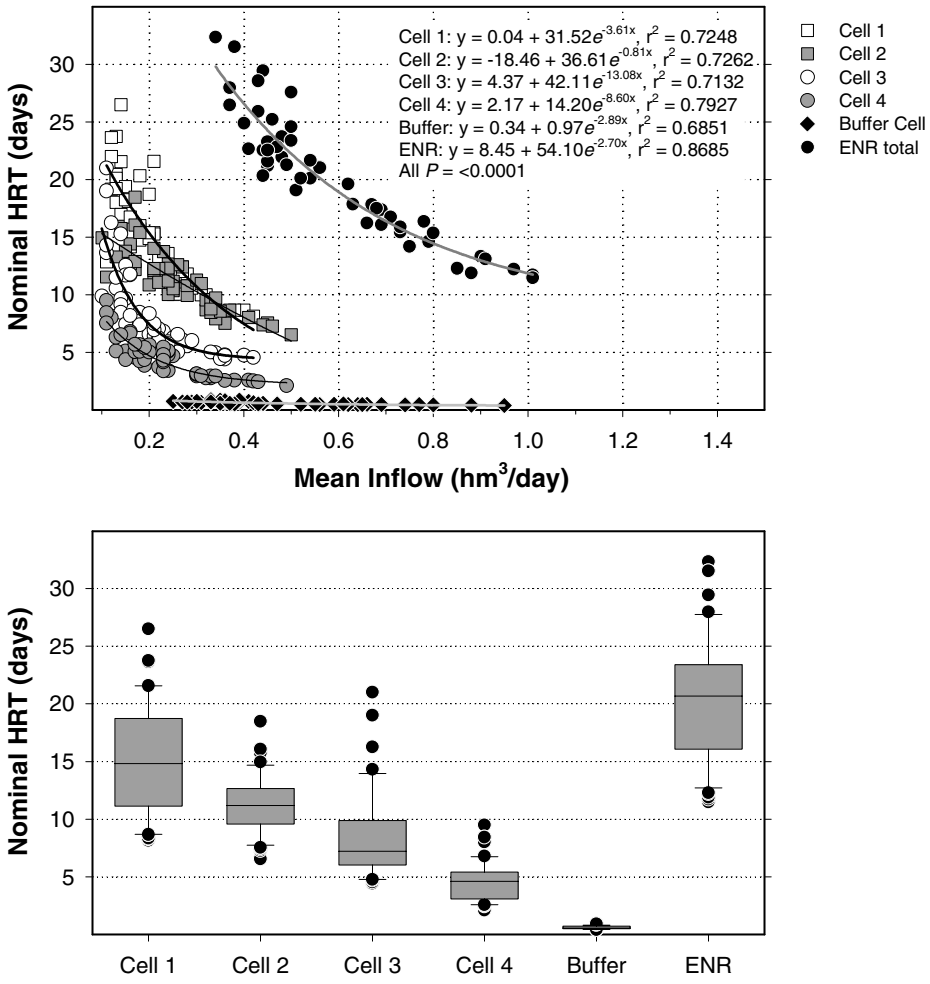

Figure 6-12. Nominal hydraulic retention times (days) for the entire Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. Top panel: comparison of retention times with corresponding mean inflow water loading rates (hm^3/day) Data have been smoothed using a three-month rolling average weighted for number of days in the month. Bottom panel: box plots of smoothed nominal hydraulic retention times summarized by cell. See Figure 6-7 for description of box plots. All exponential decay functions and regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

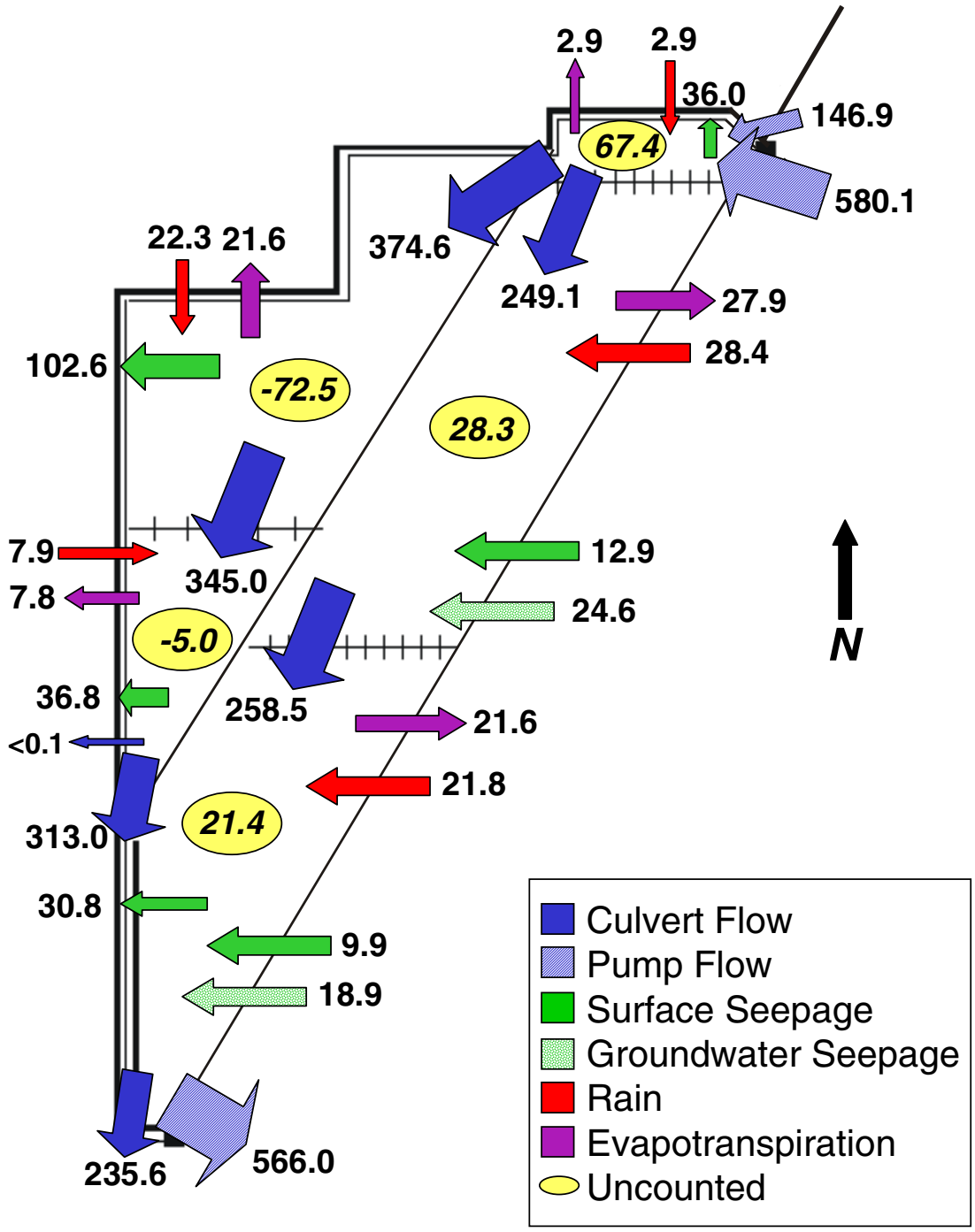

Figure 6-13. Measured and estimated water volumes (hm^3) used to compute water budgets for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 in the Everglades Nutrient Removal Project from May 1995 through April 1999.

Table 6-5. Summary of inflow and outflow water loads, water budget remainders and change in storage capacity for the entire ENR Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4[a].

	Inflow Water Load			Outflow Water Load			Remainder		ΔS
Sources of Flow	hm^3	cm/day	%	hm^3	cm/day	%	hm^3	%	hm^3
Entire ENR Project - 08/18/94 to 04/30/99									
Inflow Pumps	693.8	2.61	65.8	--	--	--	--	--	--
Seepage Return Pumps	177.9	0.67	16.9	--	--	--	--	--	--
Rainfall	103.3	0.39	9.8	--	--	--	--	--	--
L-7 Surficial Seepage	28.1	0.11	2.7	--	--	--	--	--	--
L-7 Deep Seepage	50.9	0.19	4.8	--	--	--	--	--	--
Outflow Pumps/Culverts	--	--	--	683.6	2.58	66.8	--	--	--
G258+G259	--	--	--	9.0	0.03	0.9	--	--	--
Seepage	--	--	--	237.4	0.89	23.2	--	--	--
Evapotranspiration	--	--	--	93.9	0.35	9.2	--	--	--
TOTALS	1054.0	3.97	100.0	1023.8	3.86	100.0	32.2	3.05	-1.94
Buffer Cell - 05/01/95 to 04/30/99									
Inflow Pumps	580.1	73.71	79.5	--	--	--	--	--	--
Seepage Return Pumps	146.9	18.67	20.1	--	--	--	--	--	--
Rainfall	2.9	0.37	0.4	--	--	--	--	--	--
G252	--	--	--	249.1	31.65	37.6	--	--	--
G255	--	--	--	374.6	47.60	56.5	--	--	--
Seepage	--	--	--	36.0	4.57	5.4	--	--	--
Evapotranspiration	--	--	--	2.9	0.36	0.4	--	--	--
TOTALS	729.9	92.75	100.0	662.5	84.18	100.0	67.4	9.23	0.04
Treatment Cell 1 - 05/01/95 to 04/30/99									
G252	249.1	3.24	79.1	--	--	--	--	--	--
Rainfall	28.4	0.37	9.0	--	--	--	--	--	--
L-7 Surficial Seepage	12.9	0.17	4.1	--	--	--	--	--	--
L-7 Deep Seepage	24.6	0.32	7.8	--	--	--	--	--	--
G253	--	--	--	258.5	3.36	90.3	--	--	--
Evapotranspiration	--	--	--	27.9	0.36	9.7	--	--	--
TOTALS	315.0	4.09	100.0	286.4	3.72	100.0	28.3	8.99	0.29
Treatment Cell 2 - 05/01/95 to 04/30/99									
G255	374.6	6.20	94.4	--	--	--	--	--	--
Rainfall	22.3	0.37	5.6	--	--	--	--	--	--
G254	--	--	--	345.0	5.71	73.5	--	--	--
Seepage	--	--	--	102.6	1.70	21.9	--	--	--
Evapotranspiration	--	--	--	21.6	0.36	4.6	--	--	--
TOTALS	396.9	6.57	100.0	469.1	7.77	100.0	-72.5	-18.26	0.22
Treatment Cell 3 - 05/01/95 to 04/30/99									
G253	258.5	4.38	83.6	--	--	--	--	--	--
Rainfall	21.8	0.37	7.1	--	--	--	--	--	--
L-7 Surficial Seepage	9.9	0.17	3.2	--	--	--	--	--	--
L-7 Deep Seepage	18.9	0.32	6.1	--	--	--	--	--	--
G251-G256	--	--	--	235.6	3.99	81.8	--	--	--
Seepage	--	--	--	30.8	0.52	10.7	--	--	--
Evapotranspiration	--	--	--	21.6	0.36	7.5	--	--	--
TOTALS	309.1	5.23	100.0	288.0	4.87	100.0	21.4	6.91	-0.29
Treatment Cell 4 - 05/01/95 to 04/30/99									
G254	345.0	16.06	97.8	--	--	--	--	--	--
Rainfall	7.9	0.37	2.2	--	--	--	--	--	--
G256	--	--	--	313.0	14.57	87.5	--	--	--
G258	--	--	--	0.1	0.00	0.0	--	--	--
Seepage	--	--	--	36.8	1.71	10.3	--	--	--
Evapotranspiration	--	--	--	7.8	0.36	2.2	--	--	--
TOTALS	352.9	16.43	100.0	357.7	16.65	100.0	-5.0	-1.42	0.15

a. Note that the period of record for the entire ENR Project is longer than the period for each individual cell; see text for explanation.

ruary 4, 1998, and July 17 to 30, 1998). However, excluding periods of time when G252 was closed resulted in relatively little change to the distribution of flow between the eastern and western flow-ways in water budget calculations.

There was good agreement between rolling three-month inflow water loads and corresponding outflows for each cell (**Figure 6-14**). Flow through the culverts accounted for at least 68 percent of the inflow and outflow water volumes in each water budget. Remainders to the cell water budget ranged from –18.3 to 9.2 percent of the total inflow volume (**Table 6-5**). Three remainders were positive, which signifies a greater inflow than outflow or a net gain in water to the budget. If this were a true gain in water volume, it should be reflected in the magnitude of change in storage of each cell. However, inspection of the data revealed that this was not the case. Water unaccounted for in each budget was attributed to estimation errors for the various sources of flow. One possible source of error is the values used for inflow and outflow of deep groundwater seepage, which was modeled simply in our water budgets. The District contracted with the United States Geological Survey (USGS) to conduct a study of groundwater infiltration and upwelling in the ENR Project. The findings from this study may improve our seepage estimates (the final project report was received from USGS in late August 1999 and is currently being reviewed by District staff). Another source of uncertainty in our water budgets is accounting for seepage between cells through internal levees when stage differed between the eastern and western flow-ways (**Figure 6-15**). Large stage differences (e.g., August 1997 through February 1998) would generate seepage along the head gradient dependent on the porosity of these levees. At this time our water budgets do not account for inter-cell seepage, but it is a feature we plan to add in the future. As noted for the entire project, the change in storage for each cell was a small component of each cell water budget (**Table 6-5**). Median HRTs in the Buffer Cell and Treatment Cells 1, 2, 3 and 4 were 0.6, 14.8, 11.2, 7.2 and 4.6 days, respectively (**Figure 6-12**). Three-month average water depths in all cells were moderately correlated with the corresponding water loading rates (**Figure 6-16**).

PHOSPHORUS MASS BALANCE BUDGET

Data collection and analysis

An extensive set of water quality measurements exists for the ENR Project. A list of the sample type, sampling frequency and sample locations for all water quality parameters that have been monitored in the ENR Project as a requirement of the DEP operating permit is presented in **Appendix 6-1**. An annotated list of the research and monitoring activities in the ENR Project that supplied data to support the calculation of a P mass balance budget is provided in the Chimney and Moustafa (1999). Analyses of ENR Project treatment performance for various time periods since the start of operations are presented in SFWMD (1995a, 1996, 1997, 1998a, 1999), Moustafa et al. (1999b) and Moustafa (1999). Sampling locations in the ENR Project are indicated in **Figure 6-2**. Water quality samples for TP analysis were collected as follows: (a) flow-proportioned composite samples were collected on a weekly basis using autosamplers at the Inflow, Outflow and Seepage Return Pumps; (b) composite rainfall and dry deposition samples were collected separately a weekly basis at a single wet/dry deposition sampler located along the G252 levee on; and (c) seepage entering the ENR Project from WCA-1 was sampled on quarterly at three shallow wells (~ 10 to 20 m deep) located along the L-7 levee. All TP samples were acid preserved in the field and analyzed following standard laboratory protocols (EPA method 365.3). Additional information on general field sampling and laboratory procedures is provided in SFWMD (1995b). Details on the ENR Project water quality sampling program can be found in SFWMD (1995a, 1996, 1997, 1998a, 1999).

The performance of the entire ENR Project relative to its ability to remove nutrients, specifically TP, from surface water was evaluated by examining (a) the difference in flow-weighted mean TP

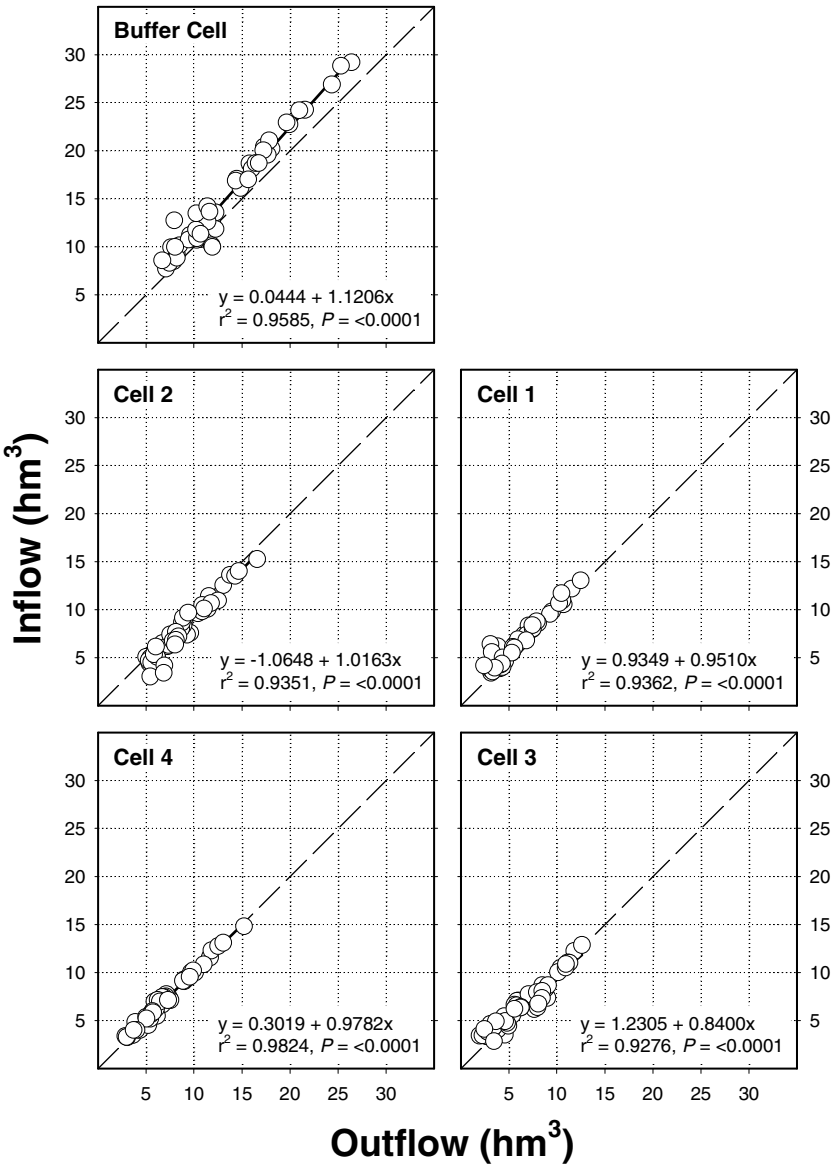

Figure 6-14. Comparison of 3-month rolling average inflow water loads with corresponding average total outflows loads (hm^3) for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 in the Everglades Nutrient Removal Project from May 1995 through April 1999. Heavy solid line represents best linear fit to the data. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

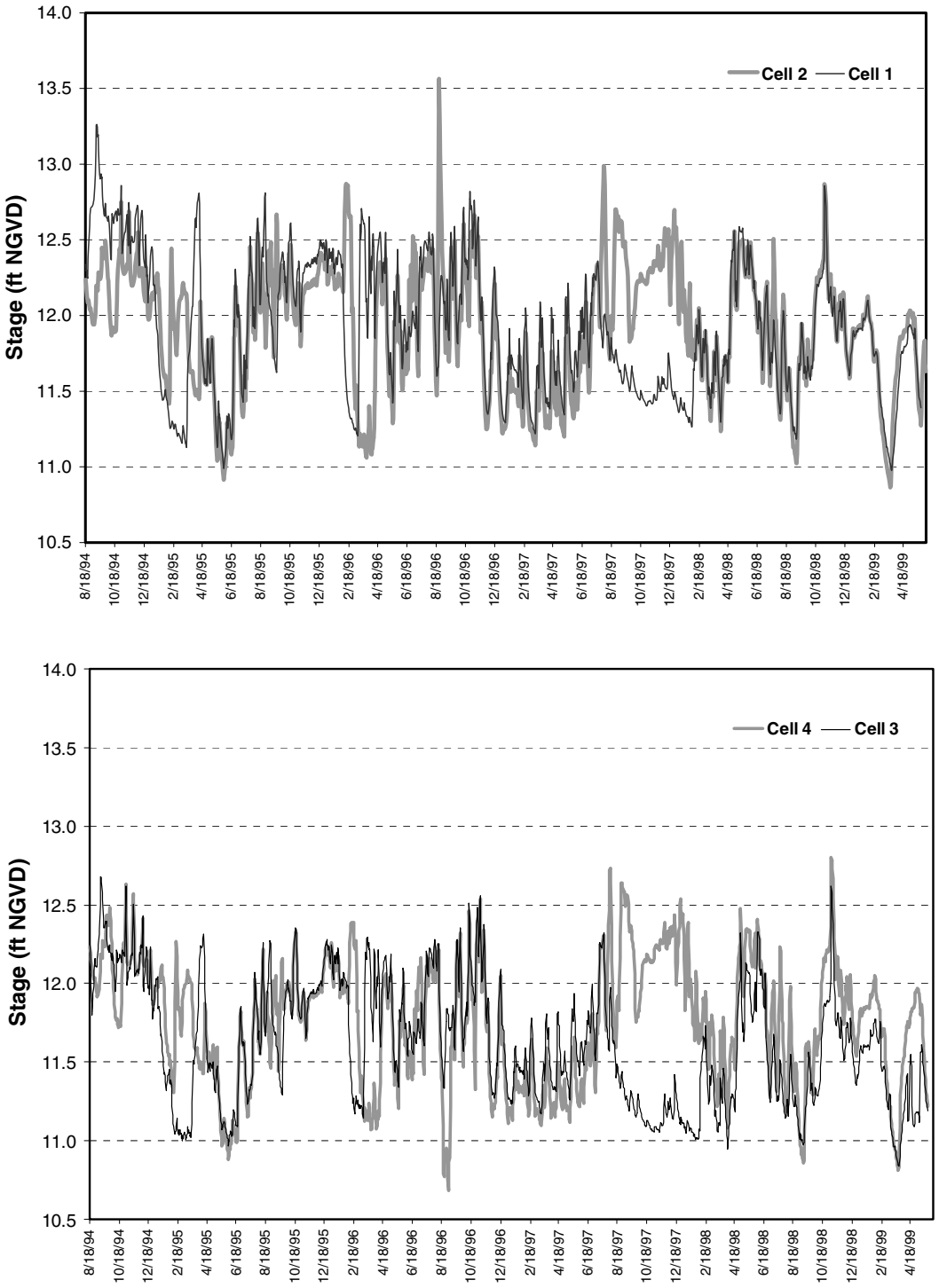

Figure 6-15. Daily stage (ft NGVD) in Everglades Nutrient Removal Project Treatment Cells 1, 2, 3 and 4 from August 1994 through April 1999.

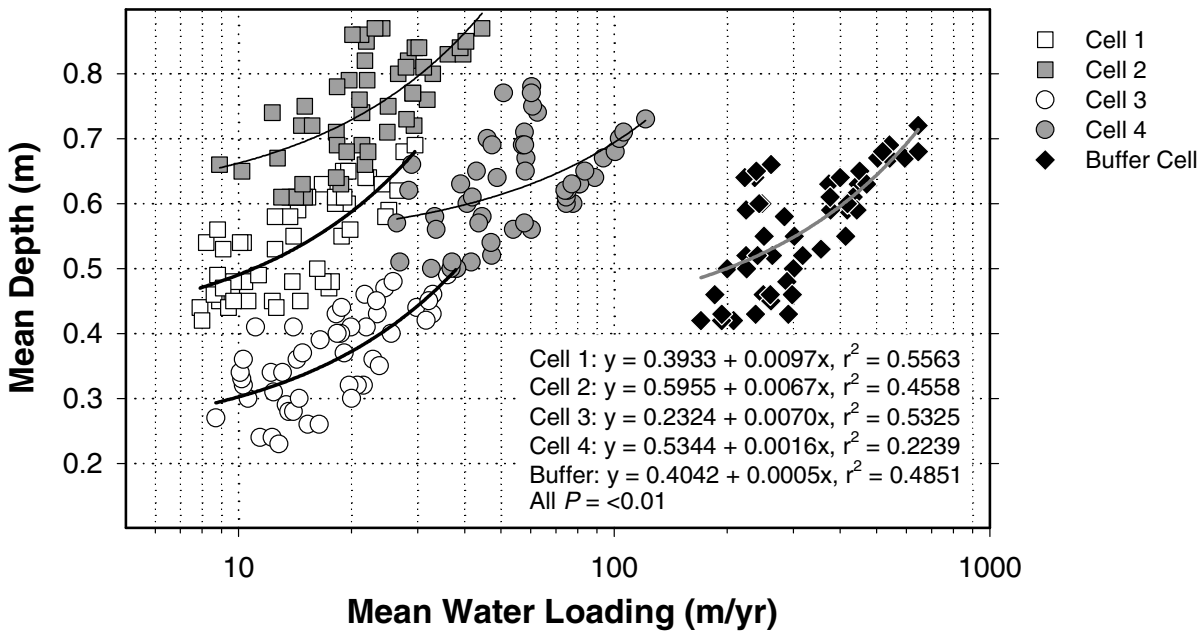

Figure 6-16. Comparison of mean water depth (m) with corresponding annualized water loading rate in the Buffer Cell and Treatment Cells 1, 2, 3 and 4 of the Everglades Nutrient Removal Project. Data have been smoothed using a three-month rolling average weighted for number of days in the month. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

concentrations measured in autosamplers at the Inflow and Outflow Pump Stations and (b) the reduction in TP load calculated as the difference between the mass exported from the project at the Outflow Pump Station relative to the total mass entering the ENR Project from all hydrologic sources. Flow-weighted mean nutrient concentrations were computed on an individual monthly and a 12-month rolling basis by first weighting each flow-proportioned sample value by the corresponding flow:

$$X_{in},\ X_{out} = \frac{\sum_{i=1}^{n}(C_1Q_1 + C_2Q_2 + \ldots C_iQ_i)}{\sum_{i=1}^{n}(Q_1 + Q_2 + \ldots Q_i)} \qquad (6.19)$$

where:

X_{in}, X_{out} = flow-weighted mean TP concentration at the ENR Project Inflow or Outflow Pump Stations (g/m^3);

C_1, C_2, C_i= TP concentration in the i^{th} flow-proportioned sample at the ENR Project Inflow or Outflow Pump Station (g/m^3); and

Q_1, Q_2, Q_i= total flow associated with the i^{th} flow-proportioned sample collected at the ENR Project Inflow or Outflow Pump Station (m^3).

All inflow and outflow TP values are reported as flow-weighted concentrations in this chapter.

The P mass balance budget calculated for the entire ENR Project incorporated daily TP loads associated with the Inflow, Outflow and Seepage Return Pumps, rainfall, L-7 surficial groundwater seepage and atmospheric dry deposition. Daily TP loads were calculated by multiplying daily water volumes derived from the water budget by the corresponding TP concentration in autosampler or rainfall samples collected during that time period:

$$L_{in} = \sum (C_{250}Q_{250} + C_{250s}Q_{250s} + C_{ss}Q_{ss} + C_{ds}Q_{ds} + C_rQ_r + \mathrm{D}) \qquad (6.20)$$

$$L_{out} = \sum (C_{251}Q_{251} + C_sQ_s) \qquad (6.21)$$

where:

L_{in} = daily TP load entering the ENR Project (kg/day);

L_{out} = daily TP load leaving the ENR Project at the Outflow Pump Station (kg/day);

C_{250} = Inflow Pump Station flow-proportioned TP concentration (kg/m^3);

C_{250s}= Seepage Return Pump flow-proportioned TP concentration (kg/m^3);

C_{251} = Outflow Pump Station flow-proportioned TP concentration (kg/m^3);

C_{ss} = L-7 surficial groundwater seepage mean TP concentration (kg/m^3);

C_{ds} = deep groundwater seepage (kg/m^3);

C_r = rainfall TP concentration (kg/m^3);

Q_{250} = daily Inflow Pump Station flow (m^3/day);

Q_{250s}= daily Seepage Return Pump flow (m^3/day);

Q_{251} = daily Outflow Pump Station flow (m^3/day);

Q_{ss} = daily surficial seepage flow (m^3/day);

Q_{ds} = daily deep groundwater seepage flow (m^3/day);

V_r = daily volume of rainfall deposited over the entire ENR Project (m^3/day); and

D = TP load associated with dry deposition over the entire ENR Project (kg/day).

The daily TP load associated with dry deposition was calculated as:

$$D = \frac{\left(\frac{M}{B}\right) \times A}{\Delta t} \qquad (6.22)$$

where:

D = TP load associated with dry deposition over the entire ENR Project (kg/day);

M = TP mass in dry deposition bucket (kg);

B = size of opening at top of bucket (0.0638 m^2); and

Δt = number of days over which the sample was collected.

At the recommendation of an expert panel (McDowell et al., 1997), the District temporarily suspended its atmospheric dry deposition sampling program in October 1997 due to problems associated with excessive sample contamination (e.g., bird droppings, insects, local recycling of dust particles, plant material, etc.). The panel concluded that the passive collection methodology used by the District (5-gallon, white plastic bulk containers left open to the atmosphere) did not efficiently collect all size classes of dry particles. Positioning the collectors near ground level may exacerbate contamination problems associated with bird roosting and resuspended dust. Furthermore, white buckets may actually attract insects. Resumption of this sampling program is dependent upon a successful resolution of these problems.

It was assumed that the entire surface area of the ENR Project was involved in nutrient removal. The geometric mean TP concentration based on all quarterly water quality samples collected from the L-7 levee wells (31 µg/L) was used in daily TP load calculations for both deep and surficial groundwater seepage coming from WCA-1. Total P load reduction was computed using daily total inflow TP loads (Inflow Pumps + Seepage Return Pumps + rainfall + surficial and deep groundwater seepage + dry deposition) versus outflow loads (Outflow Pump Station + groundwater seepage) on a monthly and a 12-month rolling basis and expressed as a percent:

$$L_{reduction} = \frac{\sum L_{in} - \sum L_{out}}{\sum L_{in}} \times 100 \qquad (6.23)$$

Nutrient removal in wetlands is presumed to be directly proportional to the chemical and biological activity at a given location (Kadlec and Newman, 1992). The net apparent settling rate (k) is a proportionality constant that relates the nutrient removal rate to wetland surface area and surface water nutrient concentrations (Kadlec and Newman, 1992; Kadlec and Knight, 1996). For the design situation in which inflow water volume and TP concentration are known and considered to be fixed, the value used for the TP settling rate determines the required size of an STA to achieve a specified level of nutrient reduction. Settling rate constants were employed in the modeling work that predicted TP deposition in the ENR Project (Burns & McDonnell, 1992b) and in the sizing equation used to design the STAs (Burns & McDonnell, 1992a, 1993). Annualized TP settling rates were calculated for the ENR Project on a three-month rolling and cumulative basis using a first-order, area-based model corrected for the

background TP concentration, the k-C* model (Kadlec and Knight, 1996):

$$k = \frac{\left[\ln\left(\frac{C_{250} - C^*}{C_{251} - C^*}\right) \times q\right]}{y} \quad (6.24)$$

$$q = \left[\frac{(V_{250} + V_{251})/2}{A}\right] \times \left(\frac{365.25}{\Delta t}\right) \quad (6.25)$$

where:

k = TP settling rate (m/yr),

C* = background TP concentration (kg/m^3);

y = fractional distance through the wetland; and

q = annualized hydraulic loading rate (m/yr).

(note that settling rates calculated previously for the entire ENR Project have not been corrected for the background TP concentration (C*); Chimney and Moustafa, 1999; Moustafa, et al., 1999b). The k-C* model assumes that the wetland experiences constant plug flow without appreciable groundwater infiltration (Kadlec, 1999). This assumption is not true for most wetlands systems, whose hydraulic characteristics can be modeled more accurately as a series of constantly stirred tank reactors (Kadlec, 1994). In addition, Dr. Robert Kadlec has proposed additional modifications to the k-C* model that correct C* for the effects of P loading from wetland sediments, rainfall, groundwater infiltration and other ecological processes (R. Kadlec, personal communication; see Burns and McDonnell, 1999). At this time we do not have sufficient understanding of the flow dynamics within the ENR Project nor the influence of groundwater on P levels to implement the modifications noted above, but will attempt to do so in a future Report. Estimates of C* were derived from TP profile data (median values) for the eastern and western flow-ways collected during a period when TP levels at the Outflow Pump Station were fairly constant (June 1996 to April 1999). For this analysis, we used the optimization technique (Microsoft Excel® Solver; Microsoft® Corporation, Redmond WA) employed by Dr. Robert Knight in Burns and McDonnell (1999) to minimize the squared differences between observed and predicted median TP concentrations by optimizing C* and k in **Equation 6.24** rewritten in the form:

$$C_2 = C^* + \left[\frac{(C_1 + C^*)}{e^{(ky/q)}}\right] \quad (6.26)$$

where:

C_1 = inlet TP concentration (kg/m^3); and

C_2 = TP concentration at fractional distance through the wetland (kg/m^3);

Phosphorus mass balance budgets were calculated for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 as subsets of the budget for the entire project using derivations of the equations listed above. See the hydrology section of this chapter for a discussion of how water budgets were prepared for the individual cells.

Status of phosphorus research and monitoring

Monthly flow-weighted mean TP concentrations ranged from 57 to 201 µg/L at the Inflow Pump Station and from 10 to 39 µg/L at the Outflow Pump Station (**Figure 6-17**). Short-term variability in TP concentrations at the project inflow was potentially influenced by a variety of factors, including:

- The amount and timing of rainfall in the EAA sub-basin serviced by the S5A Pump Station (see **Figure 6-1**) influences the volume of runoff from upstream farm fields. Large releases

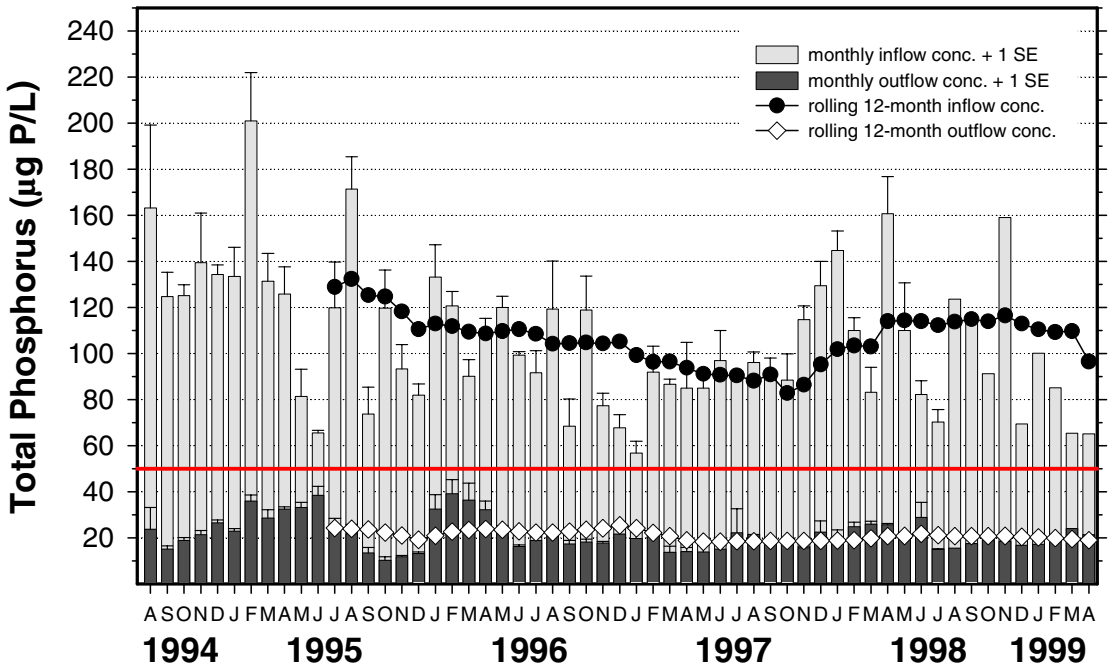

Figure 6-17. Monthly and 12-month rolling, flow-weighted total phosphorus concentrations (µg/L) at the Everglades Nutrient Removal Project Inflow and Outflow Pump Stations from August 1994 through April 1999. Heavy solid line indicates the total phosphorus target concentration of 50 µg/L. (µg/L = parts per billion [ppb] P).

over a short period of time dilute the nutrient concentration of water that eventually enters the West Palm Beach canal;

- Timing of rainfall relative to the seasonal crop cycle affects runoff from rainfall falling on fallow or recently harvested fields versus fields that still have a crop; time since last fertilizer application; burning and other crop management practices, etc.;
- The timing of water releases from the fields after a rain influences the nutrient content of runoff. Holding water as part of a BMP reduces the nutrient concentration of the runoff;
- The intensity and duration of pumping events at S5A Pump Station control flow velocities in the canals, which in turn influence resuspension of bottom sediment into the water column;
- Nutrient concentrations of water in the ENR Project Supply Canal (see **Figure 6-2**) were often greatly diluted by seepage from WCA-1 during periods of reduced or no pumping activity at the ENR Project Inflow Pump Station; and
- The West Palm Beach canal periodically conveyed large volumes of water from Lake Okeechobee southward into WCA-1. Lake water usually had lower nutrient levels compared to farm runoff, although lake stage affects water column TP concentration (i.e., higher stages enhance internal mixing which leads to increased sediment resuspension).

Because decisions to move water within the south Florida drainage system are often dictated by the timing and volume of rainfall over the region, there will probably be limited opportunity for the District to manage the system so as to influence inflow nutrient concentrations to the STAs on a consistent basis. Therefore, our approach to optimizing STA performance is focused on within-wetland operational strategies and not control of inflow nutrient loads.

The cumulative flow-weighted TP concentration at the Inflow Pump Station for the period of record was 106 µg/L, which was comparable to the anticipated inflow concentration in runoff from the EAA with best management practices (BMP) (134 µg/L; CH2M Hill, 1991). The cumulative flow-weighted TP concentration at the Outflow Pump Station during the same period was 22 µg/L. This difference represented a 79 percent concentration reduction through the system. Surficial + deep seepage and rainfall comprised 17.3 percent of inflow to the entire ENR Project (**Table 6-5**) but carried only 4.8 percent of the TP load (**Table 6-6**) and undoubtedly diluted the TP concentration in inflow waters to some extent. In addition, residual errors in balancing inflows with outflows were 3.0 percent of the annual water budget and, in part, may represent unmeasured inflow seepage. However, on a volume basis relative to the overall water budget, dilution due to seepage (both measured and potentially unmeasured) and rainfall could account for only a fraction of the TP concentration reduction observed in the ENR Project. We conclude that TP concentration reduction in the ENR Project was largely a function of nutrient removal by the wetland and not simply dilution of the inflow water by rainfall and seepage.

Twelve-month rolling TP concentrations at the outflow Pump Station ranged between 18.3 and 25.4 µg/L over the period of record, all of which were well below the 50 µg/L compliance limit (**Figure 6-17**). ***Based on the 12-month, rolling and cumulative TP data, the ENR Project achieved its secondary performance objective of reducing outflow TP concentrations to a "long-term" (as defined in the FDEP permit, i.e., on a 12-month rolling basis) average less than 50 µg/L during the period of record.***

TP loading to the ENR Project from the Inflow Pumps over the period of record (0.92 g $P/m^2/yr$) (**Table 6-6**) was less than one-half the anticipated TP loading that could be calculated using early design assumptions (2.08 g $P/m^2/yr$; CH2M Hill, 1991). Summary statistics for annual inflow and outflow TP loads, TP settling rate and TP load

Table 6-6. Summary of inflow and outflow total phosphorus loads (kg), annualized loading rates ($g/m^2/yr$) and phosphorus retained within the entire Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4[a].

	Inflow TP Load			Outflow TP Load			TP Retained			
TP Sources	**kg**	**$g/m^2/yr$**	**%**	**kg**	**$g/m^2/yr$**	**%**	**kg**	**$g/m^2/yr$**	**%[b]**	**%[c]**
Entire ENR Project - 08/18/94 to 04/30/99										
Inflow Pumps	75,502	0.99	88.3	--	--	--	--	--	--	--
Seepage Return Pumps	4,340	0.06	5.1	--	--	--	--	--	--	--
Rainfall	1,594	0.02	1.9	--	--	--	--	--	--	--
Deep+Surficial Seepage	2,451	0.03	2.9	--	--	--	--	--	--	--
Dry Deposition	1,600	0.02	1.9	--	--	--	--	--	--	--
Outflow Pumps	--	--	--	14,641	0.19	96.4	--	--	--	--
Seepage	--	--	--	542	0.01	3.6	--	--	--	--
TOTALS	85,487	1.12	100.0	15,182	0.20	100.0	70,305	0.92	82.2	82.2
Buffer Cell - 05/01/95 to 04/30/99										
Inflow Pumps	60,088	27.89	94.2	--	--	--	--	--	--	--
Seepage Return Pumps	3,641	1.69	5.7	--	--	--	--	--	--	--
Rainfall	46	0.02	0.1	--	--	--	--	--	--	--
Dry Deposition	36	0.02	0.1	--	--	--	--	--	--	--
G252	--	--	--	14,901	6.92	32.4	--	--	--	--
G255	--	--	--	28,734	13.34	62.6	--	--	--	--
Seepage	--	--	--	2,294	1.06	5.0	--	--	--	--
TOTALS	63,811	29.62	100.0	45,928	21.32	100.0	17,883	8.30	28.0	28.0
Treatment Cell 1 - 05/01/95 to 04/30/99										
G252	14,901	0.71	88.4	--	--	--	--	--	--	--
Rainfall	447	0.02	2.7	--	--	--	--	--	--	--
Surficial Seepage	401	0.02	2.4	--	--	--	--	--	--	--
Groundwater Seepage	763	0.04	4.5							
Dry Deposition	347	0.02	2.1	--	--	--	--	--	--	--
G253	--	--	--	9,945	0.47	100.0	--	--	--	--
TOTALS	16,859	0.80	100.0	9,945	0.47	100.0	6,914	0.33	41.0	10.8
Treatment Cell 2 - 05/01/95 to 04/30/99										
G255	28,734	0.46	97.9	--	--	--	--	--	--	--
Rainfall	351	0.01	1.2	--	--	--	--	--	--	--
Dry Deposition	272	0.00	0.9	--	--	--	--	--	--	--
G254	--	--	--	13,514	0.22	72.3	--	--	--	--
Seepage	--	--	--	5,166	0.08	27.7	--	--	--	--
TOTALS	29,357	0.47	100.0	18,681	0.30	100.0	10,676	0.65	36.4	16.7
Treatment Cell 3 - 05/01/95 to 04/30/99										
G253	9,945	0.61	86.9	--	--	--	--	--	--	--
Rainfall	343	0.02	3.0	--	--	--	--	--	--	--
Surficial Seepage	308	0.02	2.7	--	--	--	--	--	--	--
Groundwater Seepage	585	0.04	5.1							
Dry Deposition	266	0.02	2.3	--	--	--	--	--	--	--
G251-G256	--	--	--	8,606	0.53	89.6	--	--	--	--
Seepage	--	--	--	999	0.06	10.4	--	--	--	--
TOTALS	11,448	0.71	100.0	9,605	0.59	100.0	1,844	0.11	16.1	2.9

Table 6-6. Summary of inflow and outflow total phosphorus loads (kg), annualized loading rates ($g/m^2/yr$) and phosphorus retained within the entire Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4[a]. (Continued)

TP Sources	Inflow TP Load			Outflow TP Load			TP Retained			
	kg	$g/m^2/yr$	%	kg	$g/m^2/yr$	%	kg	$g/m^2/yr$	%[b]	%[c]
Treatment Cell 4 - 05/01/95 to 04/30/99										
G254	13,514	2.30	98.4	--	--	--	--	--	--	--
Rainfall	124	0.02	0.9	--	--	--	--	--	--	--
Dry Deposition	96	0.02	0.7	--	--	--	--	--	--	--
G256	--	--	--	6,287	1.07	86.2	--	--	--	--
Seepage	--	--	--	1,004	0.17	13.8	--	--	--	--
TOTALS	13,735	2.34	100.0	7,291	1.24	100.0	6,444	1.10	46.9	10.1

a. Note that the period of record for the entire ENR Project is longer than the period for each individual cell; see text for explanation.
b. Percent TP retained calculated relative to the amount of TP that entered only that individual cell.
c. Percent TP retained calculated relative to the amount of TP that entered the entire ENR Project.

reduction for the entire ENR Project are presented in **Table 6-4**. Inspection of monthly TP load data indicated that the ENR Project was loaded much more heavily during the first two water years compared with the last three years (**Figure 6-18**); differences in TP loading were similar to the pattern observed for water loading (**Figure 6-10**). On a cumulative basis, the project has removed 70.3 metric tons of TP from all inflow sources relative to the TP mass discharged at the Outflow Pump Station to date (**Table 6-6**). ***Despite the fact that the ENR Project was not loaded as heavily as design estimates, all 12-month rolling load reduction estimates ranged from 78 to 86 percent*** (**Figure 6-19**)**,** ***and the cumulative load reduction was 82 percent. This exceeded the primary FDEP operating permit criterion (up to 75 percent reduction) and project design assumptions*** (Chimney and Moustafa, 1999)***. The ENR Project has achieved its primary performance objective for "long-term" (as defined in the FDEP permit, i.e., on a 12-month rolling basis) TP load reduction during its operation.***

Analysis of median TP profile data for the entire period of record resulted in a C* of 24.2 µg/L for the eastern flow-way (stations G250 to G251 [**Figure 6-2**]) and a C* of <0.1 µg/L for the western flow-way (stations G250 to G256 [**Figure 6-2**]) (**Figure 6-20**). We think that the calculated C* for the eastern flow-way was an overestimation based on the fact that monthly flow-weighted TP concentrations at the Outflow Pump Station were less than this value on a number of occasions (**Figure 6-17**). The calculated C* value for the western flow-way was unrealistically low. We elected to use the TP Method Detection Limit of 4 µg/L as a conservative estimate of C* in our calculation of TP settling rates. Three-month rolling TP settling rates for the entire ENR Project ranged from 6.6 to 44.8 m/yr (**Figure 6-21**). The corresponding 57 month cumulative TP settling rate was 18.4 m/yr, which exceeds the design criteria for the STAs of 10.2 m/yr (Burns and McDonnell, 1993). A sensitivity analysis of k to changes in input parameters (**Equation 6.24**) was performed using the data from **Figure 6-21**; the settling rate was most sensitive to decreasing wetland surface area and increasing hydraulic loading rate (**Figures 6-22**). Increasing the value of C* has a positive effect on the corresponding value of k. The median change in TP setting rate for the ENR Project data using C* = 4 µg/L was only approximately 12 percent greater than k calculated using C* = 0 µg/L. ***The performance of the ENR Project, as reflected in its cumulative TP settling rate over the period of record, suggests that the TP settling rate used to design the STAs was conservative and should provide an adequate margin of error to accommodate any decrease in treatment performance that may occur as these systems mature over time.***

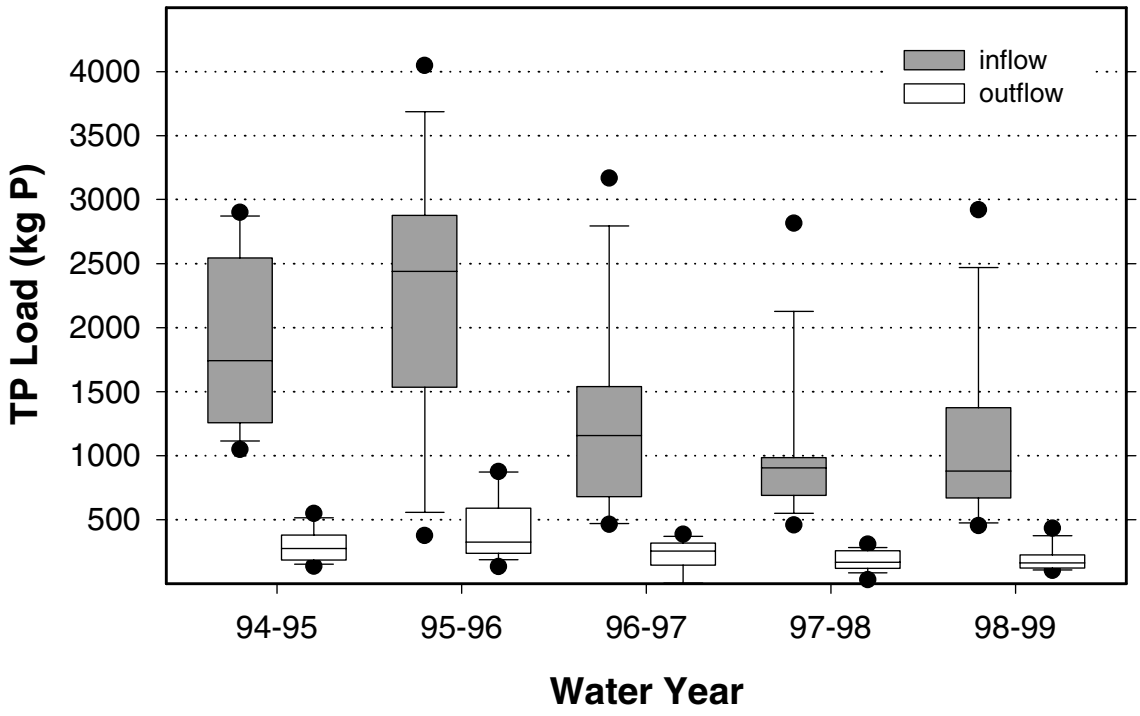

Figure 6-18. Box plots of monthly total inflow and outflow total phosphorus loads (kg P) for the entire Everglades Nutrient Removal Project summarized by water year from August 1994 through April 1999. See **Figure 6-7** for description of box plots.

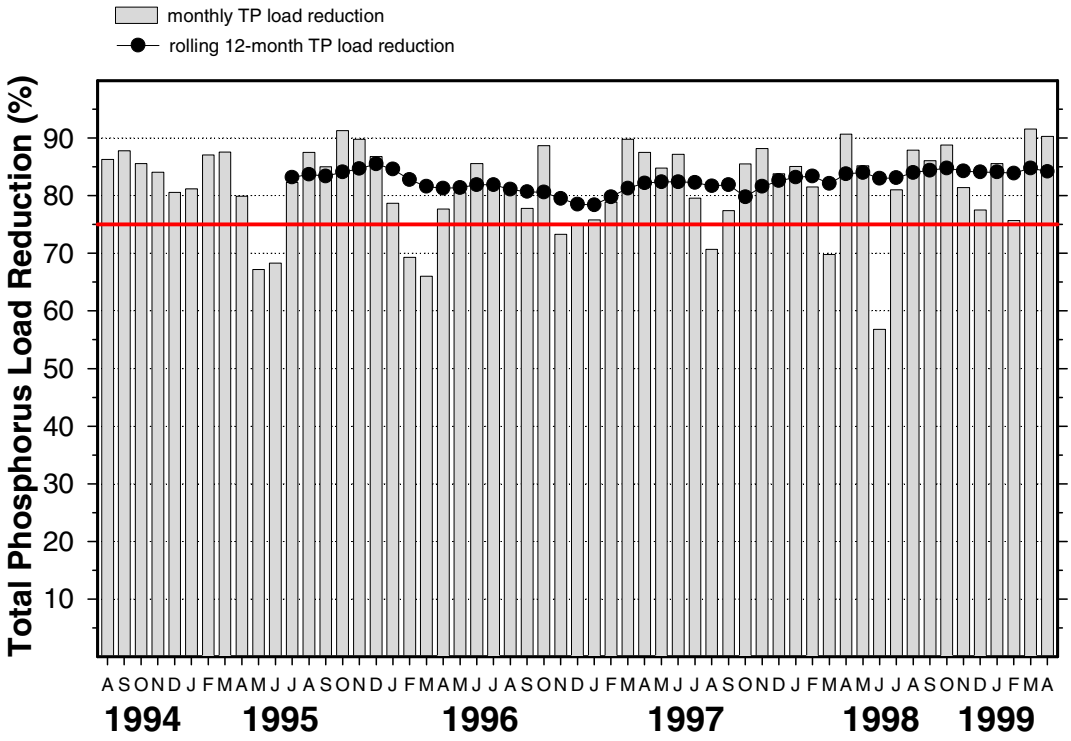

Figure 6-19. Monthly and 12-month rolling total phosphorus load reduction estimates (%) for the entire Everglades Nutrient Removal Project from August 1994 through April 1999. Heavy solid line indicates the total phosphorus target load reduction of 75%.

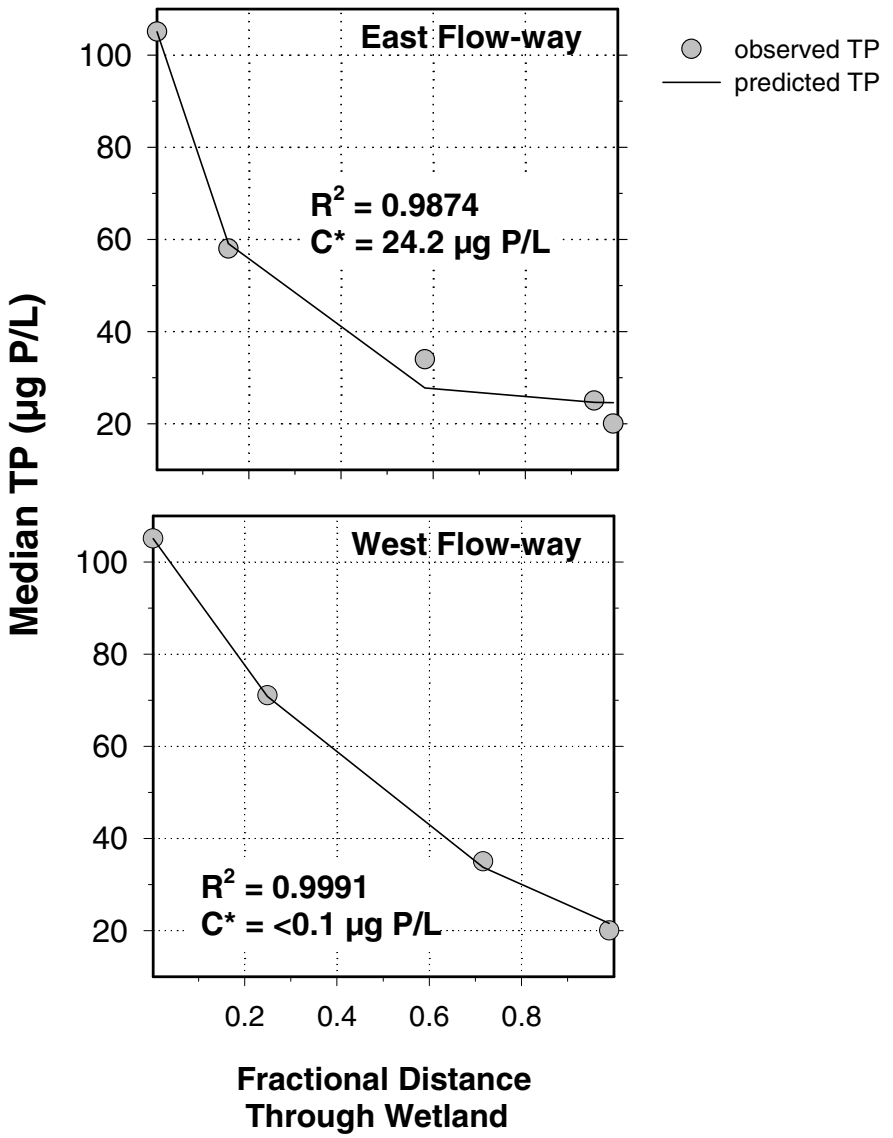

Figure 6-20. Estimates of background total phosphorus (C*) (µg/L) based on analysis of median TP concentrations in the east and west flow-ways of the Everglades Nutrient Removal Project for the entire period of record, August 1994 through April 1999.

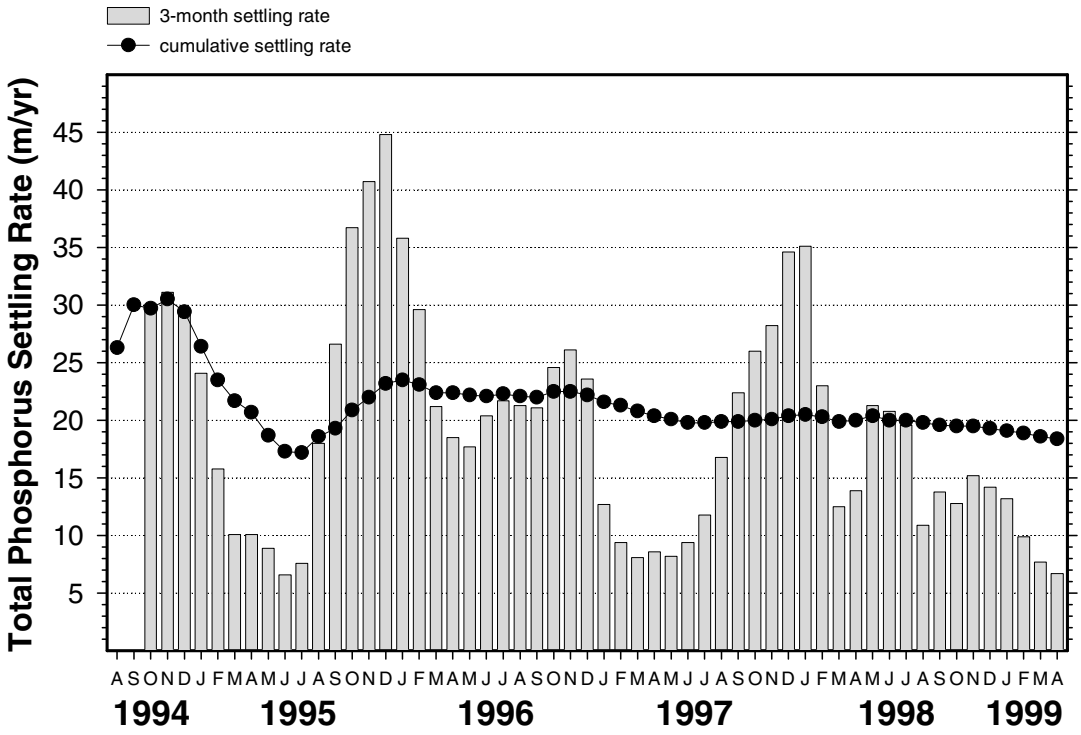

Figure 6-21. Three-month rolling and cumulative total phosphorus settling rates (m/yr) for the entire Everglades Nutrient Removal Project from August 1994 through April 1999.

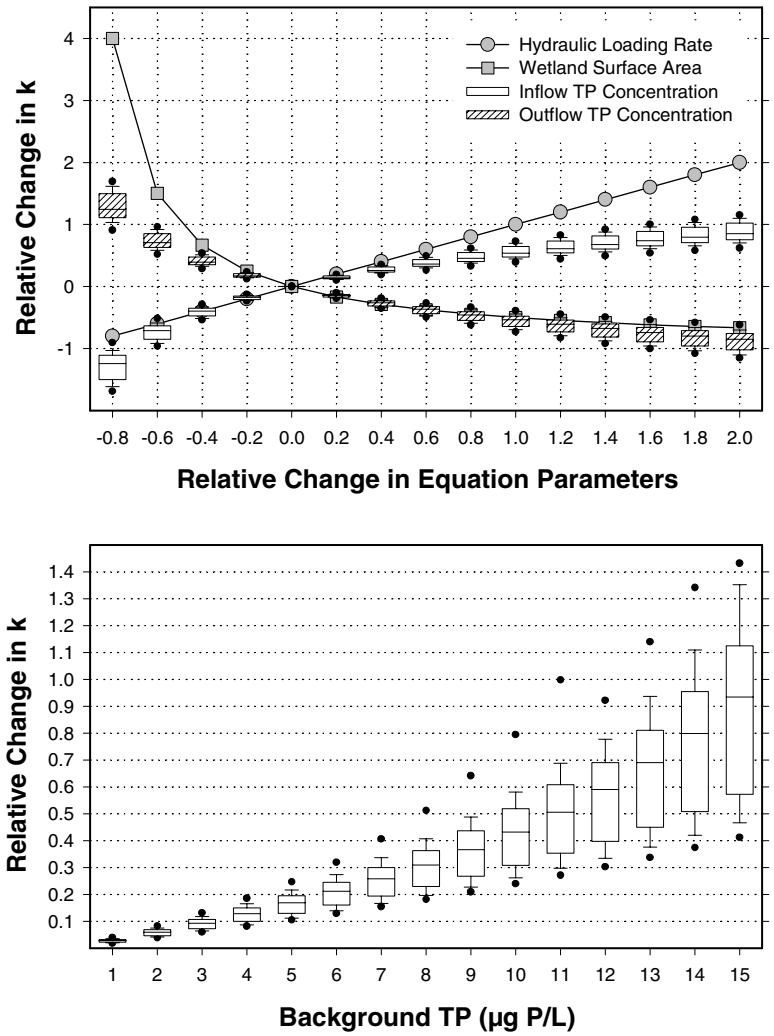

Figure 6-22. Sensitivity of the total phosphorus settling rate (k) to changes in input parameters in equation 6.24. Top panel: sensitivity of k to changes in hydraulic loading rate, wetland surface area, inflow TP concentration and outflow TP concentration. Bottom panel: sensitivity of k to changes in wetland background TP concentration. Sensitivity analysis was based on data used to calculate k values presented in Figure 6-21. See Figure 6-7 for description of box plots.

Dry deposition accounted for a relatively small portion of the overall TP budget (1.9 percent of TP over the entire period of record [**Table 6-6**] and 2.5 percent of TP for the period during which dry deposition was collected [August 1994 to September 1997]). While it is unfortunate that this inflow source of P to the ENR Project is not actively being monitored, the loss of these data is not considered to have seriously compromised the overall accuracy of our TP mass balance budget.

Concentrations of the different forms of P (TP, soluble reactive P [SRP], particulate P [PP] and dissolved organic P [DOP]) were reduced with varying degrees of efficiency as water moved through the eastern and western flow-ways of the ENR Project. The form of P most available to plants and algae, SRP, was removed from the water column quite readily and was often substantially reduced within the Buffer Cell alone (**Figures 6-23 and 6-24**). Concentrations of PP were reduced, although not as effectively as noted for SRP. Wetlands are generally thought of as being efficient traps for water-borne particles (Bastian and Hammer, 1993; Kadlec and Knight, 1996; Reed, et al., 1998). However, wetlands can also generate particles internally through a variety of mechanisms, such as sloughing of cells from periphyton mats, decomposition of macrophyte and animal tissues and resuspension of bottom sediments and litter material (Mitsch and Gosselink 1993; Kadlec and Knight, 1996). The PP that entered the ENR Project was not necessarily the same material that existed at the outflow. The concentration of DOP was not reduced by any appreciable amount. In fact, its relative downstream concentration increased in most years.

The cells within the ENR Project varied markedly in their individual TP removal performance (**Figure 6-25** and **Table 6-6**). Of the 43,761 kg of TP retained by the entire project from May 1995 through April 1999, most TP by weight was removed by the Buffer Cell (17,883 kg P). The western flow-way retained almost twice the mass of TP (17,120 kg P) than the eastern flow-way (8,758 kg P), which is impressive considering that the western flow-way is only 60 percent the size of the eastern flow-way (**Table 6-3**). The highest performance on a relative load removal basis was in Treatment Cell 4, which retained 46.9 percent of incoming TP followed in order by Treatment Cell 1 which retained 41.0 percent of incoming TP, Treatment Cell 2 which retained 36.4 percent, the Buffer Cell which retained 28.0 percent, and the lowest retention was in Treatment Cell 3 with only 16.1 percent (**Table 6-6**). However, on an aerial removal basis, the Buffer Cell had the highest performance (8.30 g $P/m^2/yr$) followed by Treatment Cell 4 (1.10 g $P/m^2/yr$), Treatment Cell 2 (0.65 g $P/m^2/yr$), Treatment Cell 1 (0.33 g $P/m^2/yr$) and Treatment Cell 3 (0.11 g $P/m^2/yr$).

Total P settling rates were markedly higher in the Buffer Cell and Treatment Cell 4 than in the remainder of the ENR Project throughout much of the period of record, while TP settling rates in Treatment Cell 2 were often higher than in either Treatment Cells 1 or 3 (**Figure 6-26**). Difference in TP removal between the eastern and western flow-ways may be explained to some extent by the fact that the western flow-way was loaded more heavily than the eastern cells (14,901 vs. 28,734 kg P and 249.1 vs. 374.6 hm^3 exited the Buffer Cell into Treatment Cells 1 and 2, respectively; **Tables 6-5** and **6-6**) and possibly by real differences in treatment performance related to the species composition or physiological efficiency of the vegetation community in each flow-way. In addition, deep groundwater seepage into the eastern flow-way from WCA-1 (see **Figure 2-8** in **Chapter 2**) may have transported sufficient P to have reduced the treatment performance of these cells relative to the western flow-way, which was not influenced by groundwater inflow. We are currently working with the USGS to better understand the contribution of deep seepage flow to water and TP mass balance budgets in the eastern flow-way.

In general, three-month rolling average TP settling rates were positively correlated with the corresponding TP loading rate, hydraulic loading rate, and water depth and negatively correlated with the nominal hydraulic residence time (**Figures 6-27** to

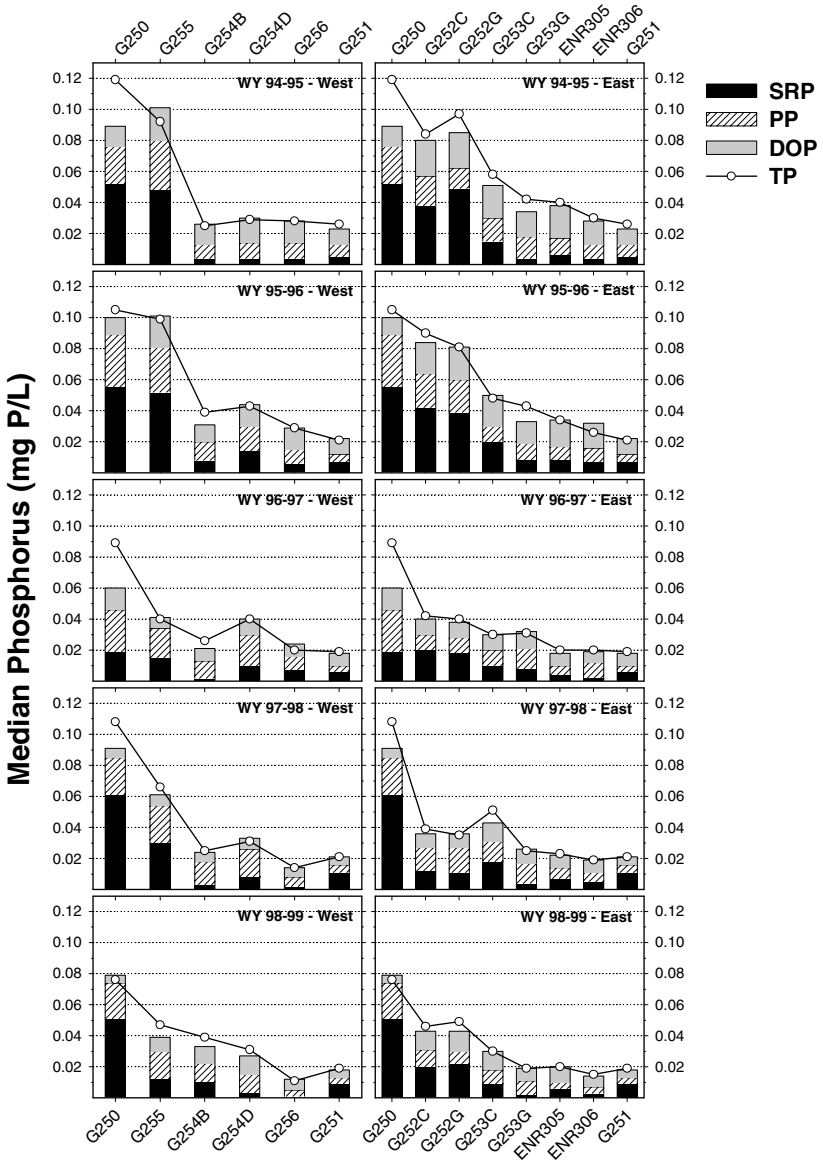

Figure 6-23. Downstream change in median concentrations of different forms of phosphorus (mg/L). Locations are sampling stations in the eastern and western flowways in the Everglades Nutrient Removal Project summarized by water years from August 1994 through April 1999. SRP = soluble reactive phosphorus; PP = particulate phosphorus; DOP = dissolved organic phosphorus; TP = total phosphorus; WY = water year. Refer to Figure 6-2 for location of sampling stations.

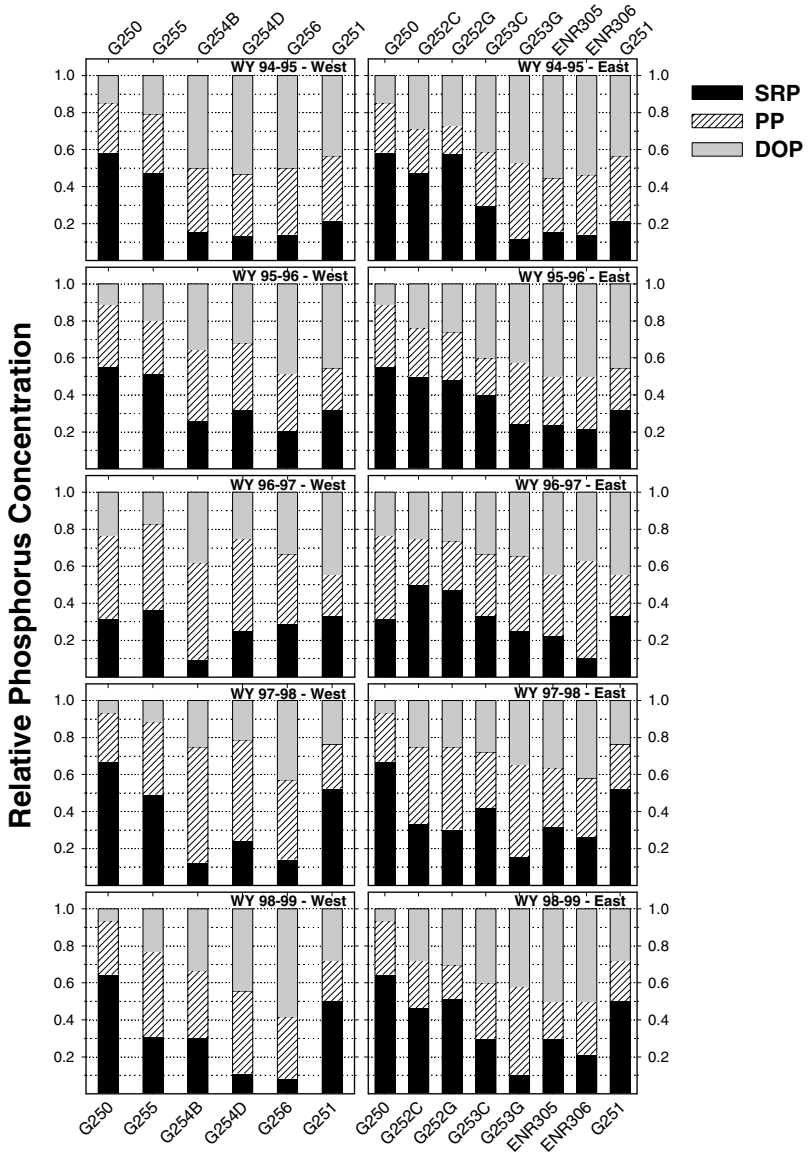

Figure 6-24. Downstream change in relative concentrations of different forms of phosphorus at sampling stations in the eastern and western flow-ways in the Everglades Nutrient Removal Project summarized by water years from August 1994 through April 1999. SRP = soluble reactive phosphorus; PP = particulate phosphorus; DOP = dissolved organic phosphorus; TP = total phosphorus; WY = water year. Refer to Figure 6-2 for location of sampling stations.

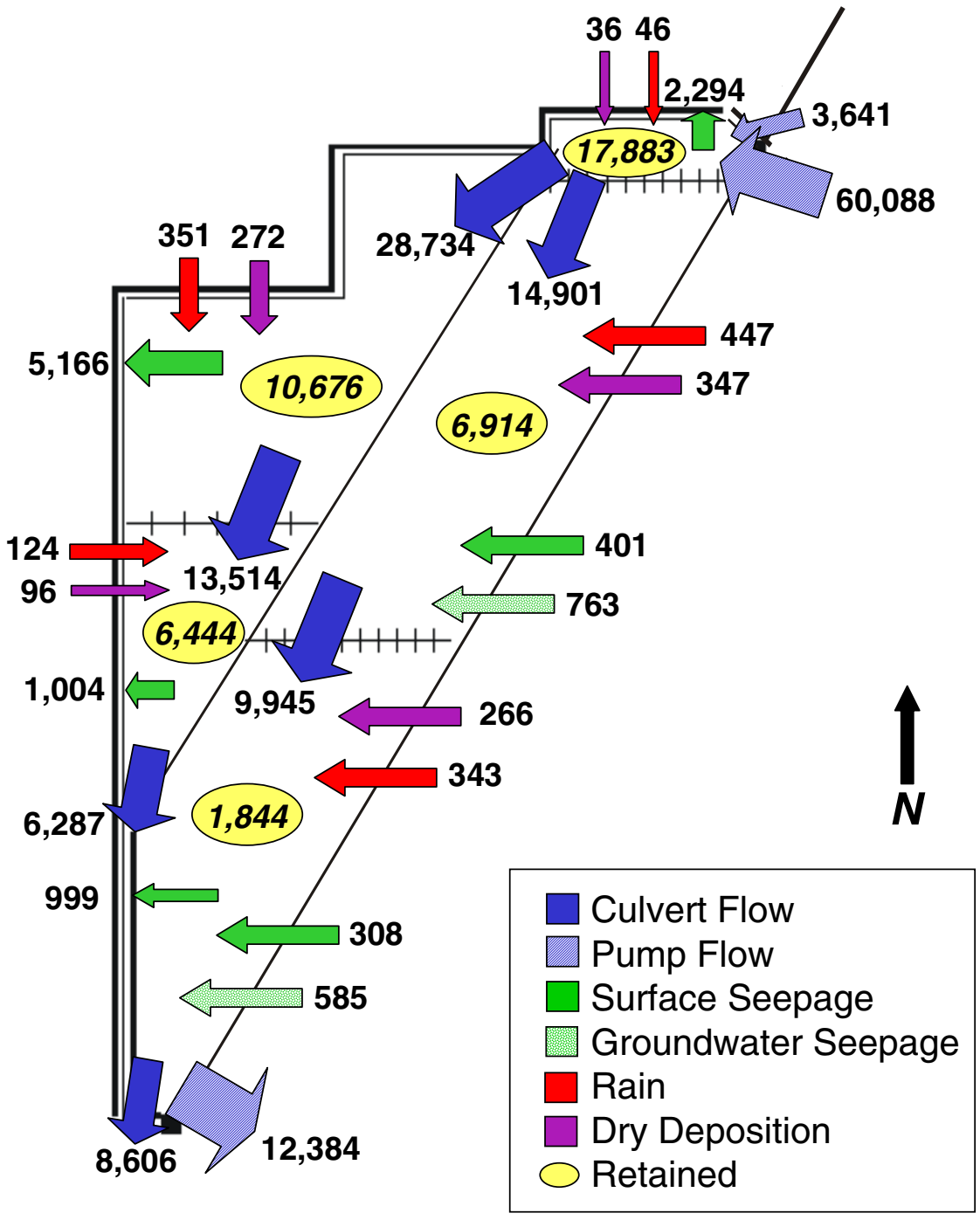

Figure 6-25. Measured and estimated total phosphorus loads (kg P) used to compute mass balance budgets for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 in the Everglades Nutrient Removal Project from May 1995 through April 1999.

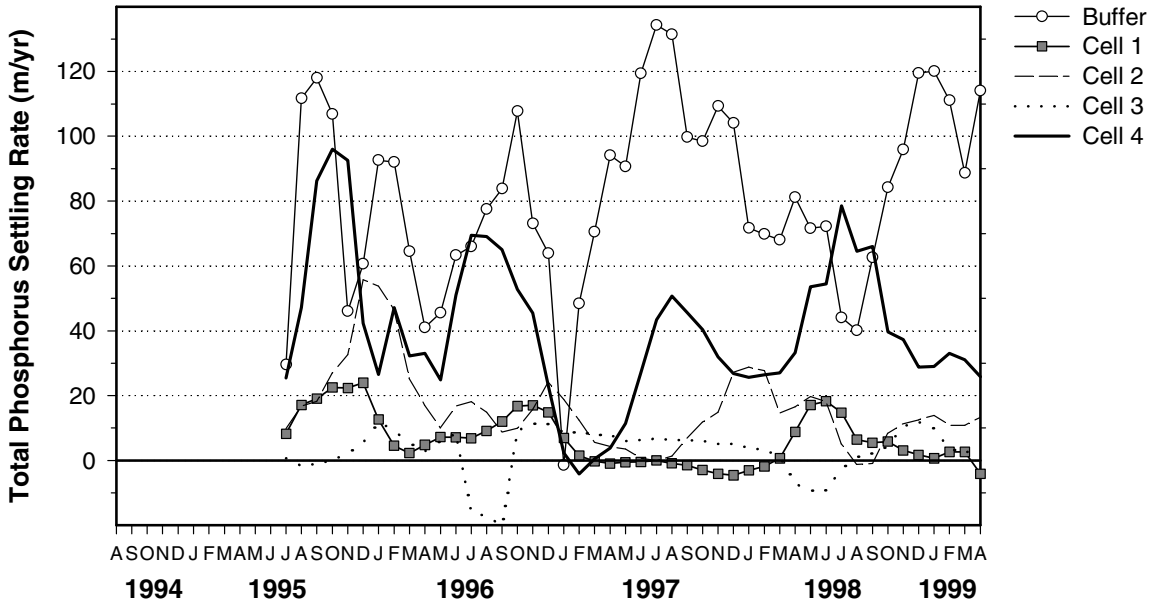

Figure 6-26. Three-month rolling average total phosphorus settling rates (m/yr) for the Buffer Cell and Treatment Cells 1, 2, 3 and 4 in the Everglades Nutrient Removal Project from July 1995 through April 1999.

6-30). However, these trends were not evident in data from the Buffer Cell and Treatment Cell 3. Flow-weighted outflow TP concentrations were positively correlated with corresponding TP and hydraulic loading rates and negatively correlated with nominal hydraulic residence time (**Figures 6-31** to **6-33**). The correlation of flow-weighted outflow TP concentrations with water depth was positive for the Buffer Cell and Treatment Cell 3, negative for Treatment Cell 4 and not statistically significant for all other cell comparisons (**Figure 6-34**).

Results from the ENR Project to date have validated the premise that treatment wetlands (i.e., STAs) constructed on former agricultural land can effectively reduce TP levels in EAA runoff and achieve an average outflow concentration no greater than 50 µg/L. However, the ENR Project's Inflow Pump Station lacked the pumping capacity to fully mimic the large pulsed flows that the STAs will experience during severe storm events. An evaluation of treatment efficacy under pulsed-flow operating conditions will come from test cell research, modeling efforts described below and practical experience gained once the STAs are operated under pulsed-flow conditions.

On an individual cell basis, Treatment Cell 4 achieved the best treatment performance based on relative and areal TP load removal. These results suggest that SAV/periphyton, the dominant plant community in this cell, was more efficient at removing TP than either the mixed marsh or cattail dominated communities in the rest of the ENR Project. However, this observation is complicated by several confounding factors, i.e., differences among cells in hydraulic loading rate, TP loading rate, HRT and depth, and influence of groundwater seepage into the two flow-ways. It is important to note that the ENR Project was designed as a large-scale demonstration project and not as a replicated experiment, so the differences among cells noted above were not unexpected. A more controlled comparison of the nutrient removal performance of SAV/periphyton with other vegetation should come from experiments planned for the test cells.

PHOSPHORUS CYCLING AND REMOVAL

Short-term P removal mechanisms postulated for the ENR Project and the STAs include (a) particulate material settling out of the water column; (b) precipitation of calcium (Ca), aluminum (Al) and iron (Fe) phosphate salts; (c) sorption to a variety of substrates; and (d) direct uptake by periphyton and macrophytes. The long-term removal mechanism is the continuous accretion and burial in the bottom sediments of all these materials. These processes have been demonstrated to be important in the biogeochemical cycling of nutrients in both natural and treatment wetlands (e.g., Richardson, 1985; Kadlec and Newman, 1992; Mitsch et al., 1995; Kadlec and Knight, 1996; Reed, et al., 1998; Reddy, et al., 1999b). Understanding key mechanisms that mediate P cycling in wetlands is critically important to understanding how these systems work and is necessary for building water quality models that simulate nutrient removal. Building a predictive model is an essential component of the District's STA Optimization Research Program. This Report includes summaries of the status of four research efforts that were initiated to provide data on P cycling and removal mechanisms:

- Sediment accretion and phosphorus storage,
- Nutrient uptake by submerged aquatic vegetation,
- Plant decomposition, and
- The effects of marsh dry out on soil P mobilization upon reflooding of the wetland.

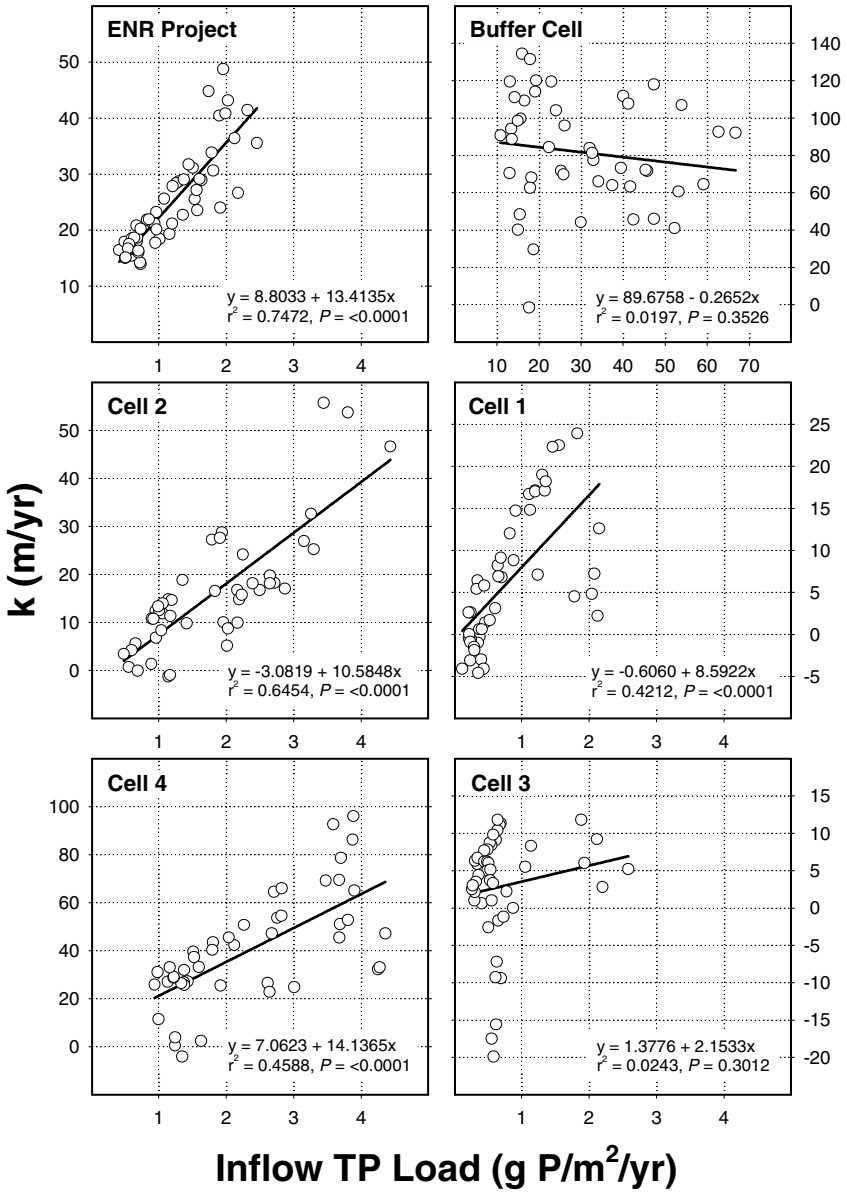

Figure 6-27. Comparison of three-month rolling average total phosphorus settling rates (m/yr) with corresponding average total phosphorus loading rates (g $P/m^2/yr$) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

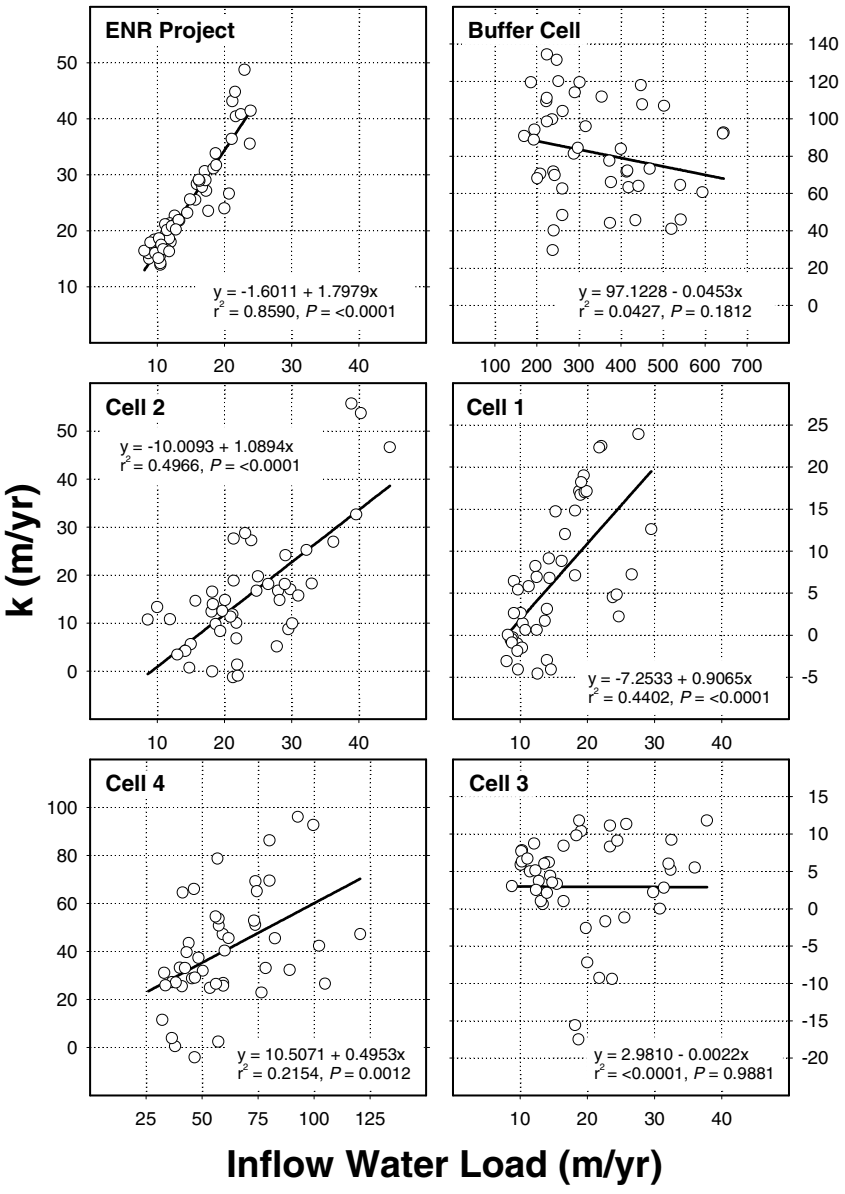

Figure 6-28. Comparison of three-month rolling average total phosphorus settling rates (m/yr) with corresponding average hydraulic loading rates (m/yr) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

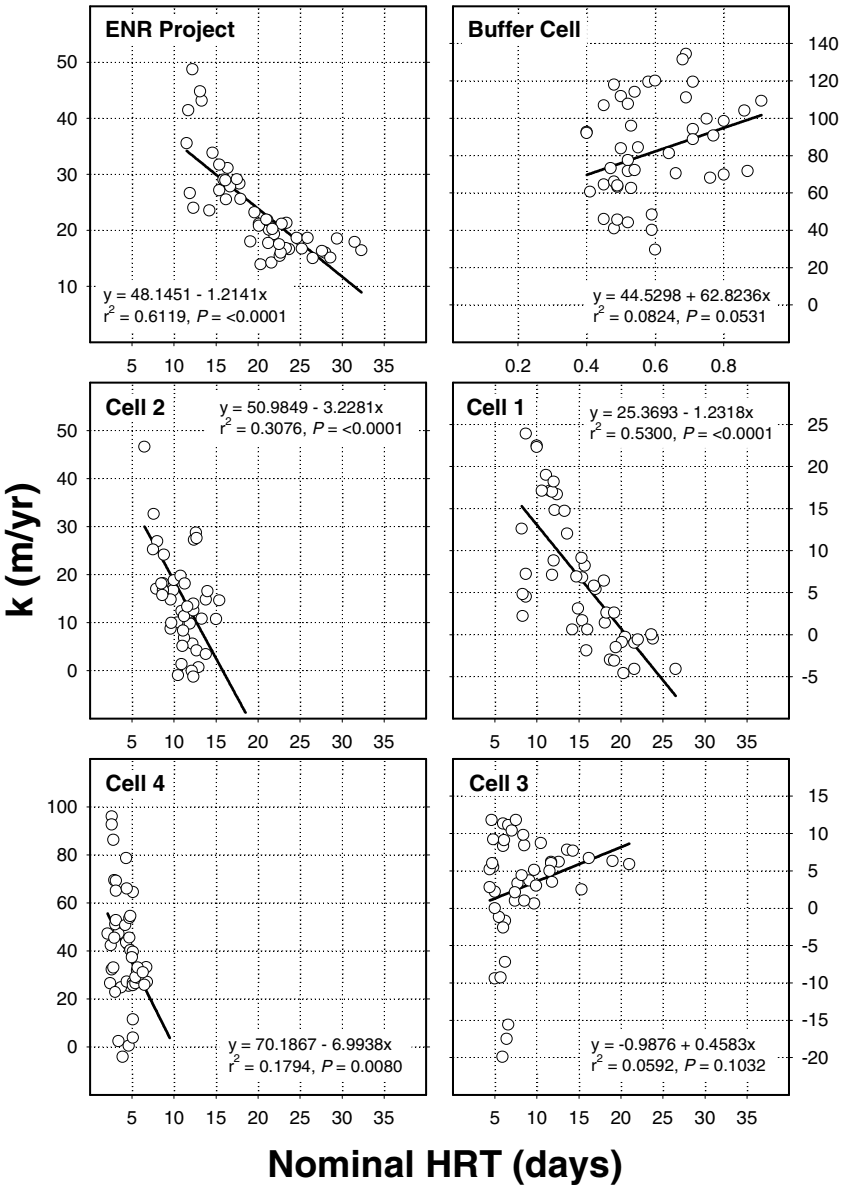

Figure 6-29. Comparison of three-month rolling average total phosphorus settling rates (m/yr) with corresponding average nominal hydraulic residence times (days) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

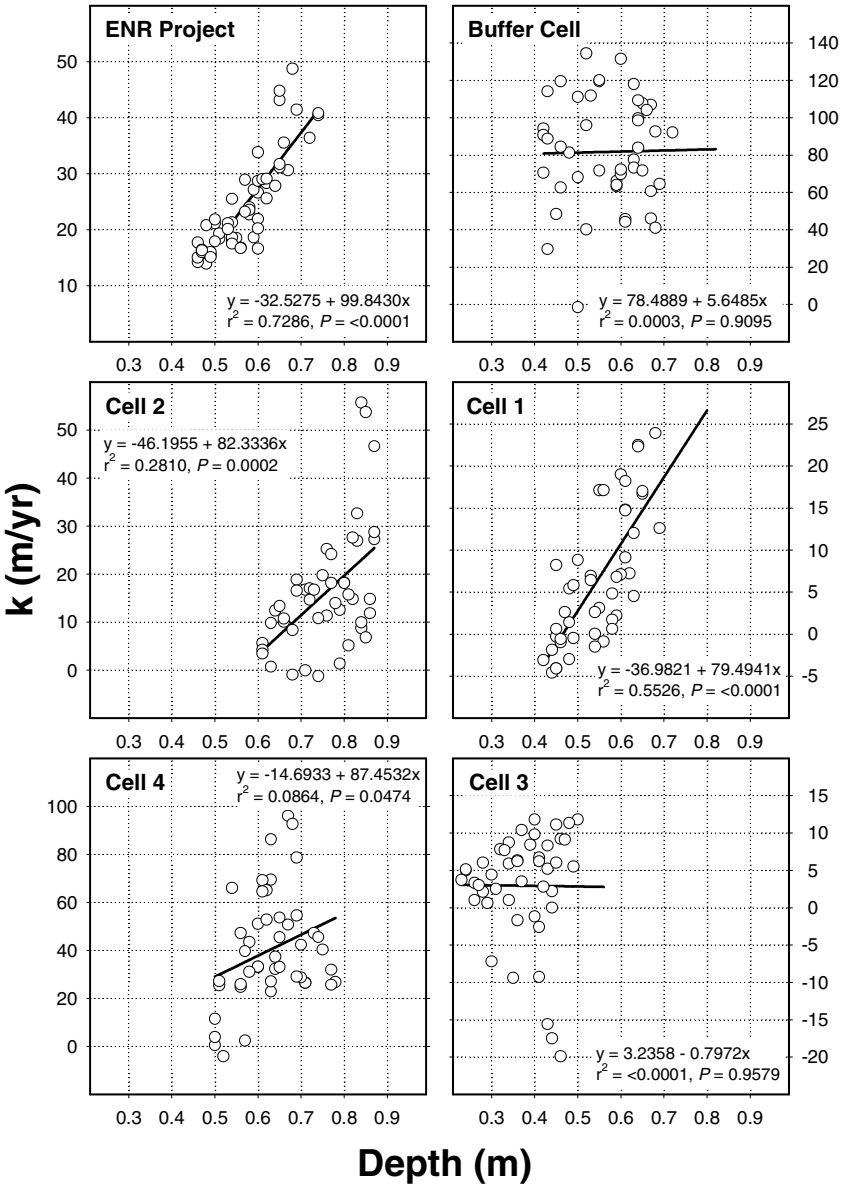

Figure 6-30. Comparison of three-month rolling average total phosphorus settling rates (m/yr) with corresponding average water depths (m) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

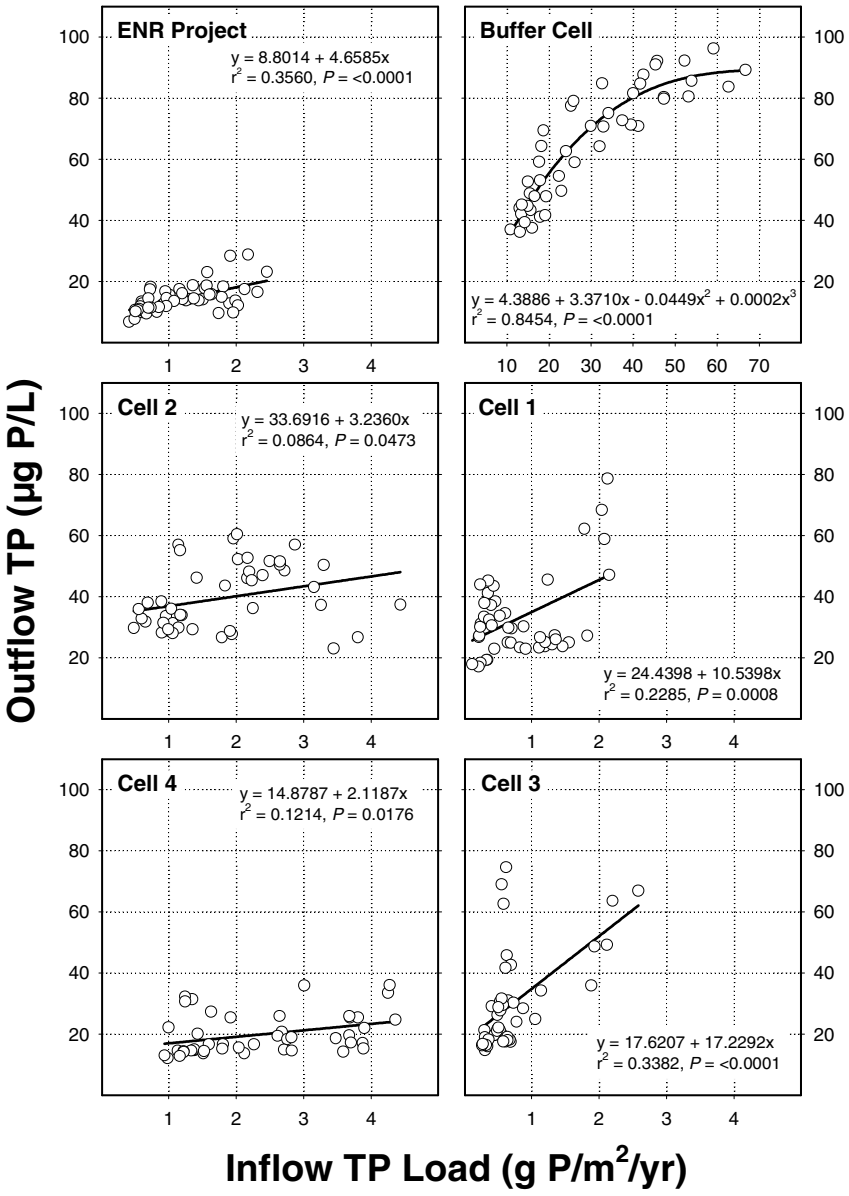

Figure 6-31. Comparison of three-month flow-weighted total phosphorus outflow concentrations (µg/L) with corresponding average total phosphorus loading rates (g $P/m^2/yr$) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

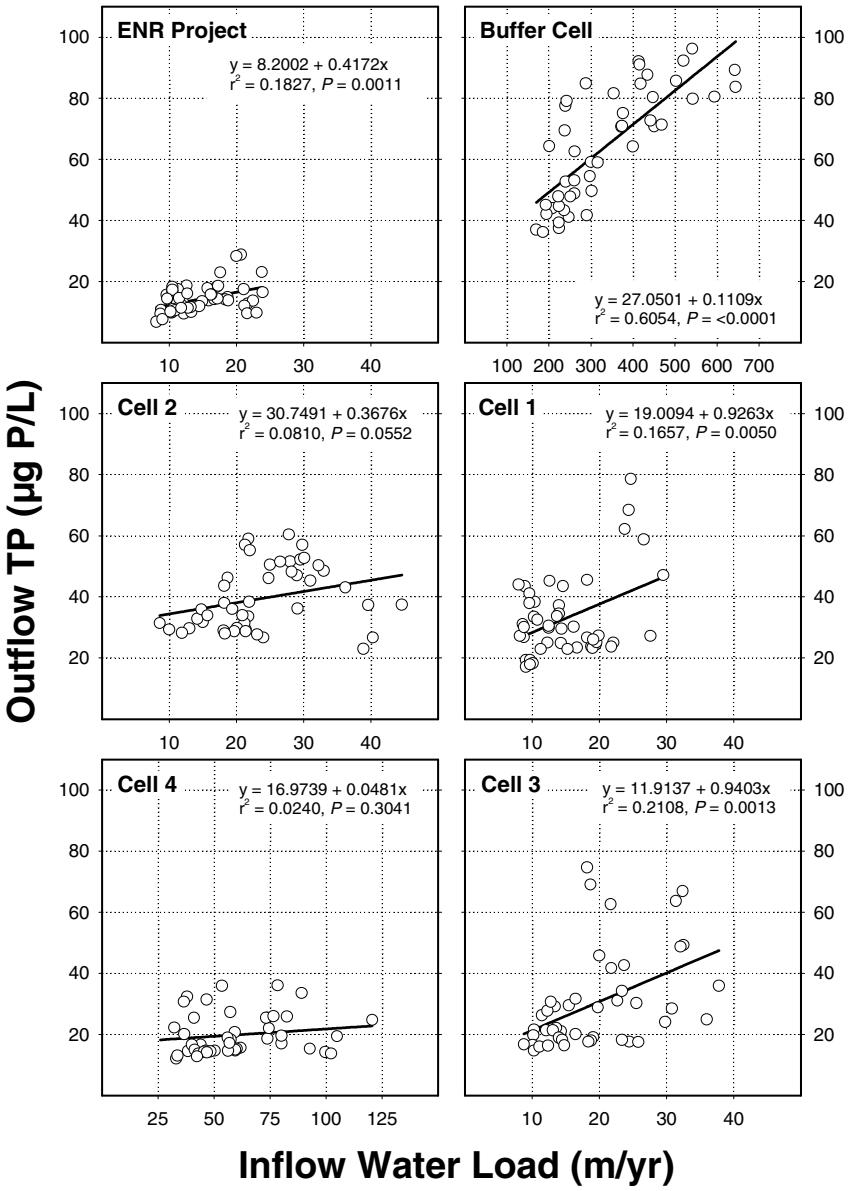

Figure 6-32. Comparison of three-month flow-weighted total phosphorus outflow concentrations (µg/L) with corresponding average hydraulic loading rates (m/yr) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statis-tics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

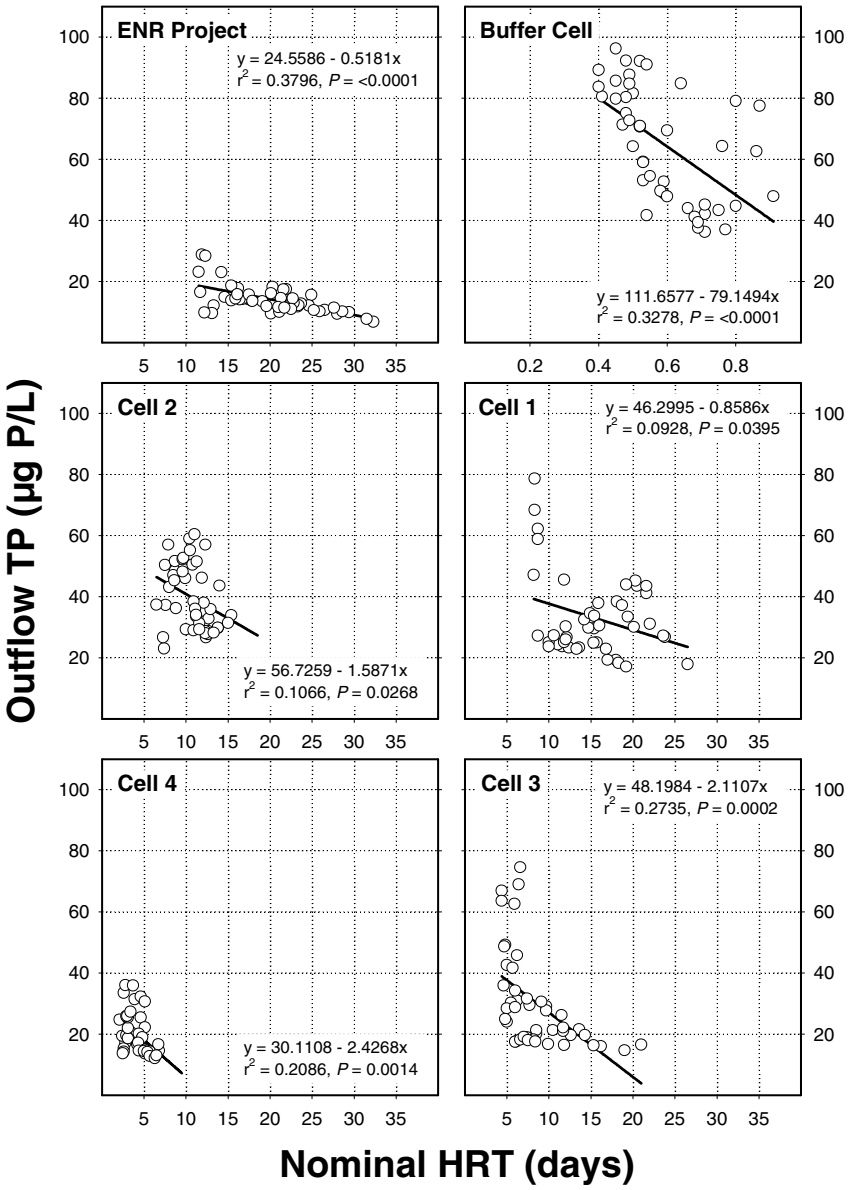

Figure 6-33. Comparison of three-month flow-weighted total phosphorus outflow concentrations (µg/L) with corresponding average nominal hydraulic residence times (days) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

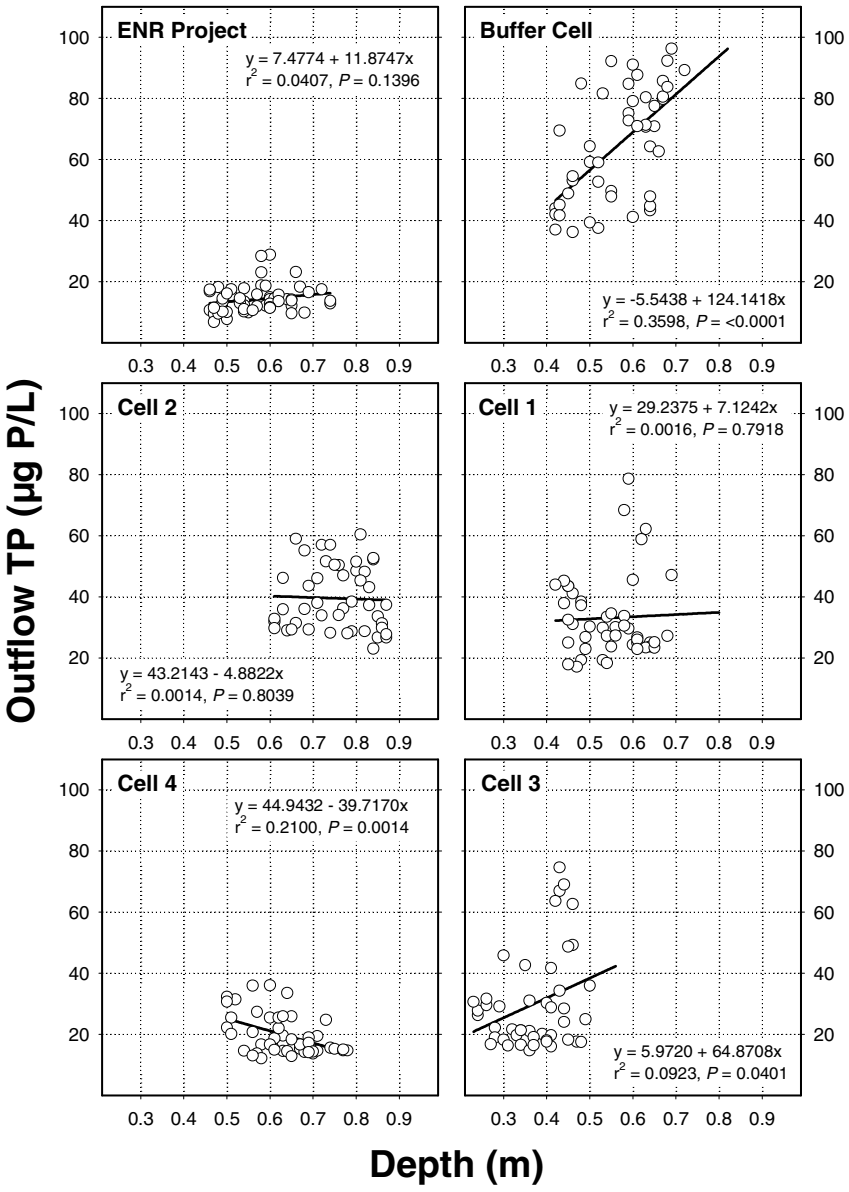

Figure 6-34. Comparison of three-month flow-weighted total phosphorus outflow concentrations (µg/L) with corresponding average depths (m) in the Everglades Nutrient Removal Project, the Buffer Cell and Treatment Cells 1, 2, 3 and 4. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

Results from other research projects that have been conducted in the ENR Project will be presented in future Reports.

SEDIMENT ACCRETION AND PHOSPHORUS STORAGE

Data collection and analysis

Feldspar horizon markers, similar to those described in Cahoon and Turner (1989), were established at 15 locations throughout the ENR Project between May and September 1995 (**Figure 6-35**) to monitor the accretion of material in the wetland sediments. Triplicate 5-cm wide cores were collected on an annual basis (August 1996, August 1997 and September/November 1998) from each site. Over the course of this study, eight horizon marker sites were destroyed by floating cattail islands that scoured the bottom when the islands moved by these locations. Sediment cores were returned to the laboratory, frozen and cut in half length-wise using a bandsaw. The thickness of material on top of the feldspar layer (i.e., the newly deposited sediment) was measured to the nearest mm at 5 mm increments along the width of each core while the core was still frozen. Missing values were recorded for sediment thickness at any point along the core that did not have a layer of feldspar. Sediment deposition rates were calculated from sediment measurements for the each core as follows:

$$D_k = \left(\sum_{i=1}^{n} m_1 + m_2 + \ldots m_i / N \right) \times \frac{365.25}{\Delta t} \quad (6.27)$$

where:

D_k = sediment deposition rate for the k^{th} sediment core (mm/yr);

m_i = the i^{th} sediment thickness measurement from the k^{th} sediment core (mm);

N = the number of sediment thickness measurements recorded from the core; and

Δt = the number of elapsed days since the feldspar horizon marker was established (day).

In the addition to the loss of entire sites, it became increasingly more difficult with each passing year to collect cores from the remaining locations that contained a feldspar layer. The disappearance of the feldspar from these sites may be associated with sediment disturbance caused by the growth of macrophyte roots, burrowing by benthic organisms or the foraging activity of fish and waterfowl. However, at this time we do not have data to support any of these hypotheses.

A series of sediment cores (30-cm deep; each core was homogenized for analysis) were collected from throughout the ENR Project in 1990 (pre-operation) to document soil conditions before the wetland was constructed (Reddy and Graetz, 1991). Subsequently, sediment cores (30-cm deep) were collected at 24 locations (**Figure 6-36**) in January 1995 and 1999, and from only Treatment Cell 1 stations in January 1996. Each of these cores was analyzed in 0-5, 5-10 and 10-30 cm sections. The 0-5 cm sections contained all the material accreted since the ENR Project started operation in August 1994. Also, material deposited on top of the feldspar layer in cores collected in 1998 (see discussion above) was recovered and analyzed.

Besides routine physical and chemical soil analyses, pre-construction sediment cores and cores collected in January 1996 were subjected to a series of sequential extractions with acid and alkaline reagents in a process known as sediment inorganic P fractionation. These analytical procedures are described in Chimney and Moustafa (1999).

The mass of P contained in newly deposited sediment was calculated for each cell in the ENR

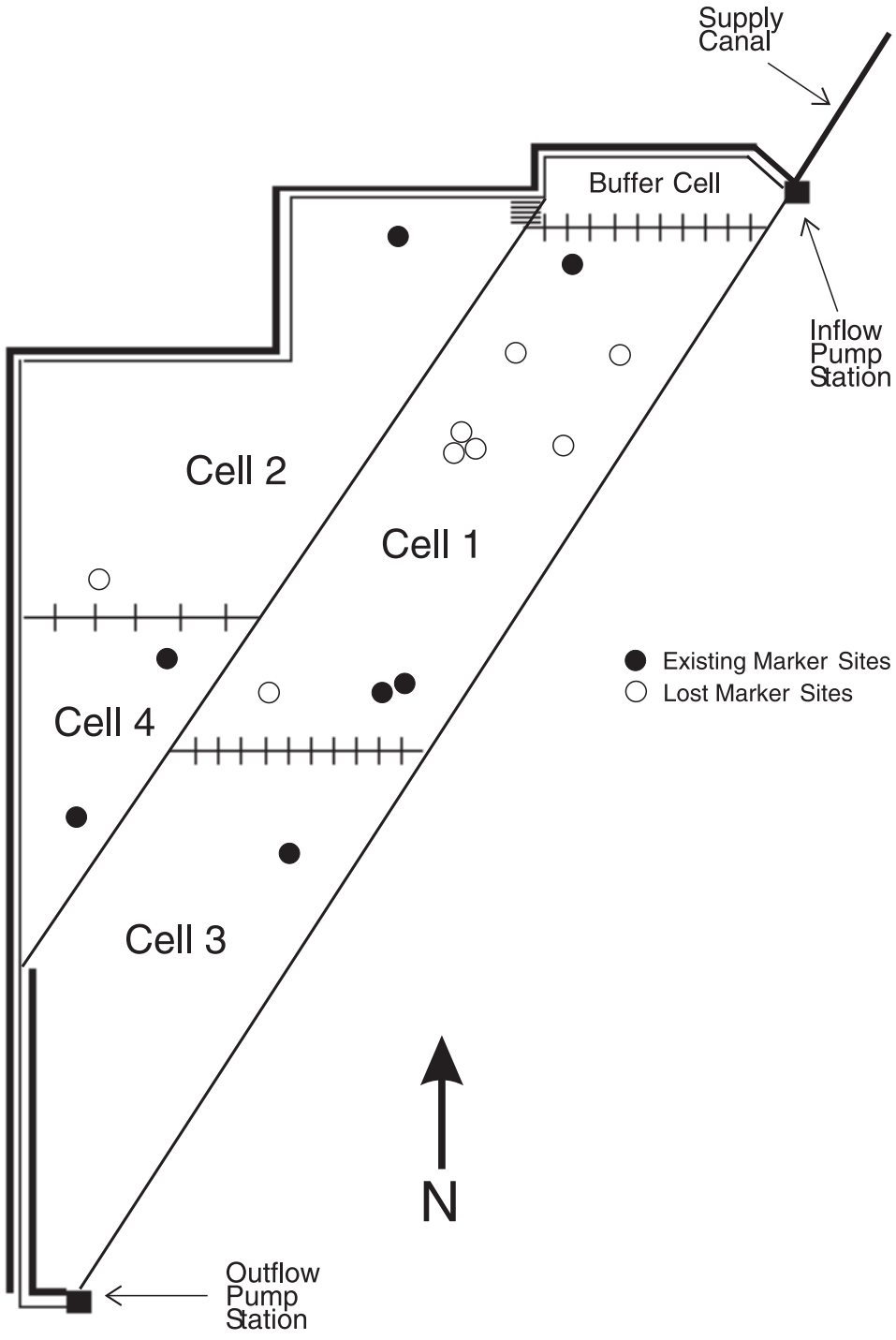

Figure 6-35. Location of feldspar marker horizon sites established between May and September 1995 in the Everglades Nutrient Removal Project to monitor sediment accretion.

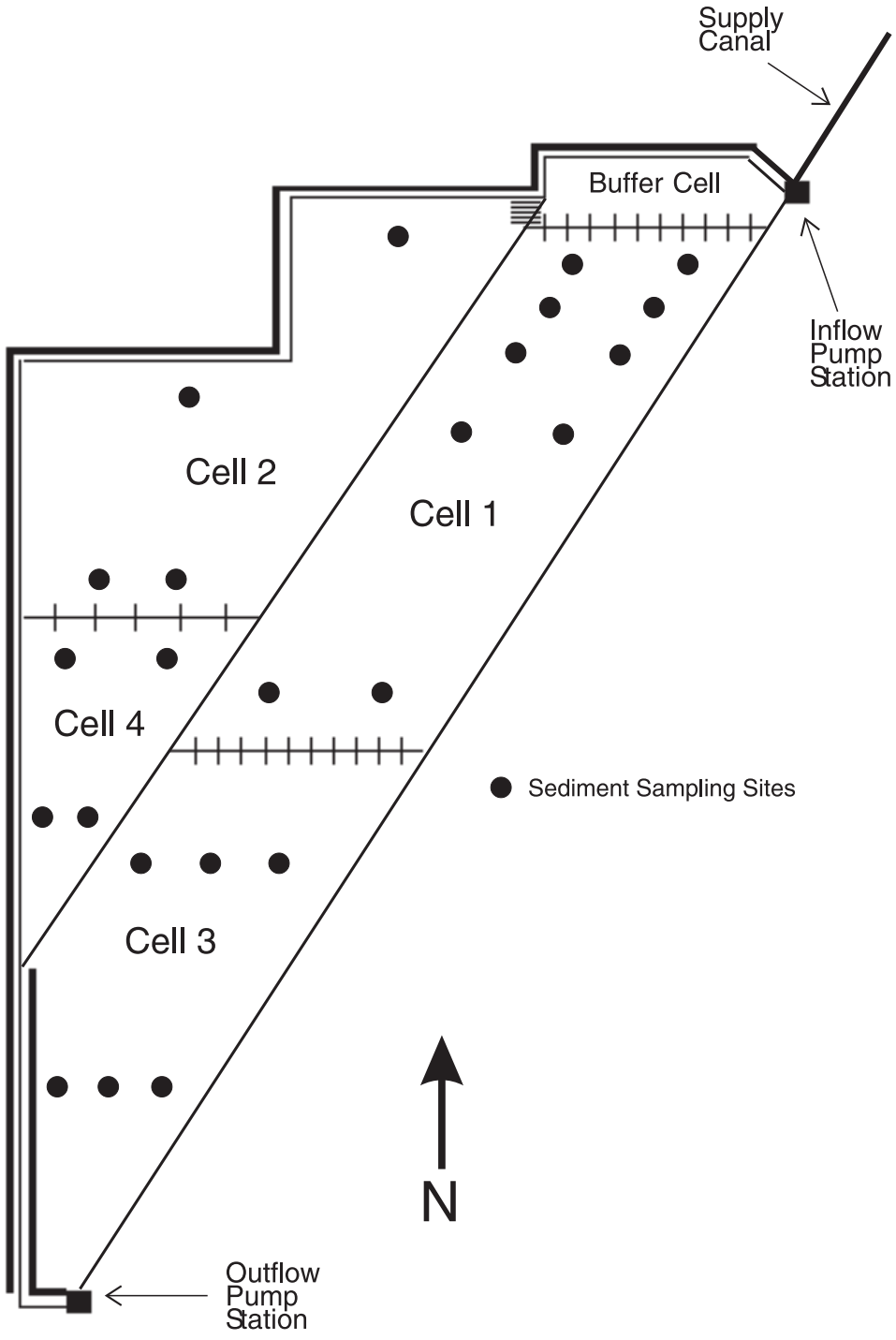

Figure 6-36. Location of sediment coring sites in the Everglades Nutrient Removal Project.

Project for the period May 1, 1995 to April 30, 1999 using the following relationship:

$$M_s = \left[\left(\frac{s}{365.25}\right)\Delta t\right] \times \left[\frac{(A \times b \times C_s)}{100}\right] \quad (6.28)$$

where:

M_s = mass of P contained in new sediment (kg);

s = sediment deposition rate (mm/yr);

Δt = elapsed time (days);

A = surface area of cell (ha);

b = sediment bulk density (g/cm^3); and

C_s = sediment P concentration (mg P/kg).

We used median values for the sediment bulk density in 1999 (0.160 g/cm^3), the sediment deposition rate in 1998 (5.6 mm/yr) and the P sediment concentration from the 1998 feldspar horizon marker cores (495.5 mg P/kg) in all these calculations. The resulting estimates of P mass deposited in new sediment were compared against the corresponding total amount of inflow TP retained within each cell (**Table 6-7**).

Table 6-7. Estimates of phosphorus contained in new sediment deposited in the Everglades Nutrient Removal Project from May 1994 through April 1999.[a]

	Buffer	Cell 1	Cell 3	Cell 2	Cell 4	East F-W	West F-W	Entire ENR
P retained in nutrient budget (kg)	17,883	6,914	1,844	10,676	6,444	8,758	17,120	43,761
P retained in new sediment (kg)	957	9,349	7,177	7,335	2,609	16,526	9,943	27,426
% P retained in new sediment	5.3	135.2	389.2	68.7	40.5	188.7	58.1	62.7

a. Assumptions used in calculation of P contained in new sediment: Elapsed # days = 1,460 (May 1, 1995 to April 30,1999); Sediment deposition rate = 5.6 mm/yr; Sediment P concentration = 495.5 mg P/kg; Sediment bulk density = 0.160 g/cm^3

Status of sediment research and monitoring

Analysis of sediment accretion data indicated that median deposition rates decreased substantially from 1996 to 1998 in Treatment Cells 1 (37.9 to 18.4 mm/yr) and 4 (33.8 to 4.6 mm/yr) (**Figure 6-37**). Accretion also appears to have slowed in areas of the ENR Project dominated by coontail (35.9 to 5.2 mm/yr) and southern naiad (39.2 to 17.7 mm/yr). However, median deposition increased markedly at sites in cattail areas from 1996 to 1997 (17.2 to 33.1 mm/yr), although the loss of markers in cattail areas has limited our ability to assess deposition for this cover type. Three of the four remaining feldspar horizon markers located in cattail areas in 1997 were in Treatment Cell 2, and these sites accounted for all the Treatment Cell 2 data for this year. By 1998, only one feldspar horizon marker remained in a cattail area, which was located in Treatment Cell 1. For the entire ENR Project, median sediment deposition has decreased from 32.1 mm/yr in 1996 to 5.6 mm/yr by 1998. These changes are attributed to two possible factors: (1) compaction of material deposited over the last several years and/or (2) a real decrease in production of plant detritus as the vegetation community shifted from the rapid accumulation of new biomass during plant colonization to the maintenance of existing biomass as the community matured.

Inspection of bulk density data indicated that, in general, the 0-5 cm layer of sediment collected after the ENR Project started operation was much less dense than in pre-construction soils; post-

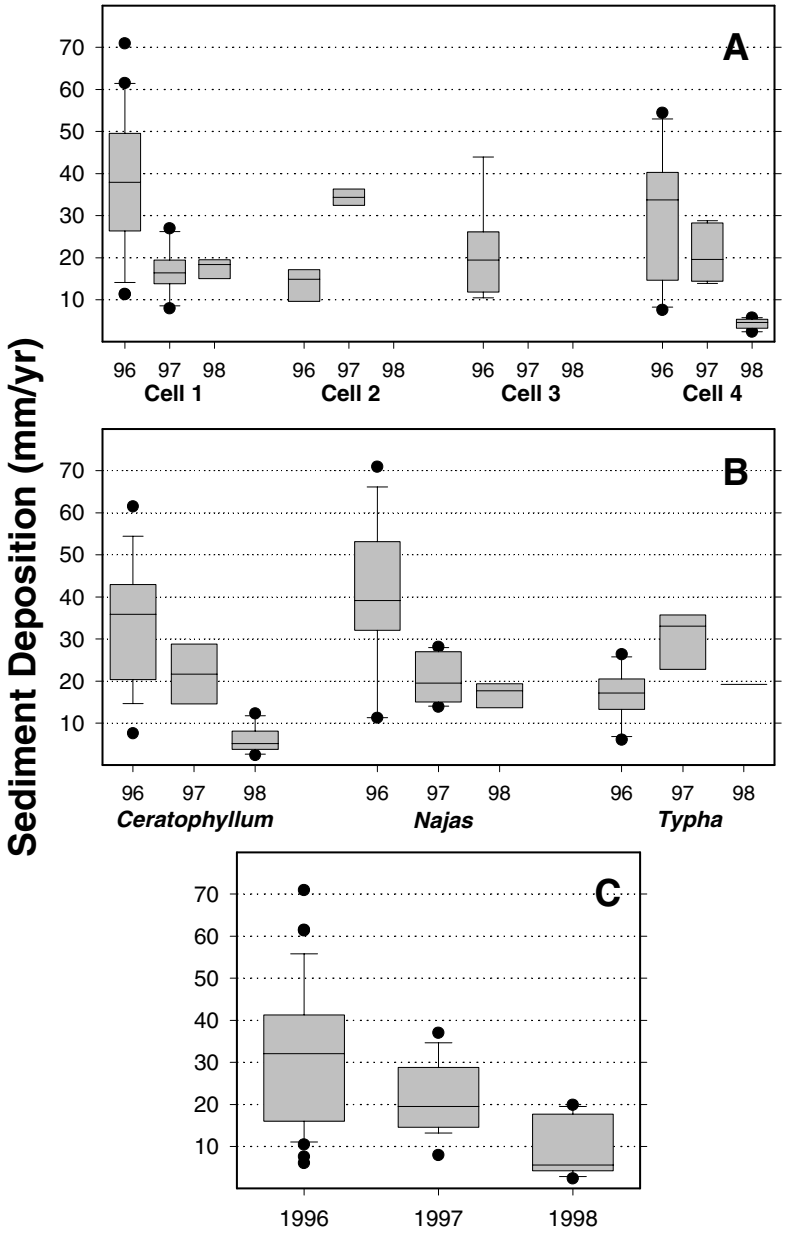

Figure 6-37. Box plots of sediment deposition rates (mm/yr) in the Everglades Nutrient Removal Project from cores collected at feldspar horizon marker sites. Panel A: accretion data summarized by treatment cell and year. Panel B: accretion data summarized by vegetation cover type and year. Panel C: accretion data summarized by year over all treatment cells and vegetation cover types. See Figure 6-7 for description of box plots. Sediment data were unavailable for Treatment Cell 2 in 1998 and Treatment Cell 3 in 1997 and 1998; only one observation was available for *Typha* spp. in 1998.

operation median bulk densities for all treatment cells ranged from 0.110 to 0.210 g/cm^3, while pre-construction median bulk density was 0.286 g/cm^3 (**Figure 6-38**). Sediment bulk densities have generally decreased over time within each treatment cell. The median bulk density for the entire ENR Project was 0.180 g/cm^3 in 1995 and 0.160 g/cm^3 in 1999. The decrease in bulk density would be expected, as newly deposited material in constructed wetlands is usually very flocculent compared to the original soil.

The median sediment P content of 0-5 cm core sections collected in 1995 and 1996 (465.0 and 650.0 mg/kg) was much higher then in pre-construction cores (251.6 mg/kg; **Figure 6-39**). This reflected the highly organic, nutrient-rich nature of the new material and suggested that on a weight:weight basis, the new sediment being deposited in the ENR Project was acting as a storage sink for P. However, when the sediment P content of these cores was corrected for bulk density, the resulting pre-construction median P content (73.3 µg/cm^3) was almost identical to the post-operation values (75.6 and 73.9 µg/cm^3; Chimney and Moustafa, 1999), i.e., the increase in the weight:weight P content was offset by the corresponding decrease in bulk density. Sediment P concentrations were not measured in the 1999 core samples and insufficient material was available in the 1998 feldspar horizon cores to determine bulk density. The median P content for the 1998 feldspar horizon marker cores (495.5 mg/kg) was comparable to the 1996 value; sediment in cattail dominated areas had the lowest median P content (332 mg/kg), while cores taken in beds of southern naiad had the highest P content observed during this study (968 mg/kg). Sediment P enrichment may be better explained on a weight:weight basis. However, expressing sediment P content on a weight:volume basis is useful when considering total nutrient total storage and nutrient availability (Reddy and Wang, 1998).

Results of the inorganic P fractionation (P_i) analyses indicated that only 18.4 percent of P in the 0-5 cm sediment layer of Treatment Cell 1 during 1996 was associated with inorganic compounds (KCl-P_i = 2.8 percent; NaOH-P_i = 6.0 percent; HCl-P_i = 9.6 percent), the remaining P (81.7 percent) was bound to organic forms (Chimney and Moustafa, 1999). Similarly, Reddy and Graetz (1991) found that 79 to 88 percent of P in pre-construction sediments from the ENR Project was organically bound. The many different compounds that comprise this organic fraction exhibit varying degrees of resistance to aerobic and anaerobic decomposition. The low percentage of non-labile P_i (Fe-Al and Ca bound P = 15.6 percent of total P) in post-operation sediments suggests that this storage mechanism will not be important in controlling P levels in the STAs (Reddy and Graetz [1991] reached the same conclusion). Ultimately, the success of the STAs in removing P will depend on the ability of these wetlands to sequester non-labile organic compounds in their sediments.

Estimates of P retention in new sediments deposited in the ENR Project were quite variable. Our calculations indicated that all of the TP mass that entered the eastern flow-way could be accounted for in new sediment, whereas only a little more than one-half and approximately 5 percent of inflow TP mass in the western flow-way and Buffer Cell, respectively, were in new sediment (**Table 6-7**). Overall, 62.7 percent of inflow TP mass to the entire project could be accounted for in sediment accretion. These data support the contention that a major P storage compartment in the STAs will be the sediment, but do not close the TP mass balance budget. We regard these calculations as preliminary in nature as they are based on limited sediment accretion and chemistry data. Our intent in this effort was only to gain an insight into the role that sediment P deposition might play in sequestering nutrients in this wetland.

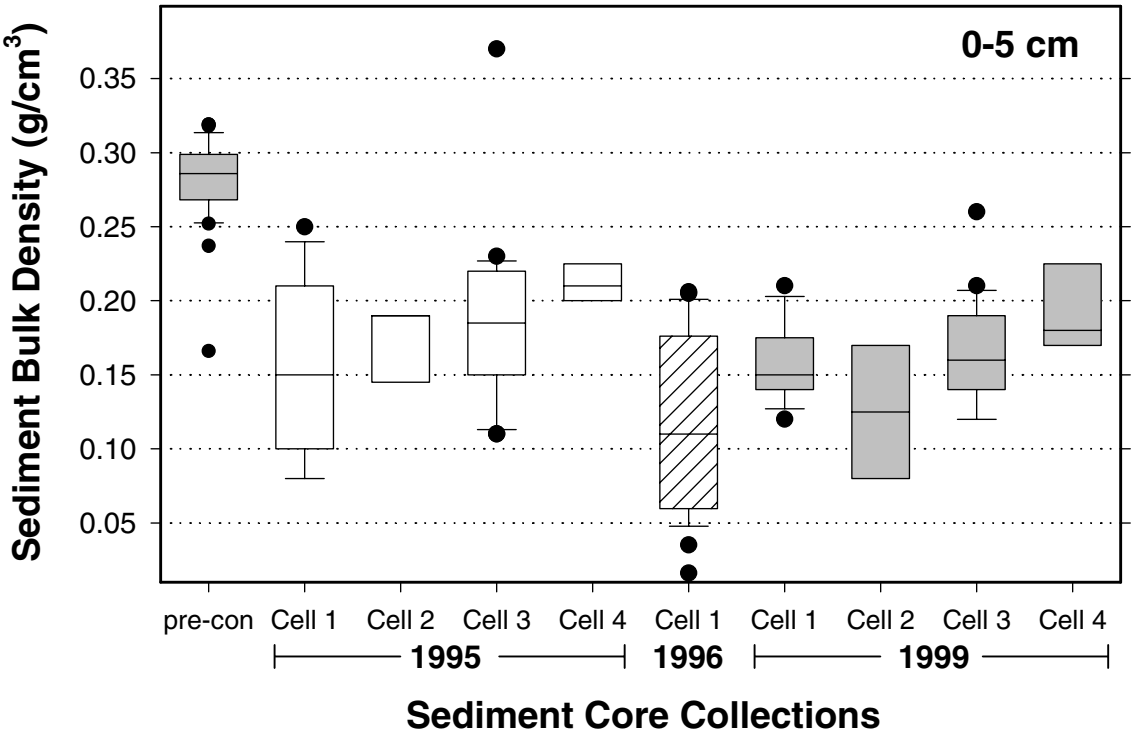

Figure 6-38. Box plots of sediment bulk density (g/cm^3) for 0-5 cm core sections collected throughout the Everglades Nutrient Removal Project during preconstruction (1990) and January 1995, 1996 and 1999. See Figure 6-7 for description of box plots.

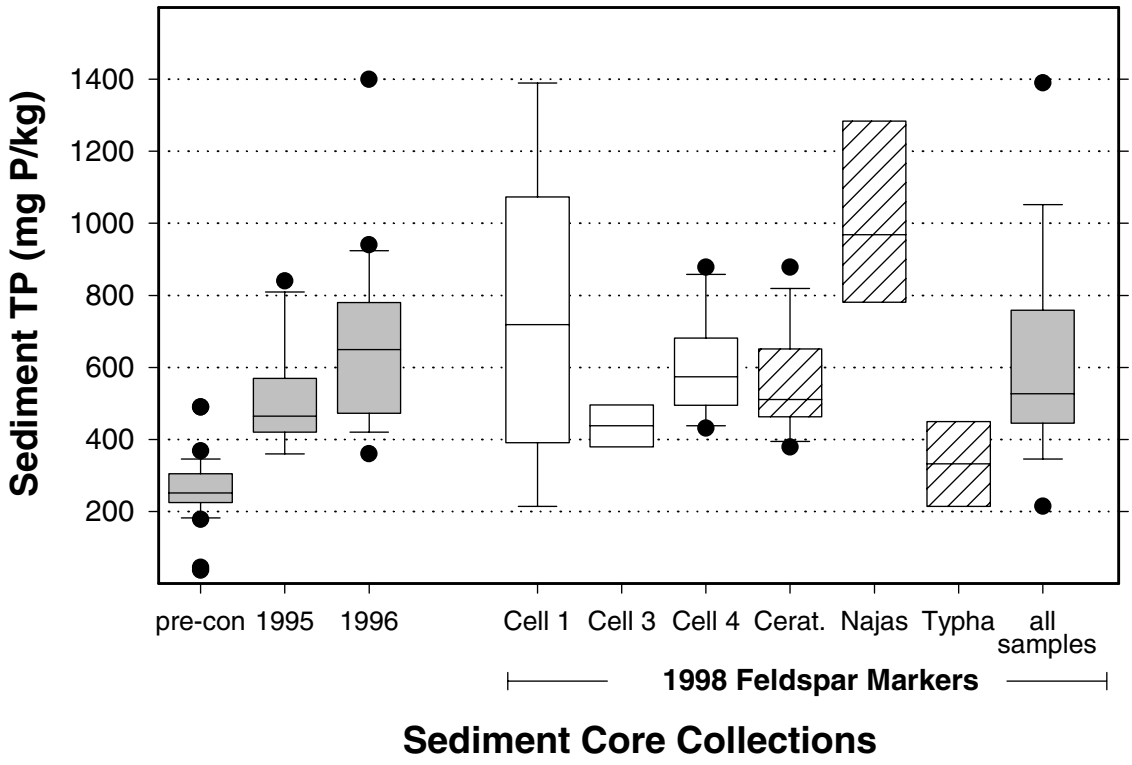

Figure 6-39. Box plots of sediment phosphorus concentrations (mg P/kg sediment) in 0-5 cm core sections collected throughout the Everglades Nutrient Removal Project during preconstruction (1990), in 0-5 cm core sections collected at sediment coring sites in January 1995 and 1996 and in cores collected at the feldspar horizon marker sites in 1998. See Figure 6-7 for description of box plots.

NUTRIENT UPTAKE BY SUBMERGED AQUATIC VEGETATION

Data collection and analysis

As already noted, nutrient uptake by plants is an important process in the biogeochemical cycling of nutrients within wetlands. Nutrient uptake is known to vary among different plant species and is correlated to some degree with variation in environmental variables such as temperature, light intensity and the nutrient history of the plant (Darley, 1982; Harrison, 1988; Borchardt, 1996). Research has been conducted in the ENR Project to quantify short-term P uptake rates by an important component of the SAV community, C*eratophyllum demersum* L. and attached periphyton (referred to as the *C. demersum*/periphyton complex). *C. demersum* is a submerged aquatic macrophyte that lacks a true root system and absorbs most of its P directly from the water column, rather than from the sediments. The objectives of this study were to:

- Document short-term P uptake rates by the *C. demersum*/periphyton complex over an annual cycle;
- Determine if variability in short-term P uptake for this community was related to the concentration of available P in the water column; and
- Determine if variability in short-term P uptake rate for this community was related to seasonal differences in light intensity.

The research sites were located in areas of Treatment Cell 1 with dense stands of *C. demersum* that approached 100 percent coverage. Initially, the study site was situated about 100 meters north of the ENR103 monitoring station (**Figure 6-2**); this location was used from October 1996 to early July 1997, when the *C. demersum* community was scoured away by floating cattail islands. For the remaining two months of the study (August and September 1997), experiments were relocated to a site about 100 meters north of the ENR102 monitoring station.

Nutrient uptake experiments were conducted in 25-liter clear plastic bags, referred to as microcosms, that were suspended at the top of the water column from 0.5-inch PVC pipe frames and left open to the atmosphere (**Figures 6-40** and **6-41**). All microcosms were filled with approximately 15-L of unfiltered marsh water and approximately equal quantities of plants and attached periphyton collected from the site at the beginning of each experiment. Triplicate microcosms were then spiked with a solution of inorganic P (NaH_2PO_4+7 H_20) to raise the SRP concentration in the microcosm to 30, 50, 100, or 200 µg/L above ambient levels. Control microcosms (filled only with marsh water and spiked with P) were run to determine if any P uptake was attributable to components of the water column other than the *C. demersum*/periphyton complex. Water quality samples were collected 10 cm below the surface of each microcosm using a peristaltic pump at 0, 10, 20, 40 and 60-minute intervals after spiking and analyzed for SRP. The dry weight of all the plant material in each microcosm was measured in the laboratory after each experiment. The dominant species of periphyton were identified each month. Photosynthetically active radiation (PAR) was monitored on a continuous basis at a weather station located in the north of treatment cell 1 (ENR105; **Figure 6-2**). To determine the water column P concentration at which the *C. demersum*/periphyton complex P uptake mechanism became saturated, additional experiments were conducted using a much wider range of spikes: 300 to 10,000 µg/L. The amount of P removed by the *C. demersum*/periphyton complex during each time interval was calculated based on the mass of SRP lost from the water in the microcosm per unit dry weight of plant material. The P uptake rate at the 60-minute point in each experiment was then computed as the total SRP mass removed over all time intervals (0-10, 10-20, 20-40 and 40-60 min) as:

$$U_i = \sum \frac{\left[\frac{(C_{t+1} - C_t)}{V_i}\right]}{W} \qquad (6.29)$$

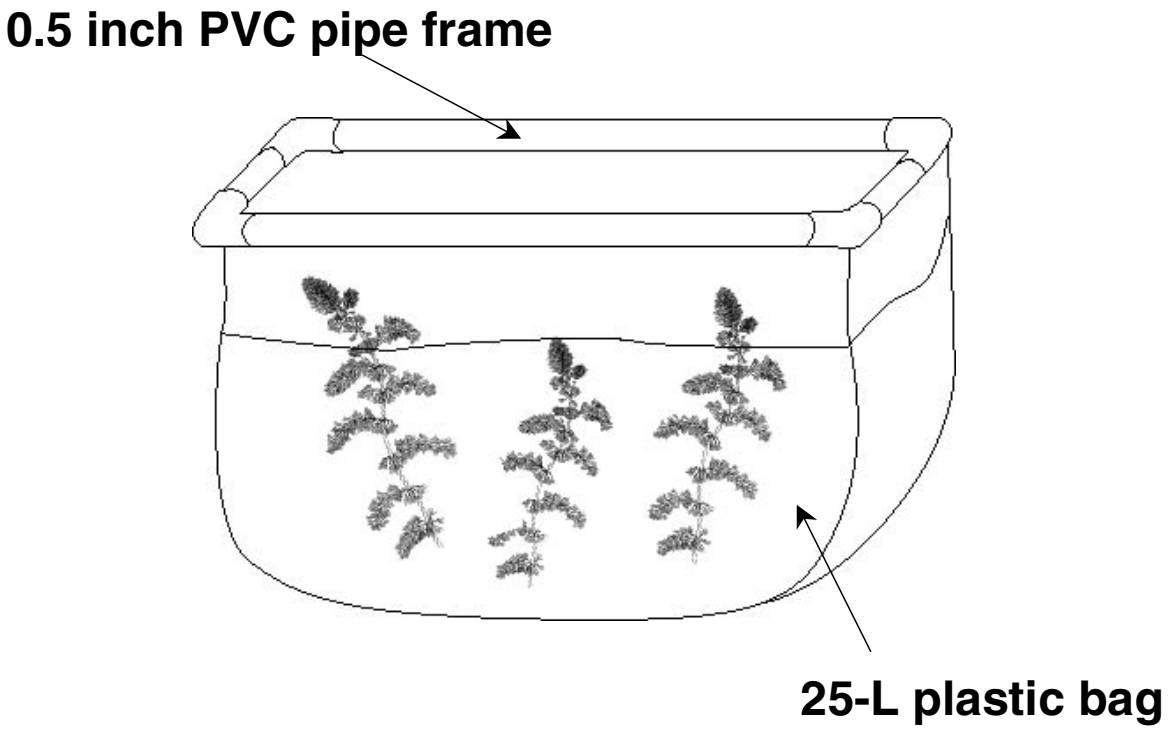

Figure 6-40. Diagram of microcosm (25-L plastic bag supported on 0.5-inch PVC pipe frame) used in experiments of short-term P uptake by the *Ceratophylum*/periphyton complex conducted in the Everglades Nutrient Removal Project.

Figure 6-41. Field crew spiking microcosms with inorganic P solution during an experiment of P uptake by the *Ceratophylum*/periphyton complex. During each experiment, the microcosms were suspended at the top of the water column by floating PVC pipe frames and left open to the atmosphere. Microcosms were filled with marsh water and a quantity of plant material collected from the immediate area.

where:

U_i = P uptake in the microcosm during time interval i (*t* to *t+1*) corrected for the dry weight of plant material (µg/g W/hr);

t = time (min);

C_t = microcosm SRP concentration at time *t* (µg/L);

C_{t+1} = microcosm SRP concentration at time *t+1* (µg/L);

V_i = volume of water in the microcosm during time interval *i* corrected for the volume of water quality samples collected from the microcosm in this and all previous time intervals (time *t* to *t+1*) (L); and

W = dry weight of plant material in the microcosm (g).

The study year was divided into two seasons based on day length. One season, termed "high" irradiance, was defined as the period running from mid-March through mid-September 1997 when day length was >12.1 hours. The other season, termed "low" irradiance, ran from mid-October 1996 to mid-March 1997 with day lengths <12.1 hours. The mean daily PAR photon flux (µmoles/sec/m^2) was significantly different between the two irradiance periods (high irradiance > low irradiance ($F=63.83$, $p < 0.05$) (SAS GLM procedure, SAS/STAT Version 6.12; SAS Institute Inc., Cary, NC). A more detailed description of the methods and materials used in this study can be found in Pietro (1998).

Status of nutrient uptake research and monitoring

A total of 41 genera of periphyton were identified during this study. The largest number of taxa were found in July and August 1997 (25 and 29 genera, respectively). The periphyton community was dominated by taxa belonging to the Chlorophyta (*Oedogonium* spp. and *Mougeotia* spp.) and Cyanobacteria (*Lyngbya* spp.) during the winter months, which were characterized by relatively low irradiance and cooler water temperatures, whereas the community was dominated only by Cyanobacteria (*Lyngbya* spp. and *Microcystis* spp.) from April through September 1997, months with relatively higher irradiance and warmer water temperatures.

Phosphorus concentrations in the microcosm experiments decreased in a relatively linear fashion for most spike treatments; (**Figure 6-42**). Control microcosms exhibited almost no P loss from the water, indicating that P removal was mediated entirely by the *C. demersum*/periphyton complex. Phosphorus uptake rates increased as the spike concentration was increased at both high and low irradiance. At all spike concentrations, the median uptake rate was always higher during the period of high irradiance (**Figure 6-43**). Differences in uptake rates were significantly different among spike concentrations ($F = 49.74$; $p < 0.001$) and periods of irradiance ($F = 29.35$; $p < 0.001$) (SAS GLM procedure, SAS/STAT Version 6.12; SAS Institute, Inc., Cary, NC). However, for a given spike concentration, there was at best only a weak correlation between P uptake rates and the average PAR flux measured during the experiment (**Figure 6-44;** note that none of the regressions of P uptake rate against PAR flux were statistically significant). A P uptake saturation curve, generated by plotting P uptake rates from all experiments against the corresponding initial SRP concentrations (5 to 11,300 µg/L), indicated a strong linear relationship ($r^2 = 0.9373$) over the entire data range (**Figure 6-45**). The fact that P uptake rates had not plateaued even at the highest initial SRP concentrations used in these experiments suggested that the short-term P uptake mechanism in the *C. demersum*/periphyton complex was not saturated.

Comparison of TN:TP atomic ratios (Redfield, 1958; Cembella et al. 1984) of water within the ENR Project (range from 40:1 to 355:1) and plant tissues (range from 19:1 to 34:1) suggested that P was the limiting nutrient throughout this study. Under nutrient limiting conditions, algae can

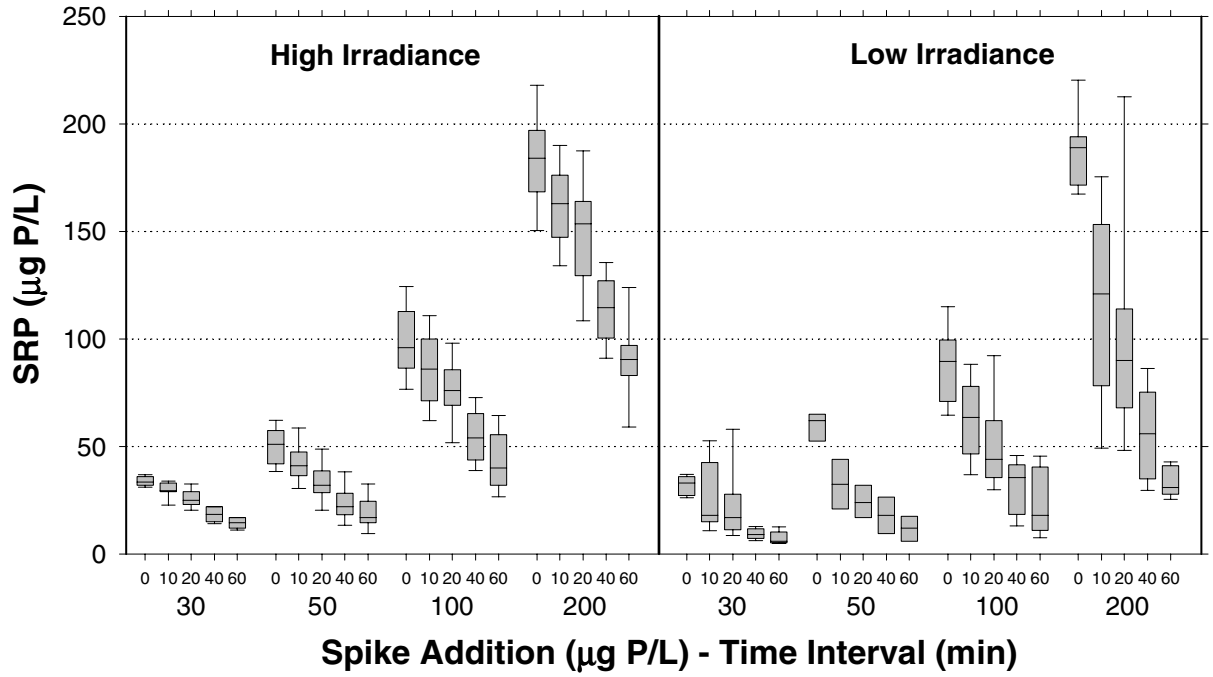

Figure 6-42. Reduction in concentrations of soluble reactive phosphorus (µg/L) in microcosm experiments of short-term P uptake by the *Ceratophylum*/periphyton complex at different spike additions during periods of high and low irradiance. The period of high irradiance ran from mid-March to mid-September 1997; the period of low irradiance ran from October 1996 to mid-March 1997. See Figure 6-7 for description of box plots.

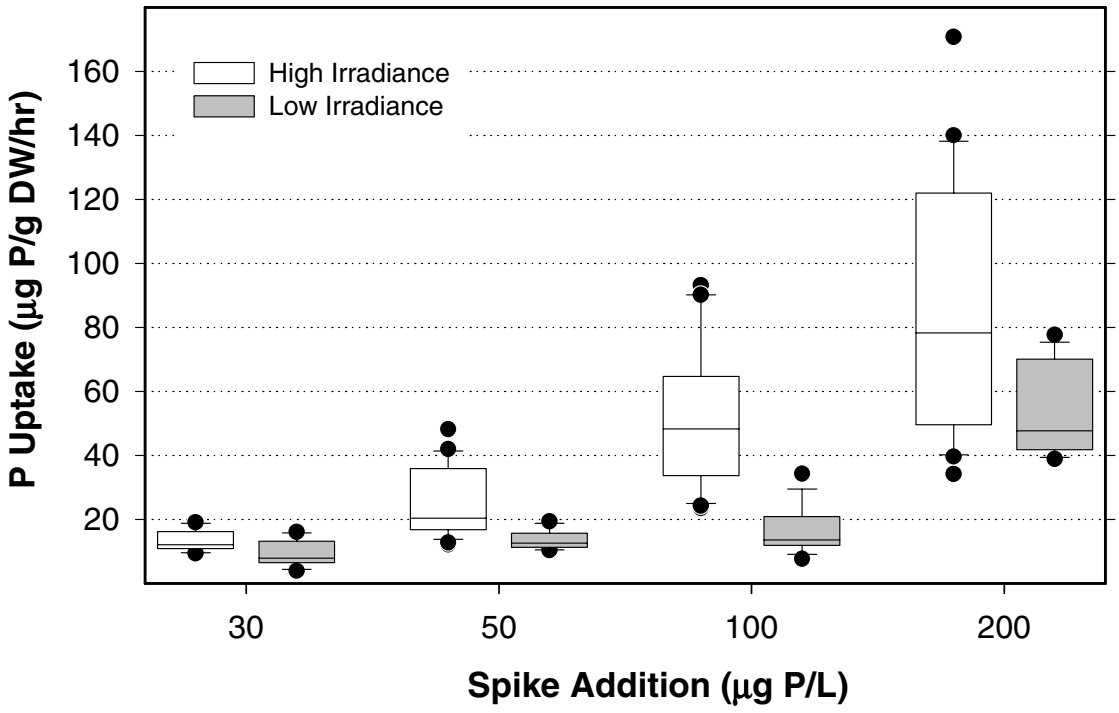

Figure 6-43. Variation in short-term P uptake rates (µg/g DW/hr) for the *Ceratophylum*/periphyton complex from microcosm experiments conducted at different spike additions under conditions of high and low irradiance. See Figure 6-42 for description of periods of irradiance and Figure 6-7 for description of box plots. (DW = dry weight).

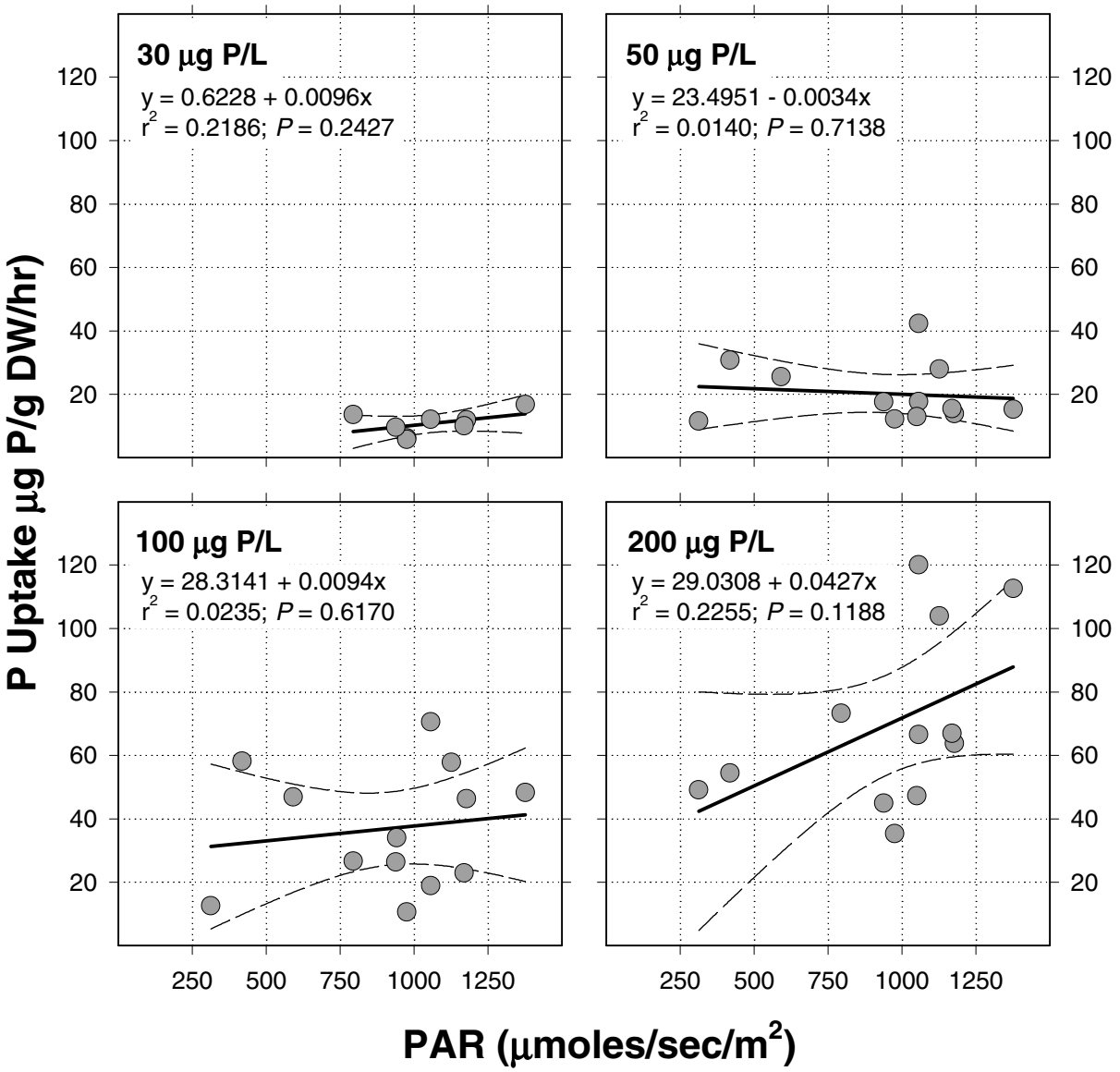

Figure 6-44. Relationship of short-term P uptake rates for the *Ceratophylum*/periphyton complex (µg/g dry weight/hr) in microcosm experiments at different spike additions with average photosynthetically active radiation photon flux (µmoles/sec/m^2). Heavy solid line represents best linear fit to the data; dashed line represents 95% confidence interval around regression line. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

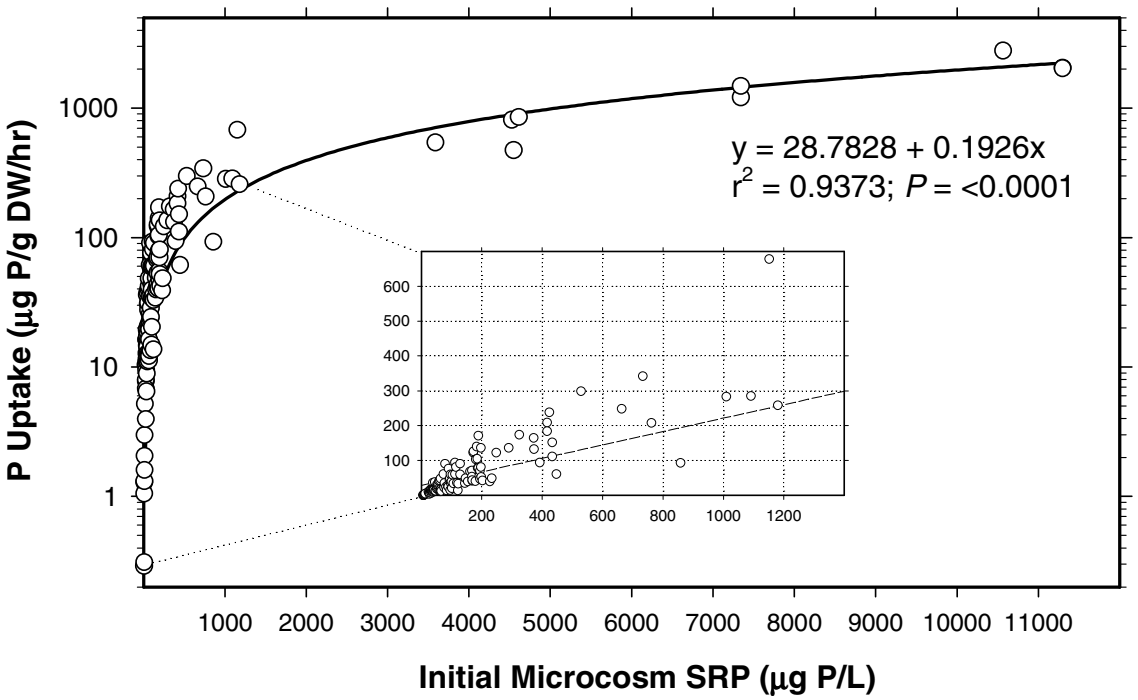

Figure 6-45. Saturation curve for P uptake rates (µg/g DW/hr) for the *Ceratophylum*/periphyton complex from all microcosm experiments plotted against initial soluble reactive phosphorus (SRP) concentrations. Heavy solid line represents best linear fit to the data. All regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL. Insert shows detail of P uptake rates over a smaller range of initial SRP concen-trations. (DW = dry weight; PAR = photosynthetically active radiation).

increase uptake rates and sequester more P than is needed to meet their immediate physiological needs as luxury uptake (Harrison, 1988). The high uptake rates measured in our experiments more than likely represent luxury uptake by the *C. demersum*/periphyton complex and would not be expected to be sustainable over long periods of time. However, these results do illustrate the capacity of one component of the plant community in a south Florida wetland to sequester P on a short-term basis.

PLANT DECOMPOSITION

Data collection and analysis

The rates of decomposition and subsequent release of P back into the water column were determined for the dominant macrophyte species in the ENR Project, i.e., cattail, water hyacinth, water lettuce and a mixed collection of coontail and southern naiad plus attached periphyton (referred to as SAV/periphyton). Plant material used in these experiments was harvested from throughout Treatment Cell 1 and air-dried to a constant weight. Approximately equal subsamples of material for each species (~ 10 g) were weighed to the nearest 0.1 g and placed into 20 x 20 cm mesh bags constructed from 3 mm mesh window screen. Cattail leaves were cut into 10-cm pieces before being placed into the bags; material for all other species was used whole in these experiments. Bags filled with plant material were returned to three locations in Treatment Cell 1. All water hyacinth, water lettuce and SAV/periphyton bags were incubated in water; one set of cattail bags was incubated in water, while another set was attached to PVC poles and remained exposed to the atmosphere to simulate decomposition of standing dead material. A long-term decomposition study was run from February 1996 through February 1997 during which triplicate bags of each species were collected at 2, 4, 6 and 12 month intervals at all locations. A separate, short-term decomposition experiment was run from July through September 1996 using the same protocol described above; bags in this experiment were collected at 1, 2, 3, 5 and 8 week intervals. All recovered bags were returned to the laboratory where the plant material was dried, reweighed and processed for chemical analyses. The relative change in plant tissue biomass was calculated as follows:

$$M_r = \frac{M_o - M_t}{M_o} \times 100 \qquad (6.30)$$

where:

M_r = relative change in plant tissue biomass at time = *t* (%),

t = time (days),

M_o = plant tissue biomass at start of incubation [time = 0] (mg), and

M_t = plant tissue biomass at end incubation [time = *t*] (mg).

Status of plant decomposition research and monitoring

Plant tissue decomposition rates (percent dry weight lost/day) in the long-term experiment differed substantially among species (**Figure 6-46**). Exponential regressions were fit to these data using SigmaPlot® (SigmaPlot version 5.0, SPSS® Inc., Chicago, IL); R^2 values for these regressions ranged from 0.9048 to 0.9941 (**Table 6-8**).

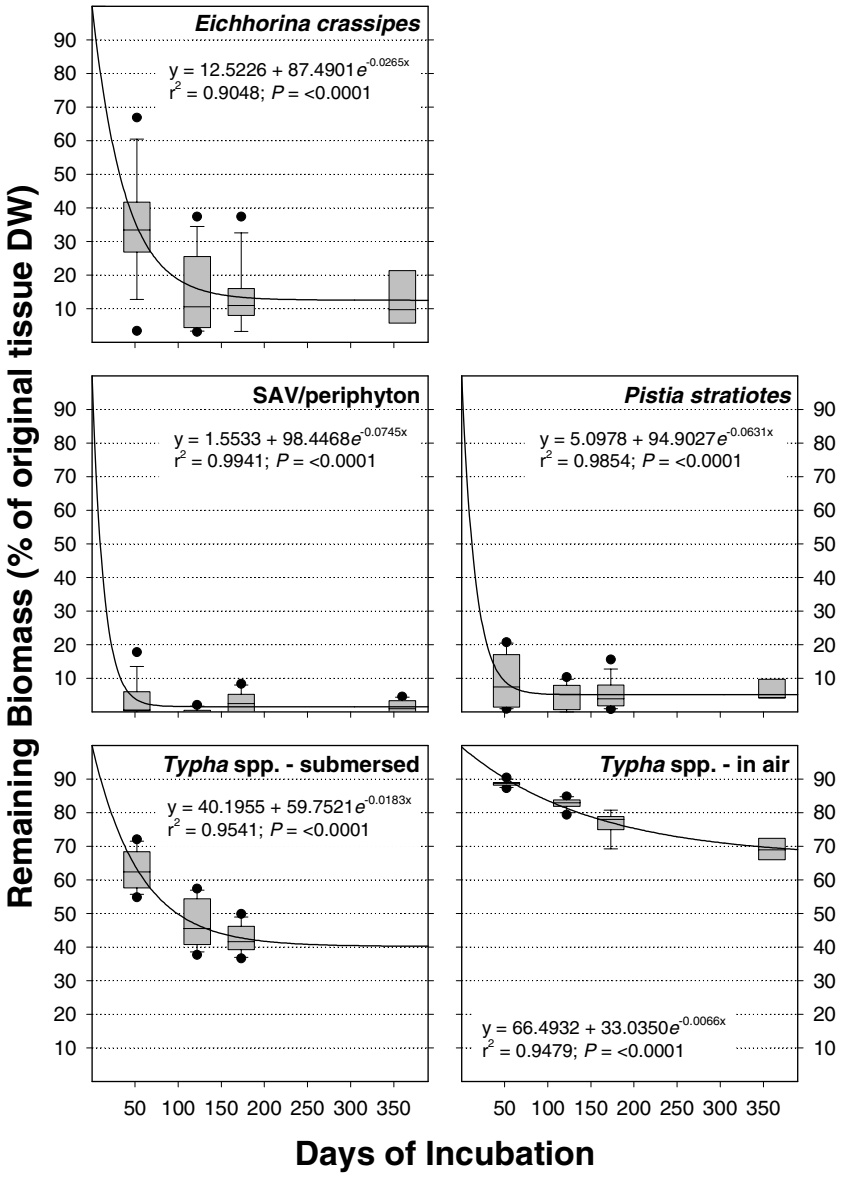

Figure 6-46. Change in dry weight biomass (percentage of original tissue DW) during a long-term decomposition study of the dominant aquatic macrophytes (*Typha* spp., *Eichhorina crassipes*, *Pistia stratiotes* and SAV/periphyton) in the Everglades Nutrient Removal Project. See Figure 6-7 for description of box plots. All exponential decay functions and regression statistics were calculated using SigmaPlot® (SigmaPlot version 5.0, SPSS®, Inc., Chicago, IL).

Table 6-8. Exponential regression equations ($y = y_0 + be^{-ax}$) for loss of dry weight biomass (% DW loss/day) from a long-term decomposition study of the dominant aquatic macrophytes (*Typha* spp., *Eichhorina crassipes*, *Pistia stratiotes* and SAV/periphyton) in the Everglades Nutrient Removal Project.

Species	Regression Equation	R^2
SAV/periphyton	$y = 01.155 + 98.447e^{-0.074x}$	0.9941
Eichhorina crassipes	$y = 12.523 + 87.490e^{-0.026x}$	0.9048
Pistia stratiotes	$y = 05.098 + 94.903e^{-0.063x}$	0.9854
Typha spp. (in air)	$y = 66.493 + 33.035e^{-0.006x}$	0.9479
Typha spp. (submersed)	$y = 40.196 + 59.750e^{-0.018x}$	0.9541

Water lettuce and SAV/periphyton decomposed quite rapidly; 50 percent of their biomass was lost (i.e., tissue half-life) within 11.9 and 9.5 days after the start of incubation, respectively. The tissue half-life for water hyacinth was 32.6 days. By the end of the long-term experiment (day 360), the median remaining biomass for these three species was ≤10 percent of the starting value. Cattail leaves were the most resistant to decay. The tissue half-life for leaves incubated in water was 100.4 days, while the median remaining biomass at the end of the study for leaves exposed to the air was almost 70 percent of the starting biomass. Cattail decomposition rates in this study were comparable to those obtained by Davis (1990) at a nutrient-enriched site in the Everglades. Rate constants from this experiment (submerged cattail = 0.018/day; water hyacinth = 0.026/day; water lettuce = 0.063/day; SAV/periphyton = 0.074/day) are within the range of dry weight biomass loss rates reported for other aquatic macrophytes (**Table 6-9**).

Table 6-9. Dry weight biomass decomposition rates (% loss/day) reported in the literature for various species of aquatic macrophytes compared to this study.

Species	Decomp. Rate	Data Source
SAV/periphyton	0.074	This study
Eichhorina crassipes	0.026	This study
" "	0.006 – 0.014	Reddy and Debusk (1991)
Hydrilla verticillata	0.116	Dierberg (1993)
Lemna spp.	0.016	Dierberg and Ewel (1984)
Potamogeton illinoensis	0.027	Dierberg (1993)
Pistia stratiotes	0.063	This study
Typha spp. (submersed)	0.018	This study
Vallisneria americana	0.088	Dierberg (1993)

The species that decomposed most readily, SAV/periphyton, water hyacinth and water lettuce (**Figure 6-46**), all lost a substantial amount of tissue P within the first week of the short-term decomposition experiment; P levels in these species decreased by 56.9 percent, 46.8 percent and 32.8 percent, respectively, from initial concentrations (**Figure 6-47**). The magnitude of these early losses was comparable to results from decomposition studies of other aquatic macrophytes (e.g., Table 20-9 in Wetzel, 1983; Dierberg, 1993) and was attributed to the leaching of soluble organic matter from the plant tissue upon rewetting. In contrast, submerged cattail lost only 10.9 percent of its tissue P over the same time period. For the remainder of the experiment, the rate of P loss either decreased substantially (water lettuce), remained relatively constant (SAV/periphyton), or actually increased (cattail and water hyacinth). Increases in tissue P concentration during incubation were attributed to colonization of the plant material by a P-rich microflora and microfauna (see Reeder and Davis, 1983). Similar P enrichment of cattail and sawgrass leaves during decomposition studies has been reported by Reeder and Davis (1983) and Davis (1990).

Analysis of the nutrient budget data (see the Phosphorus Budget Mass Balance section in the chapter) indicated that Treatment Cell 4, which was dominated a SAV/periphyton community, was more efficient at removing TP than either the mixed marsh or cattail dominated cells. This result appears to contradict the findings noted above that SAV/periphyton had the highest plant tissue decomposition and P loss rates. How can the plant community with the highest P loss rate also be most efficient at removing TP? One possible explanation may lie in rapid uptake of P available in the water column by the periphyton, which leads to a very short nutrient spiraling length for the community. Total P cycling within the SAV/periphyton community may be so efficient that most of the P released through decomposition is quickly reabsorbed with relatively little of the nutrient being flushed downstream out of the cell.

MARSH DRYOUT STUDY (MDOS)

When wetlands dry out, the organic material in the sediments is exposed to the atmosphere and begins to oxidize (decompose) largely from the action of bacteria and fungi. The breakdown of this organic material releases stored nutrients as inorganic, water-soluble molecules. When a dried wetland refloods, some portion of the inorganic nutrient pool may be flushed from the sediments back into the water column. The sediments in the ENR Project and many of the STAs are composed of highly organic peat soils that will oxidize if dried. If one of the STAs were to dry out for any length of time, the flux of nutrients from the sediment upon reflooding could potentially reduce the overall nutrient removal efficiency of the treatment system. The magnitude of the impact on treatment performance would depend on a number of factors, including the amount of oxidation that takes place. Oxidation depends on the composition of the organic material, the sediment temperature (i.e., seasonal variability) and the duration of the dryout (Reddy, 1983; Olila, et al., 1997).

To prevent the STAs from drying out, current operational plans call for these wetlands to be flooded throughout the year. It is recognized, however, that under drought conditions some drying of the STAs may be unavoidable. The District initiated a collaborative research project, the Marsh Dryout Study (MDOS), with Dr. Ramesh Reddy of the University of Florida in late FY98 to characterize the potential for nutrient release after dryout and reflooding using sediments cores collected from the ENR Project. This information will enable District managers to better assess the potential impact of dryout on STA performance.

Data collection and analysis

The purpose of the MDOS is to quantify the role of P loading, duration of dryout and the presence/absence of macrophytes on the rate of sediment P flux to the overlying water column. The MDOS is being conducted using plywood and fiberglass tanks (mesocosms) operated as flow-

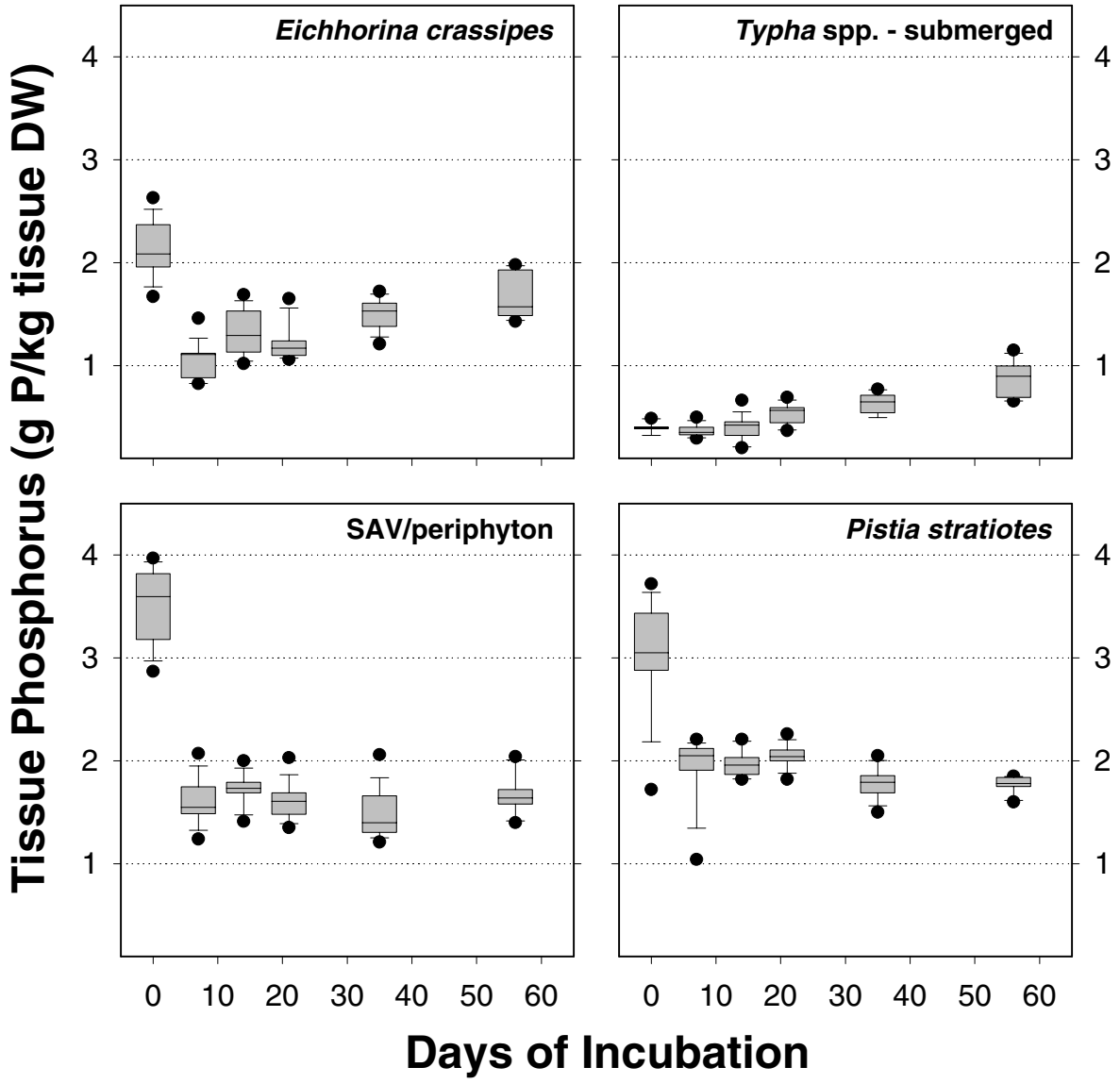

Figure 6-47. Change in tissue phosphorus concentration (g P/kg tissue DW) during a short-term decomposition study of the dominant aquatic macrophytes (*Typha* spp., *Eichhorina crassipes*, *Pistia stratiotes* and SAV/periphyton) in the Everglades Nutrient Removal Project. See **Figure 6-7** for description of box plots.

through systems at hydraulic loading rates typical of the STAs. Each mesocosm measures 5.9 m long x 1.0 m wide x 1.0 m deep and is filled with 30 cm of peat collected from the ENR Project (**Figure 6-48**). Twelve mesocosms are located at the ENR Project's Advanced Treatment Technology north research site and are being used for high P-loading dryout experiments; six of these tanks were planted with cattail, while the remaining six tanks are unplanted (**Figure 6-49**). Low P-loading experiments will be conducted in another 12 mesocosms installed at the ENR Project's south research site (see **Chapter 8** for descriptions of the Advanced Treatment Technology research sites located at the ENR Project). Water quality at the north research site is representative of post-BMP water from the Everglades Agricultural Area, while water quality at the south research site represents post-STA water quality conditions. Both sets of mesocosms will employ the same type of water delivery system. Water is first pumped into a 200-L head tank that then moves by gravity through a 2-inch PVC supply line with lateral pipes leading to the tanks. Each lateral pipe is equipped with a 5 ml pipette tip cut to deliver water at an average HLR of 2.6 cm/day resulting in a nominal hydraulic retention time of 15.4 days. The water depth in each mesocosm will be maintained at 40 cm.

The MDOS consists of four individual experiments that are summarized in **Table 6-10** and **Figure 6-49**. After the mesocosms are installed (i.e., filled with peat, planted with cattail and flooded to 40 cm), they have been operated for three months at the steady flow conditions noted above and allowed to stabilize. After stabilization, there will be two drawdown and two reflooding experiments conducted in each mesocosm. Each drawdown and reflooding experiment has three mesocosms assigned the following treatments:

- Continuously flooded mesocosms without emergent macrophytes;
- Intermittently flooded mesocosms without emergent macrophytes;
- Continuously flooded mesocosms with emergent macrophytes; and
- Intermittently flooded mesocosms with emergent macrophytes.

Both the planted and unplanted continuously flooded treatments will serve as controls and will receive a constant HLR throughout the study. One drawdown experiment is scheduled to occur during the dry season and the other during the wet season; each drawdown will last for approximately 30 days and the soil will be allowed to dry out naturally. Water quality samples will be collected at the inflow and outflow of the mesocosms. Porewater equilibrators will be used to document porewater nutrient gradients and estimate diffusive flux of P from the sediment. Soil samples will be analyzed to characterize the labile and nonlabile P pools. Plant samples will be collected and partitioned into aboveground live, aboveground dead and belowground live (roots and rhizomes) fractions. In the unplanted mesocosms, periphyton and any submerged aquatic vegetation will be sampled. All plant samples will be analyzed for total nitrogen (N) and P. A complete P mass balance will be developed for each mesocosm using water chemistry, soils, and vegetation data. Additional details on experimental methodology, field sampling protocols and other aspects of this study are described in Reddy, et al. (1999a).

Status of research and monitoring results

Installation of mesocosms at the north research site was finished and Experiment I (i.e., Stabilization Period; **Table 6-10**) was started in late-February 1999. Water quality samples were collected weekly for five weeks during the experiment at the inflow and outflow of all mesocosms and analyzed for TP, TDP, DRP, NH_4-N, NO_3-N, TKN, and Cl. In addition, at weeks 1 and 4 of the experiment, water quality samples were analyzed for TOC, Ca, Mg, Fe, SO_4, TSS, and alkalinity. The first dryout experiment (Experiment II) was initiated in late March 1999. Six mesocosms were drained and their sediments exposed to the atmosphere for a five-week period; dryout tanks were unprotected

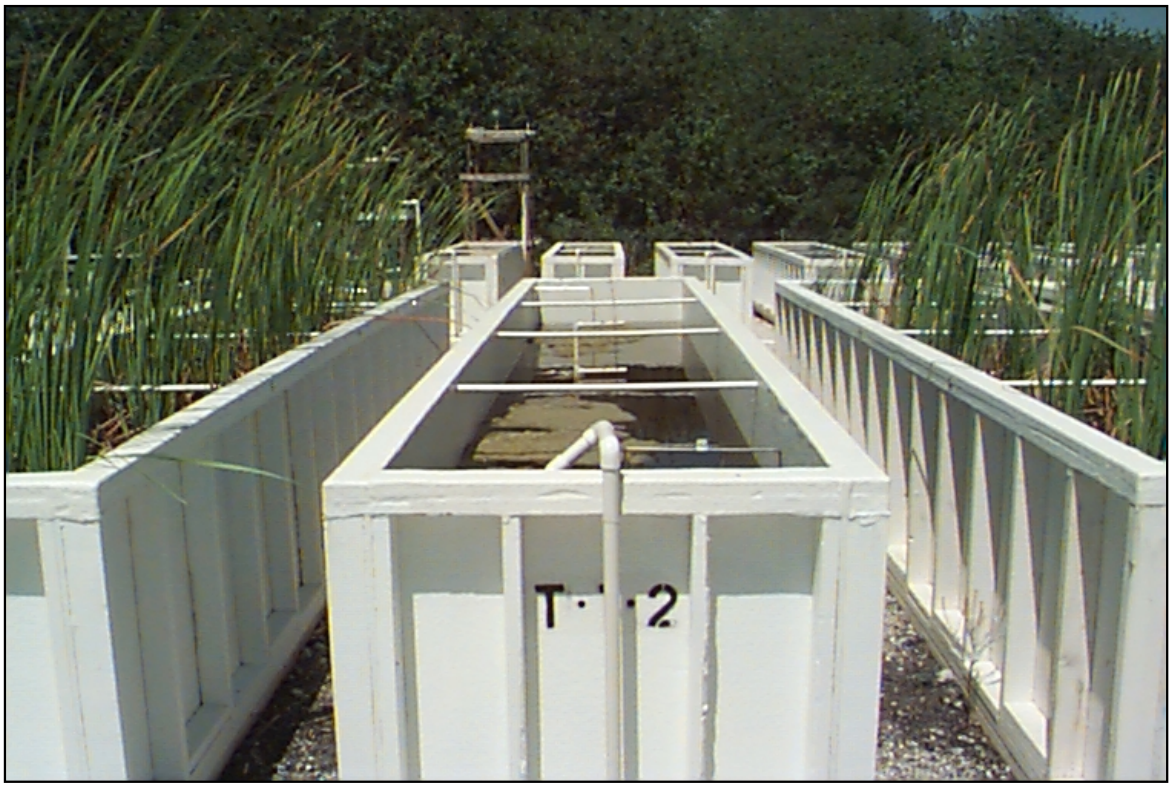

Figure 6-48. Mesocosm tanks used to conduct Marsh Dryout Study experiments at the Everglades Nutrient Removal Project.

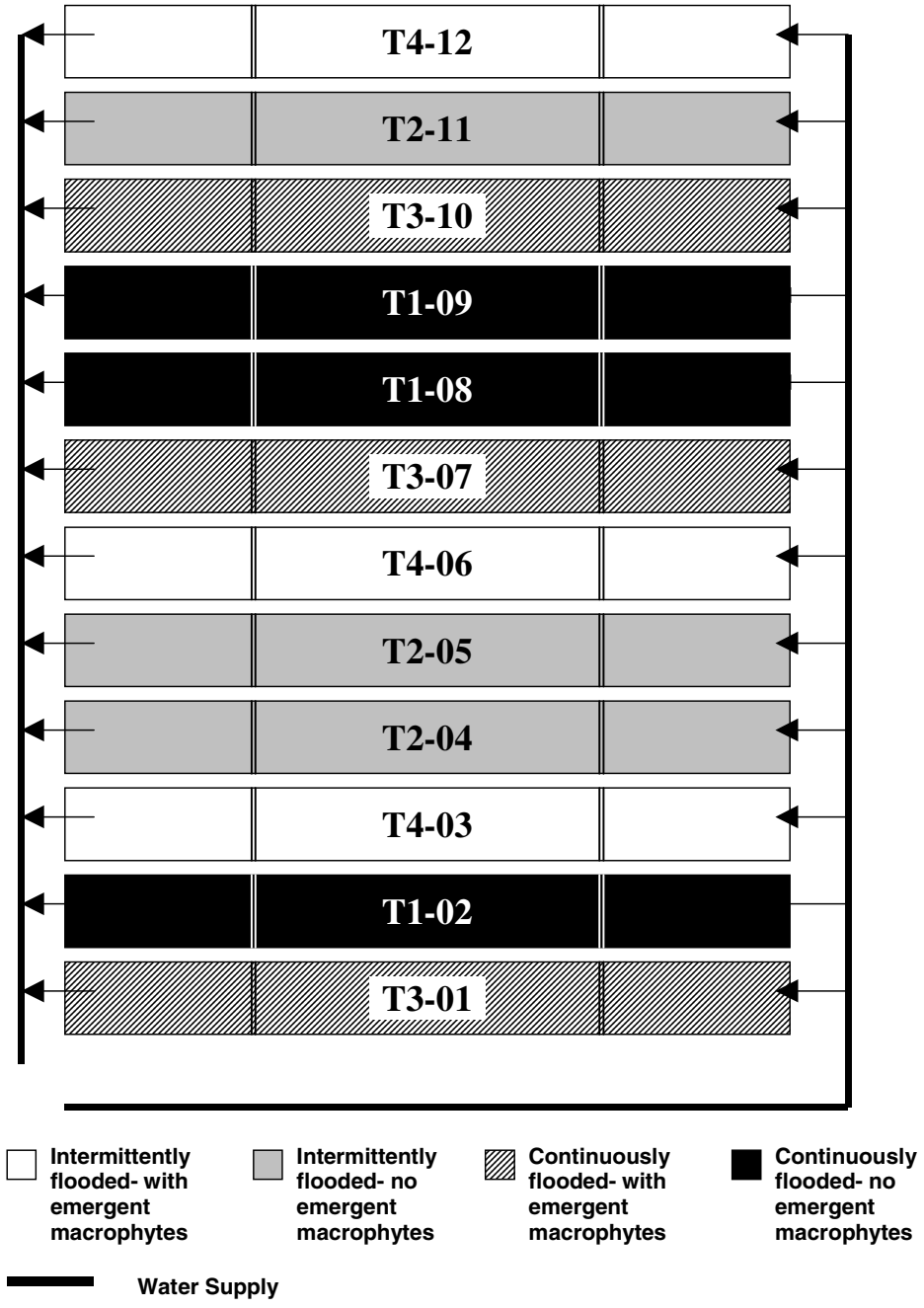

Figure 6-49. Assignment of mesocosms and experimental treatments for the Marsh Dryout Study underway at the Everglades Nutrient Removal Project. Abbreviations designate individual mesocosm tanks within an experimental treatment.

Table 6-10. Study duration and water quality/sediment parameters to be measured in Marsh Dryout Study experiments to be conducted at the Everglades Nutrient Removal Project.

Experiments	Study Duration	Water Quality Parameters	Sediment Parameters
Experiment I: Stabilization Period	Month 1 to 3	TP, TDP, DRP, NH_4-N, NO_3-N, TKN, Cl, TOC, alkalinity, Ca, Mg, Fe, SO_4, TSS	DO, pH, soil redox potential, soil P forms, soil porewater DRP and NH_4-N profiles, plant tissue P and N
Experiment II: Draw-down Period I	Month 3 to 4	TP, TDP, SRP, NH_4-N, NO_3-N, TKN, Cl, TOC, alkalinity, Ca, Mg, Fe, SO_4, TSS	Soil redox potential
Experiment III: Reflooding Period I	Month 4 to 8	TP, TDP, DRP, NH_4-N, NO_3-N, TKN, Cl, TOC, alkalinity, Ca, Mg, Fe, SO_4, TSS	DO, pH, soil redox potential, soil porewater DRP and NH_4-N profiles
Experiment IV: Draw-down Period II	Month 8 to 9	TP, TDP, SRP, NH_4-N, NO_3-N, TKN, Cl, TOC, alkalinity, Ca, Mg, Fe, SO_4, TSS	Soil redox potential
Experiment V: Reflooding Period II	Month 9 to 13	TP, TDP, DRP, NH_4-N, NO_3-N, TKN, Cl, TOC, alkalinity, Ca, Mg, Fe, SO_4, TSS	DO, pH, soil redox potential, soil P forms, soil porewater DRP and NH_4-N profiles, plant tissue P and N

from rainfall to mimic field conditions. Dryout tanks were re-flooded in May 1999 to the pre-drainage depth of 40 cm and inflow/outflow water quality sampling was resumed. Results from these experiments will be included in next year's Report.

As of this Report, mesocosms have not been installed at the south research site. We anticipate that the low P loading experiments will start at this location by October 1999.

TEST CELL RESEARCH

The District is conducting research to examine how hydrologic conditions may influence STA performance; i.e., what water management scenarios will promote maximum TP removal efficiency in these systems and conversely, under what hydrologic conditions TP removal efficiency will fail to meet mandated requirements. Experiments to address these questions are being conducted in the ENR test cells. The test cells are shallow, rectangular-shaped wetlands approximately 0.2 ha in size (about 0.5 acre) located within the boundaries of the ENR Project and are arranged into two groups (i.e., banks) of 15 cells each; the north bank of test cells (north test cells) is located within Treatment Cell 1 and the south bank of test cells (south test cells) is sited within Treatment Cell 3 (**Figure 6-2**). Ten test cells are currently assigned to STA Optimization research experiments (six north test cells and four south test cells). The remaining 20 cells are being used for Advanced Treatment Technology (ATT) and Marsh Dry Out research projects (**Table 6-11**; descriptions of ATT research projects

are presented in **Chapter 8**; Marsh Dry Out research is discussed in this chapter). Based on historical water quality monitoring data from the ENR Project, it is anticipated that inflow TP concentrations at the north test cells will range between 60 and 150 µg/L and represent "high" TP conditions, while inflow TP concentrations at the south test cells will range between 30 and 50 µg/L, representing "low" TP conditions.

Table 6-11. Assignment of ENR test cells to Stormwater Treatment Area Optimization, Advanced Treatment Technology[a] and Marsh Dry Out research projects.

Cell #	North Test Cells	South Test Cells
1	SAV/Limerock	**control cell**
2	Managed Wetlands	**STA Optimization - high HLR**
3	Managed Wetlands	PSTA
4	Managed Wetlands	SAV/Limerock
5	**control cell**	Managed Wetlands
6	**STA Optimization - high HLR**	Managed Wetlands
7	**STA Optimization - low HLR**	Managed Wetlands
8	**STA Optimization - low HLR**	Periphyton-STA
9	**STA Optimization - high HLR**	SAV/Limerock
10	**control cell**	Periphyton-SAV
11	Low-intensity Chemical Dosing	Periphyton-SAV
12	Low-intensity Chemical Dosing	Periphyton-SAV
13	Low-intensity Chemical Dosing	Periphyton-STA
14	Marsh Dry Out	**STA Optimization - low HLR**
15	SAV/Limerock	**control cell**

a. Descriptions of Advanced Treatment Technology research projects are provided in Chapter 8 of this Report.

The test cells are comparable in size to 16 operational treatment wetlands listed by Knight, et al. (1993) in the North American treatment wetland database. In addition, the test cells generally meet the criteria suggested by Bastian and Hammer (1993) for researchers to consider when conducting wetland performance tests (e.g., full exposure of the system to weather and other atmospheric effects; minimum linear dimension at least 10x the size of the largest component of the system; accurate measurement and consistent water loading; minimization of edge effects). Based on the above, we believe that the test cells are of sufficient size to faithfully replicate most of the important biological and hydrological processes that will mediate nutrient removal in the larger STAs. Therefore, the relationship between performance and operating conditions observed in the test cell experiments should be transferable to maximizing operation of the STAs.

Hydraulic factors that have the greatest impact on wetland treatment efficiency influence (a) the duration of water-biotic interactions and (b) the proximity of water to areas of the most intense biotic, chemical and physical activity (Kadlec and Knight, 1996; Reed, et al., 1998). These factors include water depth, hydraulic loading rate (HLR) and HRT. Experiments in the test cells will manipulate HLR and water depth to address the following questions:

- Low HLR experiments: What is the maximum nutrient removal efficiency that can be achieved at low hydraulic loading rates (and subsequently long retention times), i.e., to what level can the STAs ultimately reduce outflow TP concentrations when water is moved slowly through these systems?
- High HLR experiments: At what point along a gradient of increasing higher hydraulic loading rates (and subsequently shorter retention times) will TP removal efficiency fall below acceptable levels, i.e., when will STA outflow TP concentrations fail to meet a specified target level when water is flushed rapidly through these systems?
- Water depth experiments: How will STA treatment performance be impacted by holding the STAs in a "deep" water condition for long periods of time or by repeatedly cycling these systems between shallow and deep water conditions, situations which may occur during severe storm events and/or normal operations?

These experiments are described in greater detail in SFWMD (1998b). Due to the relatively short duration of these experiments, we, a *priori*, expect that there will be little or no impact on vegetation diversity and density, and sediment characteristics. However, to verify this assumption, we will monitor changes in these parameters during each experiment (see following section on additional research efforts). Information to be gained from this research will provide the District with a set of guidelines that will help tailor STA operations to maximize nutrient removal and correspondingly avoid situations that promote poor system performance.

The test cells were extensively modified from their original configuration for use in STA Optimization research. Changes made included (a) installation of a full liner in each test cell to isolate it hydrologically from the adjacent treatment and test cells and allow for independent control of HLR and depth and (b) a complete rebuilding of the water inflow and outflow distribution system for each test cell bank. Inflow water for the test cells is obtained from the surrounding treatment cell. Water is first pumped into a storage cell, which is maintained at a stage several feet above that of the test cells (**Figure 6-50**). Water from the storage cell then flows into a 30-inch feeder pipe and is delivered in parallel fashion to the test cells through 8-inch lateral pipes, each fitted with one of several calibrated orifice caps. The end of the inflow feeder pipe is equipped with an orifice to keep water delivery system well-flushed even if all the test cells are operating at low flow rates or are closed-off altogether. This feature was incorporated into the system design to prevent water within the feeder pipe from stagnating, which might cause large changes in water quality along the length of the pipe and negatively impact experiments being conducted within the test cells. The rate of flow into each test cell is regulated by changing the orifice cap. Outflow from each test cell is controlled by an adjustable 90° v-notch weir. Raising or lowering the weir controls water depth within that cell.

START-UP PERIOD

After all modifications to the north and south test cells were completed, the District officially took custody of the facilities from the contractor in June 1998 and November 1998, respectively. Before experimental work in the test cells could be initiated, a number of critical activities had to be completed during a start-up period. These activities included:

- Vegetation establishment—the test cells were operated in flow-through mode at a nominal 60 cm- water depth during start-up to promote vegetation growth. Individual test cells had been flooded for varying periods of time to start the vegetation grow-in process before the District officially took custody of each test cell bank from the contractor. Vegetation became established from the native seed bank, roots, shoots, and tubers present within the sediment used to fill each test cell after the liner was installed.

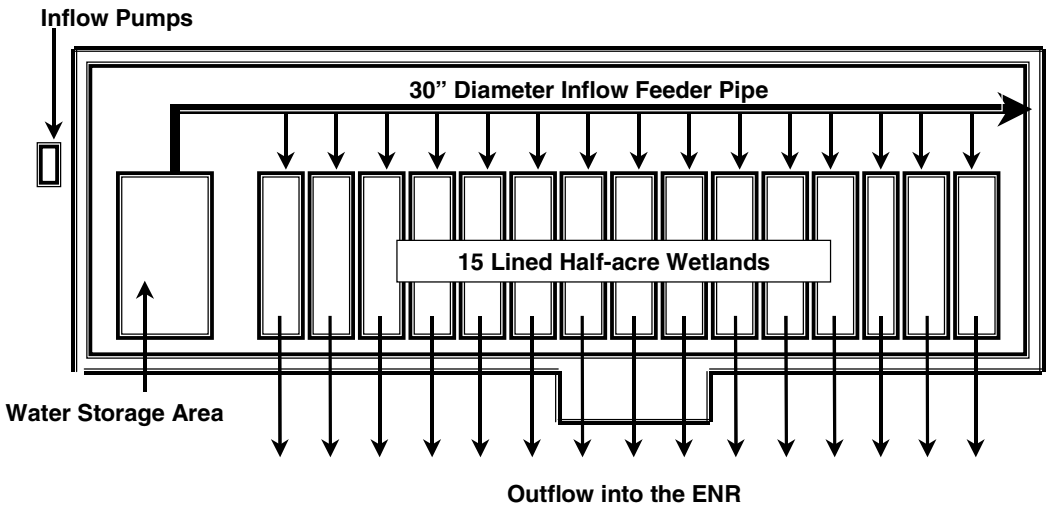

Figure 6-50. Design and water flow pathways of the Everglades Nutrient Removal test cells.

- Preliminary water quality evaluation—weekly/biweekly grab samples were collected from the outlet of the storage cell and the inflow to each test cell and analyzed for a number of parameters to document any differences in water quality that occurred along the length of the inflow feeder pipe delivering water to the test cells (**Figure 6-50**). Samples were analyzed for temperature, conductivity, pH, dissolved oxygen (DO), TP, ammonia (NH_3), nitrate+nitrite (NO_x), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), chloride (Cl), total suspended solids (TSS) and alkalinity.
- Inflow orifice calibration—a flow equation was developed for each sized orifice and calibrated to stage within the storage cell.
- Outflow weir calibration—outflow measurements from each test cell were used to calculate the discharge coefficient for the weirs.
- Installation of monitoring equipment—monitoring equipment (stage recorders and autosamplers) was scheduled for installation in the north and south test cells.

Vegetation Community Development

The development of the vegetation community in the test cells during the start-up period was tracked by visually estimating the percent coverage of the dominant species in each cell on a quarterly basis. This effort was supplemented by conducting vegetation line-transect surveys (Bonham, 1937; Brower, et al., 1997) in those test cells dedicated to STA optimization research (**Table 6-11**) and by inspecting aerial and ground-based photographs of all test cells. Nine macrophyte taxa were recorded in the north test cells and eight taxa in the south test cells (**Table 6-12**). Two species of cattail, *Typha*

Table 6-12. Checklist of plant species observed during start-up monitoring of the Everglades Nutrient Removal Project test cells.

Species	Test Cell Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
North Test Cells															
Typha spp.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sagittarria latifolia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sagittaria graminea		✓	✓												✓
Cyperus spp.				✓					✓	✓		✓			
Spirodela polyhriza	✓					✓	✓								
Ludwigia octovalvis						✓	✓	✓	✓	✓	✓	✓		✓	✓
Chara vulgaris	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		
Najas guadalupenssis					✓	✓									
Ceratophyllum demersum												✓			
South Test Cells															
Typha spp.	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Sagittarria latifolia		✓		✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
Sagittaria graminea	✓	✓													
Eleocharis cellulosa			✓	✓		✓	✓	✓					✓	✓	
Ludwigia octovalvis	✓			✓	✓	✓	✓							✓	
Chara vulgaris				✓					✓		✓	✓	✓	✓	
Najas guadalupenssis			✓												
Hydrilla verticillata	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

domingensis, Pers. and *Typha latifolia*, L., are present in both the north and south test cells, but were not differentiated from each other for this analysis. The north test cells were largely vegetated by the time of the first line-transect survey in September 1998 (**Figure 6-51**). Cattail was the dominant vegetation type and covered at least 70 percent of test cells 2- through 14-North by March 1999. A contact herbicide (Rodeo®) was applied to test cells 1 and 15 North in January and April 1999 to remove all emergent vegetation and promote the growth of SAV. These two test cells have been assigned to an ATT research project (SAV/ Limerock; **Table 6-11**) that requires a dense growth of SAV. Cattail coverage also increased in the south test cells between the time of the first and second vegetation surveys (**Figure 6-52**) except in test cells 4- and 9-South, which are reserved for the SAV/Limerock study and were treated with herbicide in January and April 1999. Test cells 3-, 8- and 13-South, which are reserved for another ATT research project (PSTA; **Table 6-11**), were treated with AQUASHADE® in October 1998 to reduce light penetration into the water column and inhibit the growth of all emergent macrophytes and SAV.

Preliminary water quality evaluation

The presumption in using the test cell facilities is that there are no significant differences in influent water quality within a bank of test cells, that is all test cells would receive the same inflow nutrient and chemical concentrations, and all test cells would have equivalent treatment performance. Sampling of the storage cell outlet and test cell inlets and outlets was initiated in the north test cells in September 1998 and in the south test cells in November 1998 to confirm these hypotheses. All test cells were operated with a 0.75-inch orifice to produce equal HLRs and at the same depth (~ 60 cm) throughout the start-up period.

There were no substantive differences noted for TP, NH_3, NO_x, TKN, Cl, TOC, TSS, alkalinity, conductivity and temperature during start-up between the north storage cell outlet and test cell inlets, nor were any important differences observed among the individual test cell inlets (**Figures 6-53** to **6-56**). Small differences in pH and a substantial difference in DO were noted between the storage cell and the test cells. A small downstream decrease in TSS (i.e., from cell 1-North to 15-North) also was evident. The large increase in DO was attributed to aeration of the water as it flowed through the orifice caps and was collected by the sampling crews. The decrease in TSS was assumed to reflect settling out of particles as the water moved down the inflow feeder pipe. The diameter of the orifice at the end of the inflow feeder pipe was changed (from a 1-inch to a 4-inch diameter orifice) to increase flow through the pipe and reduce the settling of particles.

There were no substantive differences noted for TP, NH_3, TKN, Cl, TOC, alkalinity, conductivity and temperature during start-up between the south storage cell outlet and test cell inlets, nor were any important differences observed among the individual test cell inlets (**Figures 6-53** to **6-56**). Small differences in DO and pH were noted between the storage cell and the test cells. A pronounced downstream decrease in TSS (i.e., from cell 1 to 15 South) also was evident. The increase in DO in the south test cells also was attributed to aeration of the water as it flowed through the orifice caps. The decrease in TSS also was assumed to reflect particle settling within the inflow feeder pipe. The diameter of the orifice at the end of the inflow feeder pipe was increased (from 1-inch to a 4-inch diameter orifice) to reduce the loss of TSS. Interestingly, NO_x concentrations increased in a downstream direction from the storage cell to cell 15-South. At present, we do not have a hypothesis to account for this observation.

Mean values for specific conductance, alkalinity, chloride, NH_3, TKN, TP and TOC during the start-up period were somewhat higher at the north test cells compared to the south test cells (1,200 vs. 1,100 µS/cm; 274 vs. 263 mg $CaCO_3$/L; 218 vs. 176 mg/L; 0.244 vs. 0.134 mg/L; 2.088 vs. 1.879 mg/L; 0.047 vs. 0.023 mg/L and 32.87 vs. 30.50 mg C/L, respectively). In contrast, mean values for DO, pH, NO_x, and TSS were higher at the south

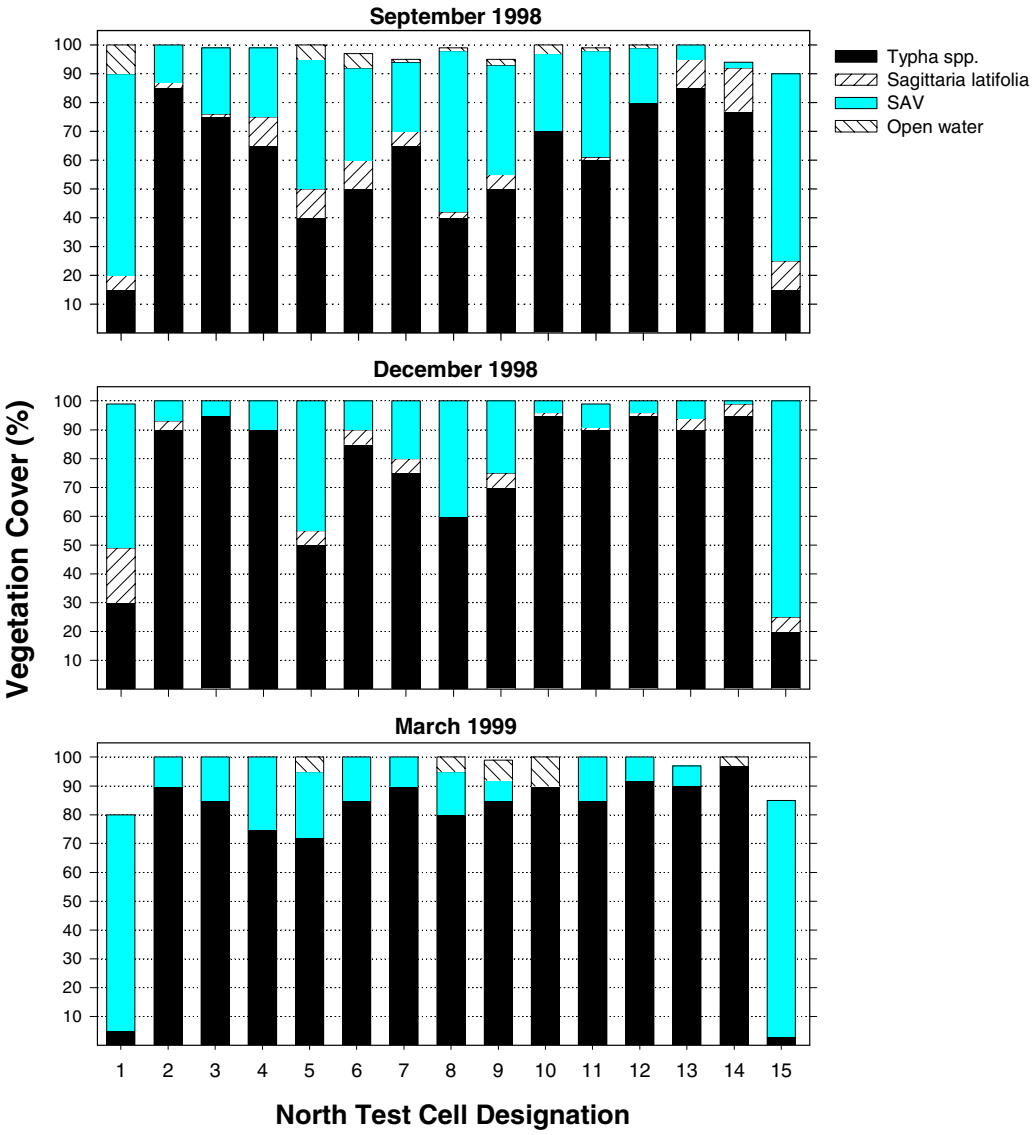

Figure 6-51. Changes in the relative coverage of emergent (*Typha* spp. and *Sagittaria latifolia*) and submerged aquatic vegetation (SAV) in the 15 north test cells during the start-up period determined by ground-based vegetation surveys.

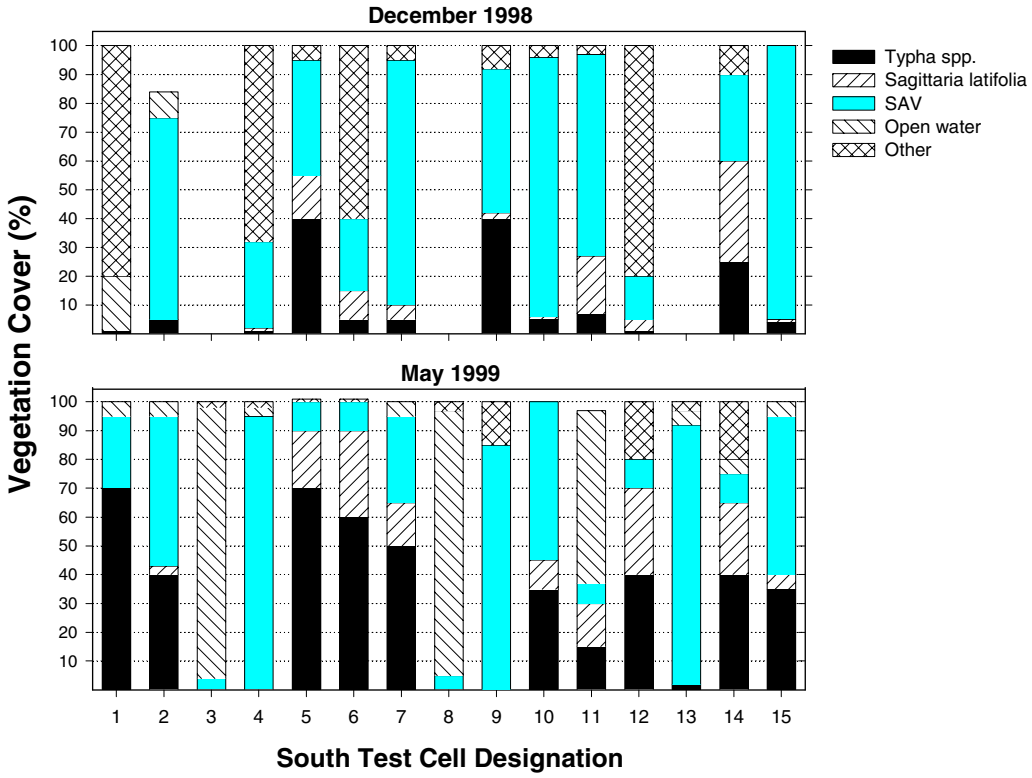

Figure 6-52. Changes in the relative coverage of emergent (*Typha* spp., *Sagittaria latifolia* and other species) and submerged aquatic vegetation (SAV) in the 15 south test cells during the start-up period determined by ground-based vegetation surveys.

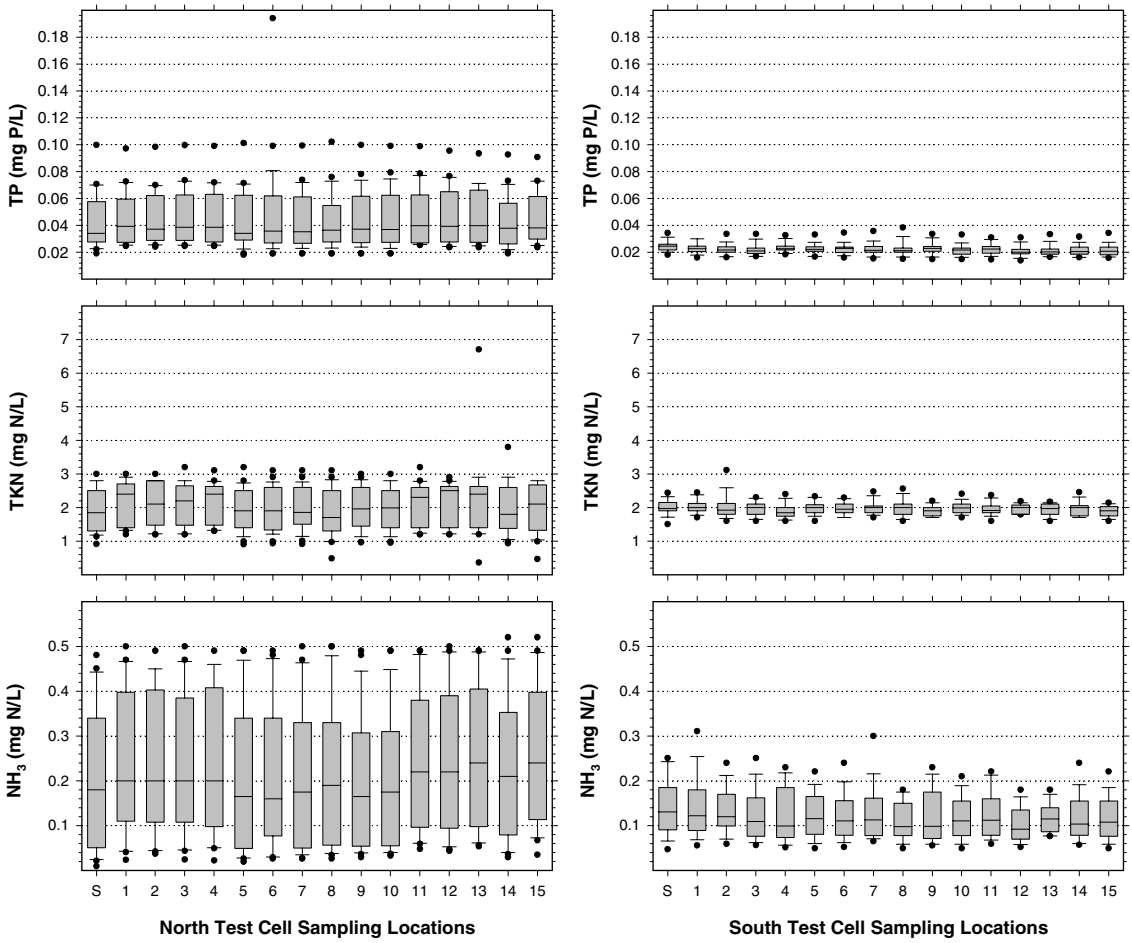

Figure 6-53. Comparison of weekly/biweekly measurements of total phosphorus (mg/L), total Kjeldahl nitrogen (mg/L) and ammonia-nitrogen (mg/L) at the storage cell outlet and test cells inlets during start-up of the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). See Figure 6-7 for description of box plots.

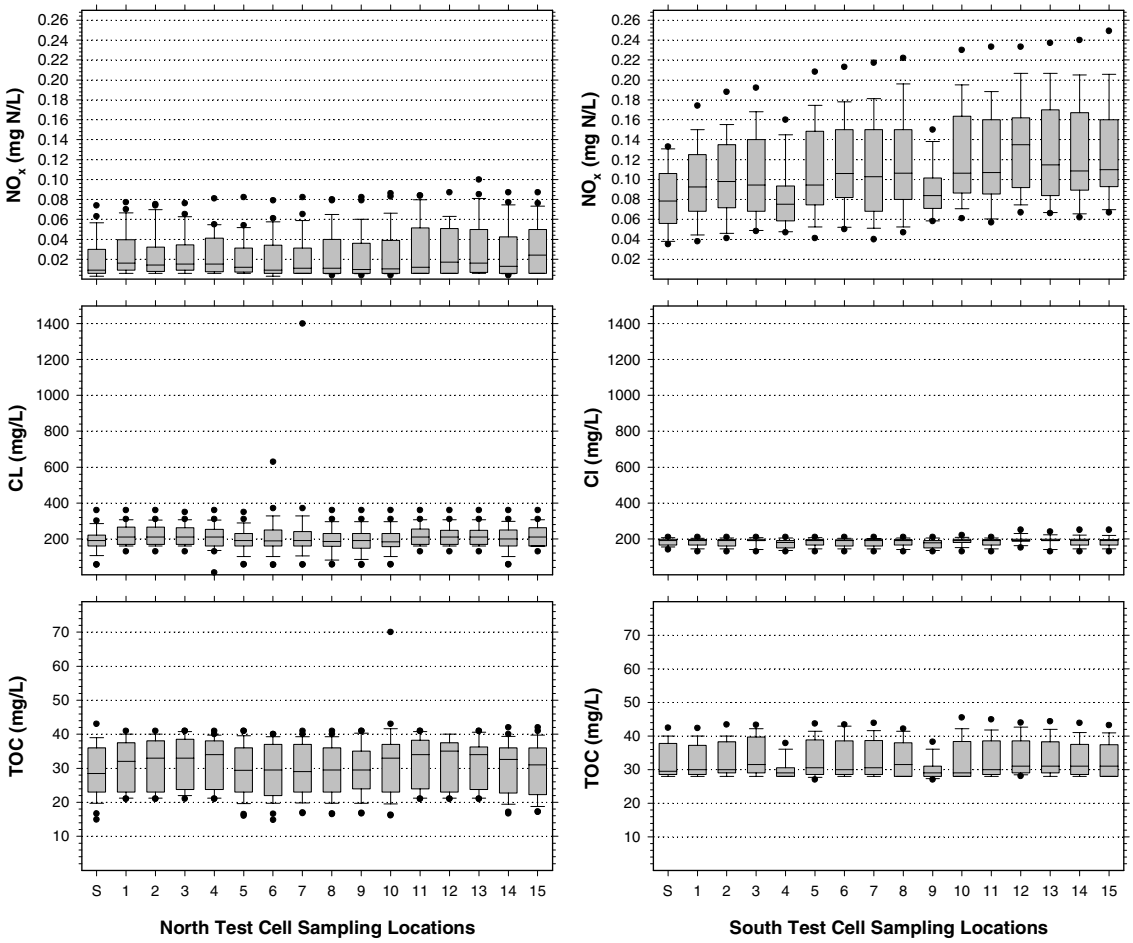

Figure 6-54. Comparison of weekly/biweekly measurements of nitrite+nitrate nitrogen (mg/L), chloride (mg/L) and total organic carbon (mg C/L) at the storage cell outlet and test cells inlets during start-up of the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). See Figure 6-7 for description of box plots.

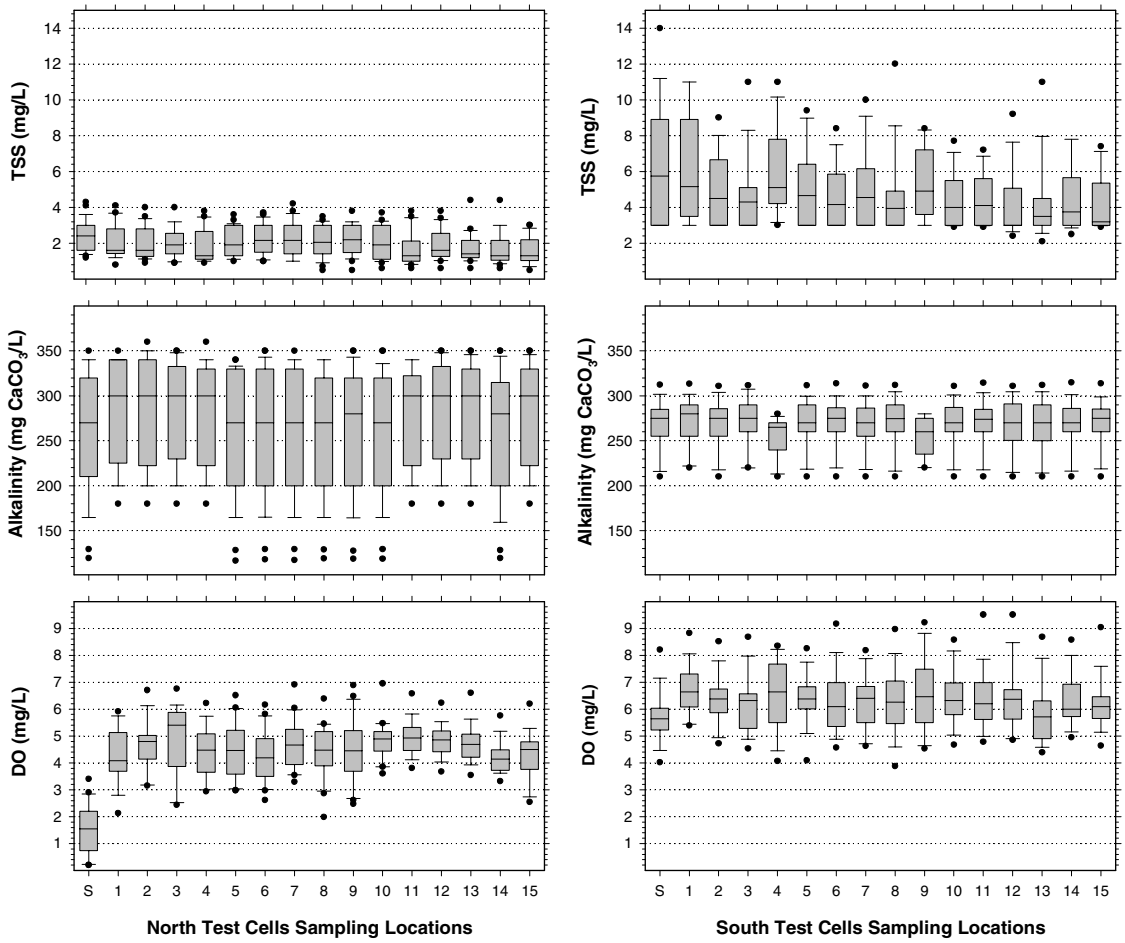

Figure 6-55. Comparison of weekly/biweekly measurements of total suspended solids (mg/L), alkalinity (mg CaCO3/L) and dissolved oxygen (mg/L) at the storage cell outlet and test cells inlets during start-up of the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). See Figure 6-7 for description of box plots.

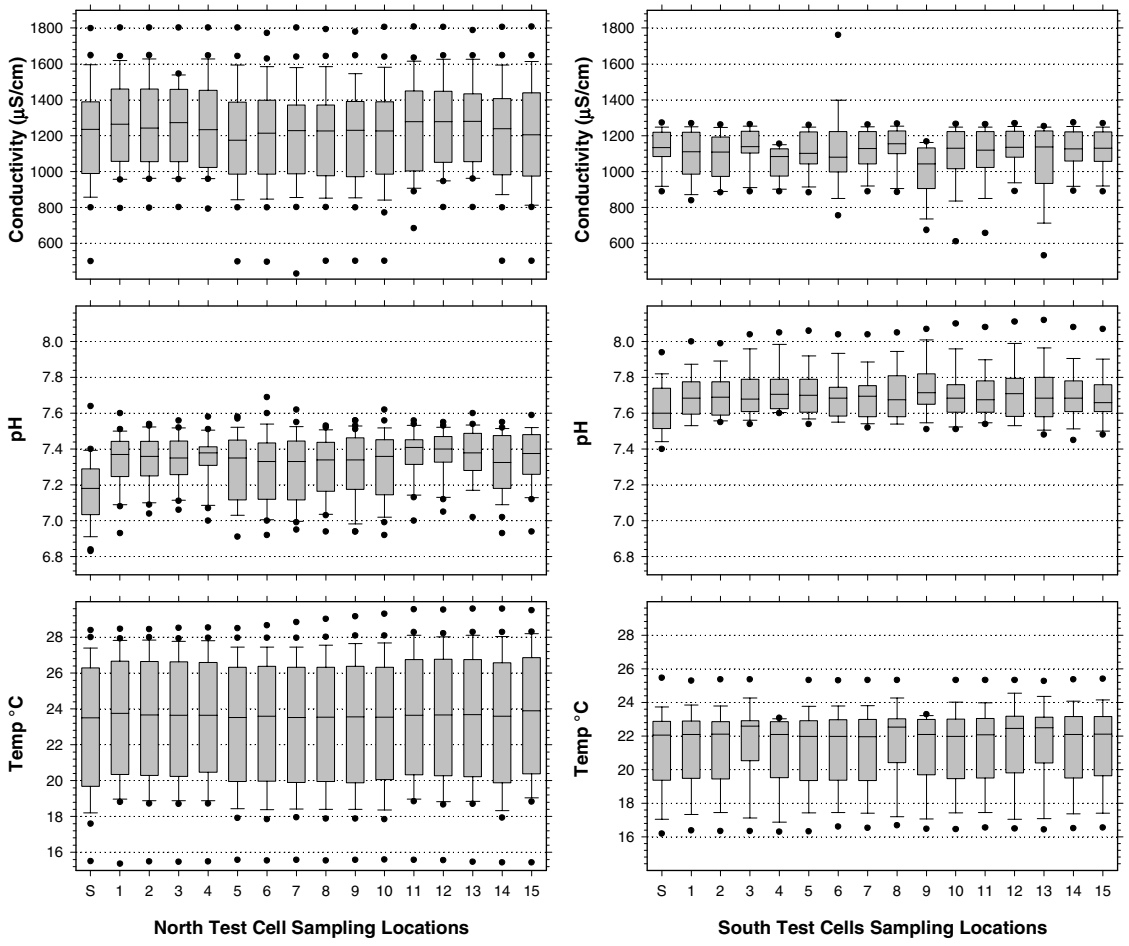

Figure 6-56. Comparison of weekly/biweekly measurements of conductivity (µS/cm), pH (standard units) and temperature (°C) at the storage cell outlet and test cells inlets during start-up of the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). See Figure 6-7 for description of box plots.

test cells (6.35 vs. 4.13 mg/L; 7.71 vs. 7.32; 0.098 vs. 0.027 mg/L; and 5.8 vs. 1.8 mg/L, respectively) (**Table 6-13**). Water quality data were not flow-weighted for this analysis.

Table 6-13. Descriptive statistics for water quality parameters monitored at the inlets to the north and south test cells during the test cell start-up period.

Variable	# Samples	Mean[a]	Minimum	Maximum
North Test Cells[b]				
Dissolved oxygen (mg/L)	300	4.13	0.10	6.90
Specific conductance (µS/cm)	300	1220	4	1808
pH	300	7.32	6.83	7.69
Alkalinity (mg $CaCO_3$/L)	280	274	116	3600
Chloride (mg/L)	280	218	11	1400
Total organic carbon (mg/L)	281	32.87	14.81	70.00
Ammonia (mg/L)	280	0.244	0.019	0.520
Nitrate-nitrite (mg/L)	280	0.027	0.004	0.100
Total Kjeldahl nitrogen (mg/L)	281	2.088	0.360	6.700
Total phosphorus (mg/L)	280	0.047	0.023	0.194
Total suspended solids (mg/L)	278	1.8	0.5	4.4
South Test Cells[c]				
Dissolved oxygen (mg/L)	159	6.35	3.90	9.50
Specific conductance (µS/cm)	159	1100	532	1761
pH	159	7.71	7.40	8.12
Alkalinity (mg $CaCO_3$/L)	117	263	210	290
Chloride (mg/L)	117	176	130	250
Total organic carbon (mg C/L)	114	30.50	28.00	39.70
Ammonia (mg/L)	117	0.134	0.047	0.310
Nitrate-nitrite (mg/L)	117	0.098	0.0350	0.190
Total Kjeldahl nitrogen (mg/L)	117	1.879	1.500	2.400
Total phosphorus (mg/L)	117	0.023	0.014	0.038
Total suspended solids (mg/L)	117	5.8	2.1	14.0

a. Mean values are not flow-weighted.
b. Statistics for the north test cells based on data collected from September 1998 through April 1999.
c. Statistics for the south test cells based on data collected from November 1998 through April 1999.

A preliminary evaluation of treatment performance in the test cells during the start-up period was based on comparing inflow vs. outflow time series data (mean values for all cells ± 1 SE) (**Figures 6-57** to **6-60**). Concentrations for most parameters at the storage cell outlet were quite similar to those at the test cell inflow, indicating little change in water quality within the inflow feeder pipe (note the exception for TSS and NO_x in the south test cells; see discussion above). In general, the test cells were effective at reducing concentrations of TP, NO_x, NH_3 and TSS. Reduced or little treatment effect was noted for TKN, Cl and TOC. Inflow-outflow changes in alkalinity were also observed in both banks of test cells. Even though the periods of record for the north (September 1998 through April 1999) and south test cells (November 1998 through April 1999) were not exactly the same, comparison

of all data indicated that there were marked differences in inflow water quality to the two groups of test cells (**Figures 6-53** to **6-60**). These differences were expected given the location of each bank of test cells. Water entering the north test cells from Treatment Cell 1 was less "processed" by the ENR Project than water from Treatment Cell 3 that entered the south test cells. The differences were a design feature for these facilities.

Inflow orifice calibration

Accurate estimates of flow into the test cells are critical to calculating accurate water and nutrient mass balance budgets. Inflow to each test cell is controlled by the stage in the storage cell, elevation difference between the storage cell stage and the orifice opening (i.e., head drop) and the size of the orifice opening. Stage is recorded to the nearest 0.01 ft on a continuous basis and the data transmitted back to the District daily. A flow equation was developed for each orifice by regressing flow against stage using the following relationship (Aisenbrey et al. 1978):

$$Q_o = C_o A_o \sqrt{2gH_o} \qquad (6.31)$$

where:

Q_o = discharge through the orifice (cfs);

C_o = orifice discharge coefficient;

A_o = cross-sectional area of the orifice (ft^2);

g = acceleration due to gravity (ft/sec^2); and

H_o = head on centerline of the orifice (ft).

The resulting flow equations accounted for 89 to >99 percent of the variability in the data for the different sized orifices that have been calibrated to date (**Table 6-14**). This table also provides the range of flow rates for each orifice based on the expected range of stages within the storage cell as it fills and drains during normal test cell operation and the resulting average HLR to the test cells. To check our calibrations, we independently measured orifice flow using a double-sided tipping bucket similar to a prototype developed at the University of Connecticut and based on the same operating principles as USGS tipping rain gauges (**Figure 6-61**). To date, comparisons have been completed for two orifices; measured flow using the tipping bucket was within 1 and 8 percent of computed flow for the 0.5-inch and 0.75-inch diameter orifices, respectively. Orifices greater than 1.0 in diameter will be calibrated by measuring flow only with the tipping bucket. The method initially used to collect water for the other calibrations (5 gal bucket for the 0.25 to 1.5-inch orifices) is unusable at the higher flow rates produced by the larger orifices because excessive water splashes out of the bucket. Water splash-out results in less precise flow measurements, e.g., note the lower R^2 value (89 percent) for the 1.5-inch orifice.

Outflow weir calibration

Flow over the outflow weir is a function of the stage in the test cell. Stage is measured to the nearest 0.01 ft on a continuous basis by an automated stage recorder and the data transmitted back to the District daily. The standard 90° v-notch weir equation (Aisenbrey et al. 1978; Brater and King, 1976; Grant and Dawson, 1978; McKiernan, 1952) was used to calculate outflow from each test cell:

$$Q_w = C_w H_w^{2.5} \qquad (6.32)$$

where:

Q_w = outflow from the test cell over the weir (cfs);

C_w = weir discharge coefficient; and

H_w = head on the weir (ft).

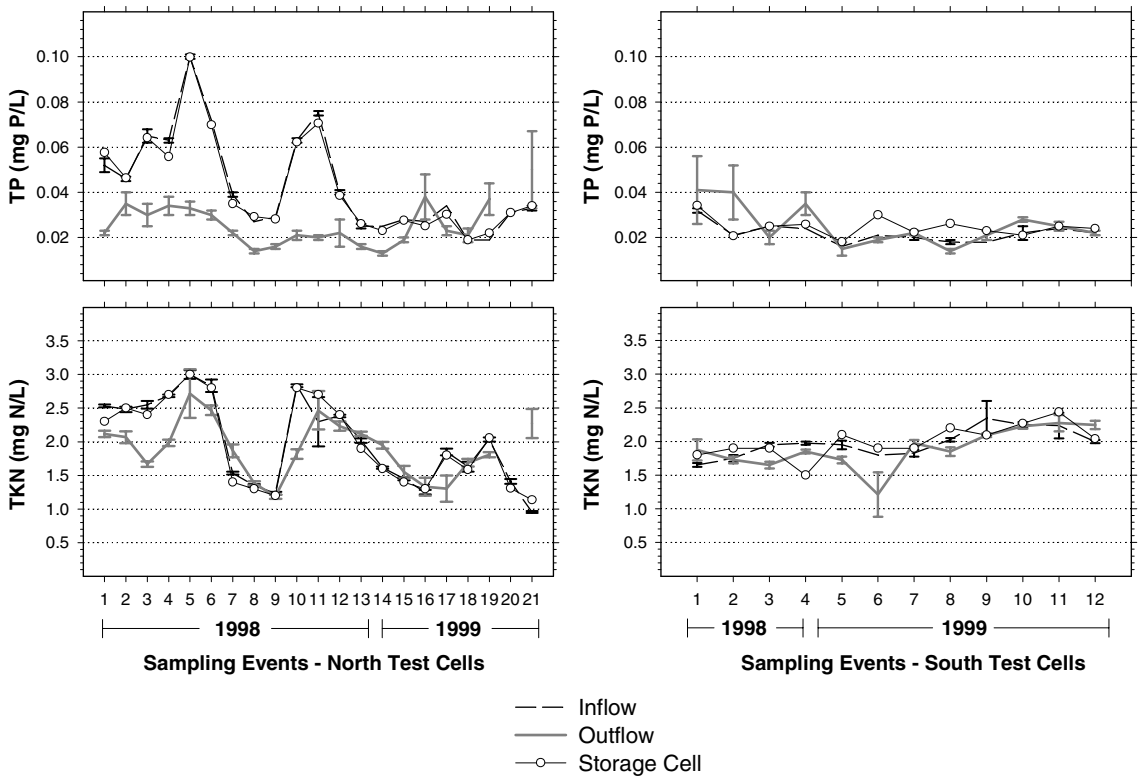

Figure 6-57. Temporal variation in total phosphorus (mg/L) and total Kjeldahl nitrogen (mg/L) at the storage cell outlet and the test cell inflows and outflows during start-up for the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). Values for the test cell inflow and outflow represent the mean for all cells ± 1 SE (SE = standard error of the mean).

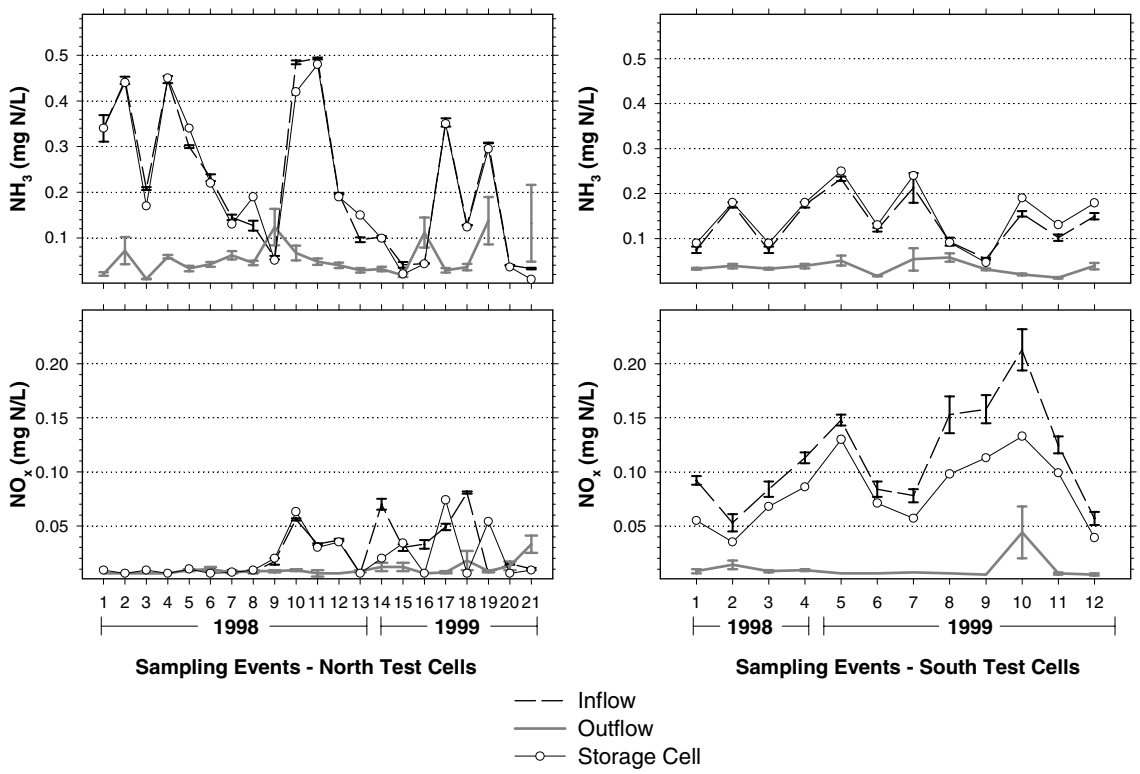

Figure 6-58. Temporal variation in ammonia-nitrogen (mg/L) and nitrite+nitrate nitrogen (mg/L) at the storage cell outlet and the test cell inflows and outflows during start-up for the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). Values for the test cell inflow and outflow represent the mean for all cells ± 1 SE (SE = standard error of the mean).

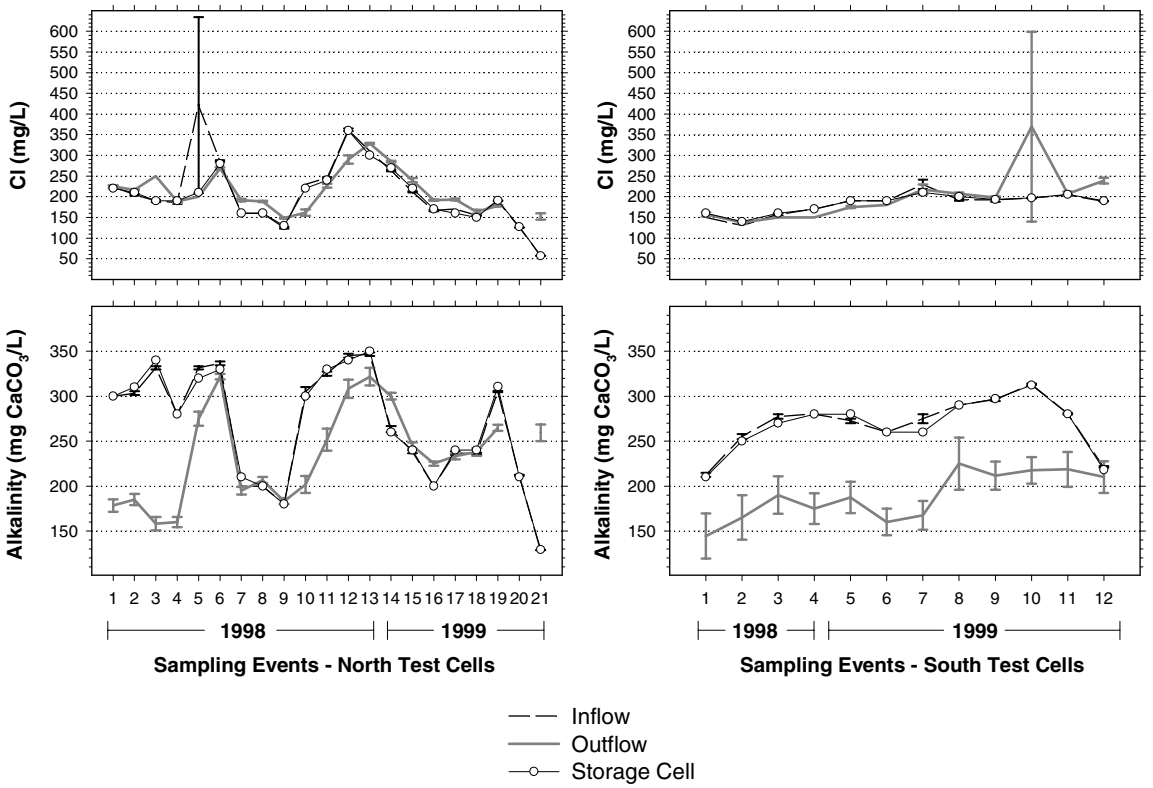

Figure 6-59. Temporal variation in chloride (mg/L) and alkalinity (mg $CaCO_3$/L) at the storage cell outlet and the test cell inflows and outflows during start-up for the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). Values for the test cell inflow and outflow represent the mean for all cells ± 1 SE (SE = standard error of the mean).

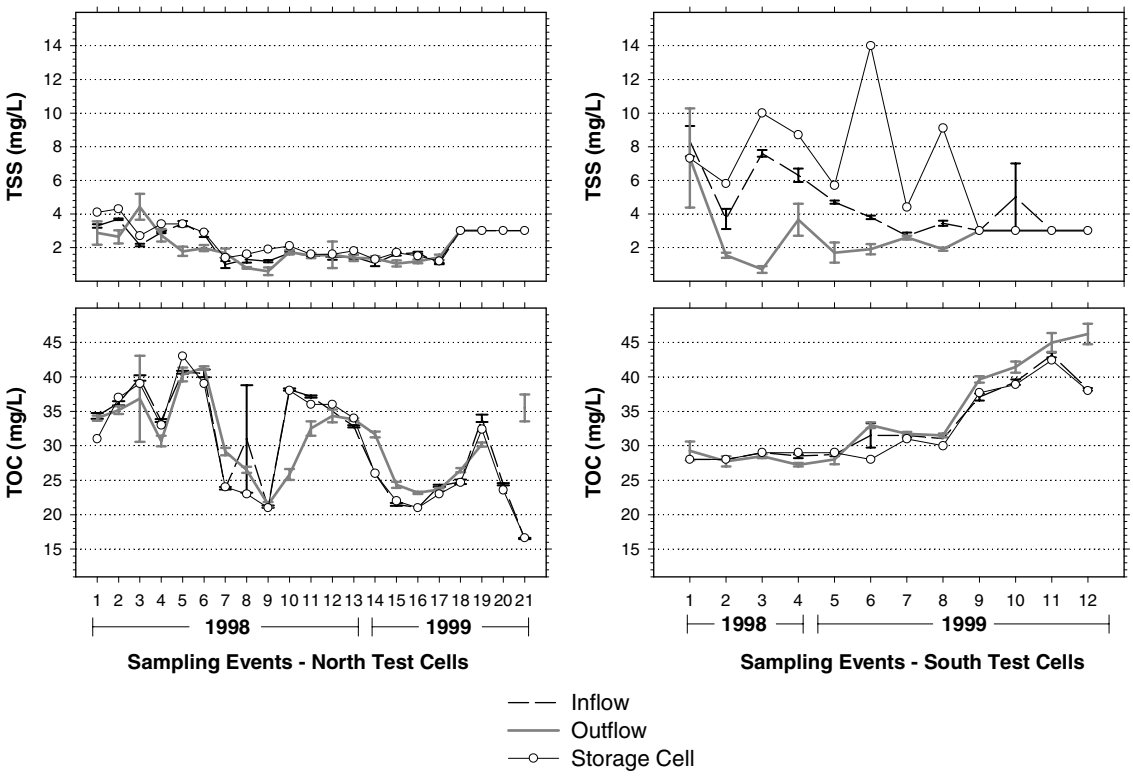

Figure 6-60. Temporal variation in total suspended solids (mg/L) and total organic carbon (mg/L) at the storage cell outlet and the test cell inflows and outflows during start-up for the north test cells (September 1998 through April 1999) and south test cells (November 1998 through April 1999). Values for the test cell inflow and outflow represent the mean for all cells ± 1 SE (SE = standard error of the mean).

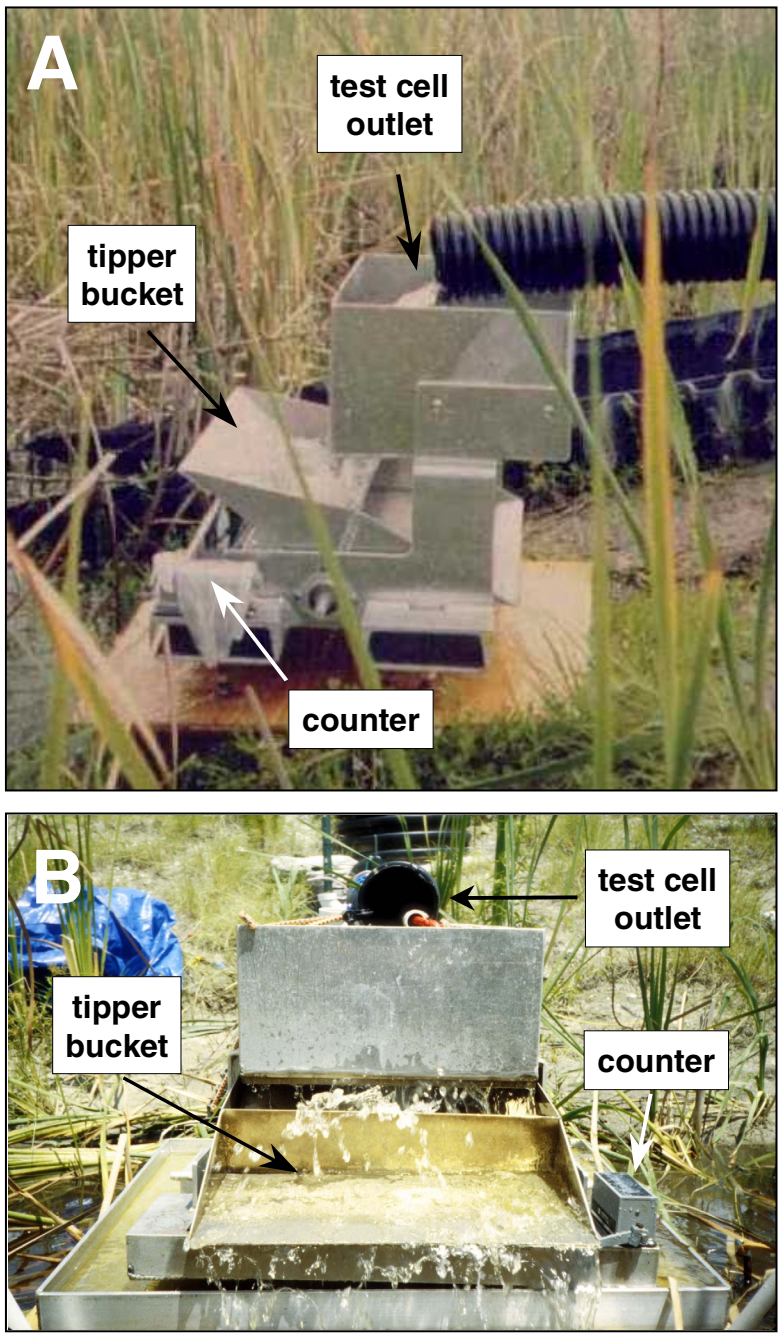

Figure 6-61. Double-sided tipping bucket used to validate flow calibrations for different sized orifices in Everglades Nutrient Removal test cells. Panel A: side view of tipping bucket; Panel B: front view of tipping bucket.

Table 6-14. Predictive flow equations based on regression of measured flow through the orifice with stage in the storage cell and the resulting regression coefficient for each flow equation. The range of flow values are based on expected stage variation in the storage cell and the corresponding mean hydraulic loading rate (HLR) to the north and south test cells for different sized orifices.

Orifice Diameter (in)	Predictive Flow Equation[a]	R^2	Flow Range (cfs)	Mean HLR (cm/day)
	North Test Cells			
0.25	[(Stage - Head Drop)*0.0004] - 0.0064	0.9741	0.0026 – 0.0031	0.27
0.375	[(Stage - Head Drop)*0.0008] - 0.0117	0.9940	0.0063 – 0.0073	0.64
0.5	[(Stage - Head Drop)*0.0018] - 0.0285	0.9995	0.0129 – 0.0149	1.30
0.75	[(Stage - Head Drop)*0.0046] - 0.0763	0.9389	0.0256 – 0.0313	2.66
1.0	[(Stage - Head Drop)*0.0084] - 0.1378	0.9315	0.0481 – 0.0590	4.99
1.5	[(Stage - Head Drop)*0.0138] - 0.1981	0.8881	0.1069 – 0.1242	10.82
2.0	Data collection/analysis not complete	--	--	--
3.0	Data collection/analysis not complete	--	--	--
4.0	Data collection/analysis not complete	--	--	--
	South Test Cells			
0.25	Data collection/analysis not complete	--	--	--
0.375	Data collection/analysis not complete	--	--	--
0.5	Data collection/analysis not complete	--	--	--
0.75	[(Stage – Head Drop)*0.0046] – 0.0756	0.9916	0.0286 – 0.0332	2.89
1.0	[(Stage – Head Drop)*0.0086] – 0.1427	0.9918	0.0540 – 0.0626	5.45
1.5	data collection/analysis not complete	--	--	--
2.0	Data collection/analysis not complete	--	--	--
3.0	Data collection/analysis not complete	--	--	--
4.0	Data collection/analysis not complete	--	--	--

a. Stage = stage in the storage cell (ft); Head Drop = elevation difference between the storage cell and the orifice opening (ft).

A discharge coefficient (C_w) was calculated for each weir. Three of the north test cells have substantially longer outflow pipes running from these cells to their weir-box structures than do the other 12 north test cells (the three test cells in question are adjacent to the old outflow sump area, which was part of the original test cell design; the sump area was filled in when the test cells were modified creating, in effect, a much wider levee through which the outflow pipe from the these three cells had to run to reach their weir-box structures). The original design assumption that the longer outflow pipes would not influence flow was found to be incorrect. The discharge coefficient calculated for the three test cells with long outflow pipes (2.95) was significantly different than the coefficient for the other north test cells (2.43) ($F = 39.12$, $p = 0.001$) (Proc GLM, SAS/STAT Version 6.12; SAS Institute, Inc., Cary, NC). We are currently calibrating discharge for weirs at the south test cells.

Installation of monitoring equipment

Installation of stage recorders and telemetry controls at the inflow and outflow of all north test cells was completed by May 1998. Monitoring equipment is currently being installed in the south test cells. Installation of autosamplers at the storage cell outlet and outlets of all test cells assigned to STA Optimization research (**Table 6-11**) is also underway.

STA OPTIMIZATION EXPERIMENTS

Depth and HLR experiments

Two test cells at both the north and south sites have been dedicated as control cells (**Table 6-11**). They will be operated throughout the duration of the STA Optimization research at a mean HLR of 2.7 cm/day and a depth of 0.6 m approximating the average design conditions for the STAs. The HLR for two north test cells and one south test cell will be incrementally decreased every 15 weeks from the initial value of 2.7 cm/day to approximately 0.3 cm/day (low HLR experiments). Concurrently, the HLR in the remaining north and south test cells will be incrementally increased every 15 weeks to approximately 20 cm/day (high HLR experiments). The first step change in the HLR was made on May 19, 1999. Following completion of the HLR experiments, all cells will be returned to a HLR of 2.7 cm/day, after which water depth will be incrementally increased step-wise in all experimental cells to a maximum of 1.2 m over four 15-week periods. Grab samples have been collected weekly or biweekly at the storage cell outlet and the inflow and outflow of all STA Optimization test cells since the initiation of start-up sampling (September 1998 at the north test cells and November 1998 at south test cells). Autosamplers are currently being installed at the outflow of the storage cell and the STA optimization test cells for weekly time-composite samples of TP and total nitrogen (TN). The results of these experiments will be presented in next year's Report.

Additional research efforts

During each 15-week experimental period, we plan to measure water velocity, sediment oxidation-reduction potential (redox), plant stem density and species coverage, and cellulose decomposition rates concurrent with inflow and outflow water chemistry in the STA Optimization test cells. Plant stem density will be measured using standard line-transect census methodologies (Bonham, 1937; Brower, et al., 1997) along the length and width of each cell. Water velocity will be measured using a low-flow Sontech ADV meter at a single depth along similar transects.

Cotton strip frames (Maltby, 1985) and redox rods (Snoeyink and Jenkins, 1980) will be placed at the inflow and outflow areas to document differences in cellulose decomposition and electron availability at the high and low points along the nutrient gradient in the cells. A test deployment of cotton strip frames detected no discernible differences in cellulose decomposition rates in the sediment between inflow and outflow areas but did find markedly lower decomposition rates measured as loss in tensile strength in the water column at the outflow compared to the inflow (**Figure 6-62**).

ANALYSIS OF DATA FROM OTHER WETLANDS

The District has evaluated data from regional constructed and natural wetlands such as the WCAs, Iron Bridge (Orlando) and Boney Marsh (Kissimmee) to gain insight into the long-term treatment performance that might be expected from subtropical wetlands and to help establish design criteria for the ENR Project and the STAs (see Kadlec and Newman, 1992; Walker, 1995). Operational data have also been analyzed for Boney Marsh and the U.S. EPA's North American Treat-

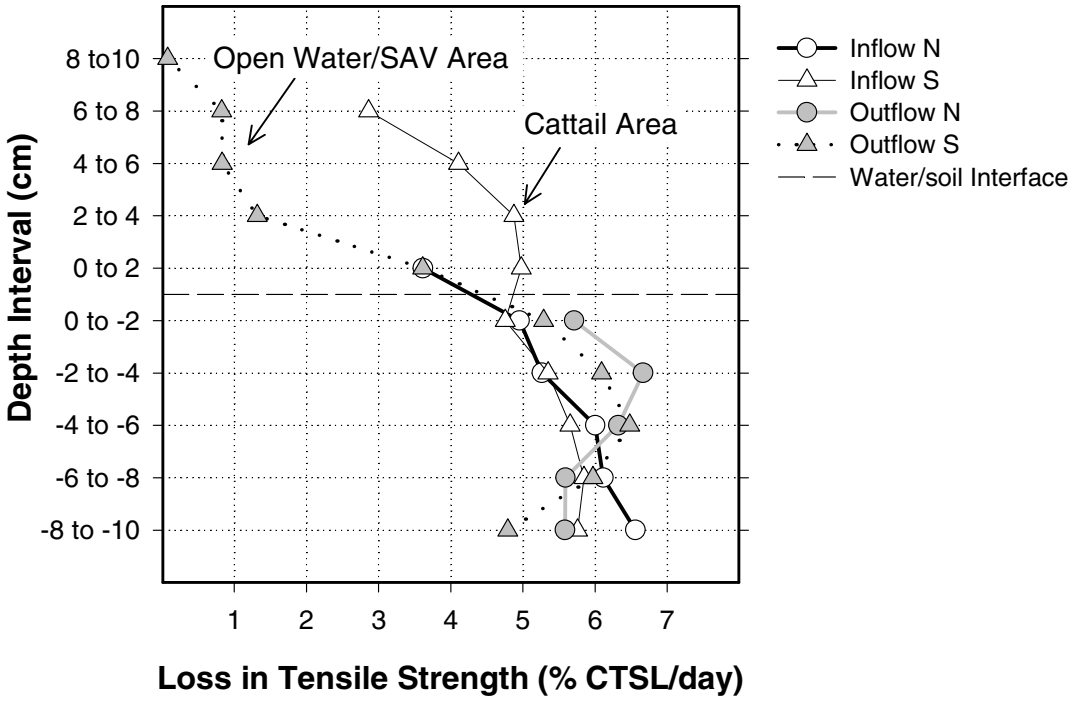

Figure 6-62. Comparison of differences in cotton strip tensile strength loss (CTSL) in a test deployment at inflow and outflow areas of both north and south test cells in the Everglades Nutrient Removal Project.

ment Wetland database (Davis, 1981; Mierau and Trimble, 1988; Moustafa, et al., 1996, 1998; Moustafa 1997, 1998, 1999a). Boney Marsh was a small treatment wetland (48 ha) built by the District on the Kissimmee River floodplain in Highlands County, FL and operated from 1976 to 1987 to evaluate the effectiveness of overland flow as a means of improving water quality. The U.S. Environmental Protection Agency (USEPA) wetland database contains performance information from 454 wetland treatment systems located throughout North America (see Knight, et al., 1993 and Knight 1994 for description of the database).

The relationship that water depth, HLR and P loading rate had on P load reduction in wetlands was examined using the Boney Marsh and USEPA datasets. Highest removal efficiencies (80-95 percent) occurred at (a) water depths less than 20 cm with P loading rates up to 9.5 g $P/m^2/yr$, or (b) when HLR was less than 6 cm/day and loading rates ranged between 1 and 6 g $P/m^2/yr$. The lowest removal efficiencies (<60%) occurred at (a) water depths greater than 80 cm and/or when the P loading rate exceeded 8.5 g $P/m^2/yr$ and water depth was greater than ~ 30 cm, or (b) when the P loading rate exceeded 6 g $P/m^2/yr$ for all HLRs (Moustafa 1999a). A simple model based on Vollenweider's lake model and several graphical tools was developed to predict outflow P concentration or P load reduction knowing nutrient and hydraulic loading rates and estimates of P removal rate (Moustafa 1997; Moustafa, 1998; Moustafa 1999a). The status of the District's research efforts to date in analyzing performance data from other wetlands is summarized in greater detail in the 1999 Everglades Interim Report (Chimney and Moustafa, 1999). There are no new research efforts to report at this time.

WETLAND WATER QUALITY MODEL

The District, in conjunction with HydroQual, Inc., is developing a time-variant fate and transport model, the Wetland Water Quality Model (WWQM), that simulates changes in wetland water quality under alternative management scenarios (HydroQual, 1995). This model incorporates the important hydrological, biological and chemical processes that mediate nutrient cycling and retention in wetlands and will provide a quantitative, predictive methodology to characterize flow distributions and nutrient processes occurring in these systems. The model has been calibrated to data from WCA-2A and the ENR Project (HydroQual 1997a, 1997b, 1997c, 1998). An evaluation of the water quality submodel output indicated that further developmental work, such as adding an SAV component to the model, was needed before the full model can accurately simulate all the biological and chemical processes that remove nutrients in wetlands. HydroQual Inc. is performing additional calibration runs using ENR Project data to investigate the impact that the following scenarios have on model predictions:

- High and low hydraulic loading rates;
- High and low TP mass loading rates;
- Shallow and deep water depths; and
- Variation in coverage type (cattail, periphyton and open water).

Once fully developed, the WWQM will be a valuable decision-making tool for the District and will enable water managers to evaluate the short-term impact that various operational scenarios will have on nutrient removal performance of the STAs. The status of the WWQM is covered in greater detail in Chimney and Moustafa (1999).

WATER QUALITY STANDARDS

Results from the water quality monitoring program for other parameters required by the FDEP operating permit for the ENR Project (**Appendix 6-1**) have been reported in SFWMD (1995a, 1996, 1997, 1998a, 1999). For many parameters, the District has been able to demonstrate during the period of record that constituent levels in outflow waters were at undetectable levels and/or did not violate Florida Class III water quality standards. Subsequently, FDEP has eliminated these parameters from the monitoring program (see indicated parameters in **Appendix 6-1**). Dissolved oxygen (DO) concentrations at the Inflow, Outflow, and WCA-1 (control) sampling stations were frequently below the 5 mg/L standard. We examined the database for possible bias in the time of day when DO was recorded and found that the majority of measurements at all three stations (79.5 to 96.4 percent) were made between 9:00 and 11:00 a.m. Rather than a product of sampling bias at a given station, the low DO levels are thought to be indicative of low background dissolved oxygen concentrations frequently observed throughout the day in productive Everglades habitats (see **Chapter 4**; McCormick, et al., 1997). Ametryn and atrazine were the only organic compounds routinely found at concentrations above the detection limit. Levels for both chemicals at all sampling stations were characteristic of water-borne contamination in areas of intense agricultural activity. Neither chemical is used within the ENR Project. Outflow concentrations for only three other parameters exceeded permit requirements during the entire period of record: specific conductance (one sampling date), silver (two sampling dates), and total coliform bacteria (three sampling dates) (SFWMD, 1995a, 1966, 1997, 1998a, 1999).

ANNUAL REPORT ON STA OPERATIONAL PERFORMANCE

STA-1WEST

Project description

STA-1 West (STA-1W) is located in central Palm Beach County, along the northwestern boundary of WCA-1 and on the eastern boundary of the EAA (**Figures 6-1** and **6-2**). When completed, this STA will provide approximately 2,711 ha (6,700 acres) of wetland treatment area for removal of P from agricultural runoff and other source waters before the effluent enters the Everglades Protection Area (EPA). A portion of STA-1W has been operating since August 1994 as the ENR Project (1,545 ha [3,818 acres]). The ENR Project has exceeded its P removal goals, averaging 22 µg/L at its outflow, and has removed over 70 metric tons of P that would otherwise have entered WCA-1. Inflow to STA-W will be directed along one of three flow-paths:

- Treatment Cells 1 and 3 which encompass 985 ha (2,434 acres) and were part of the former ENR Project;
- Treatment Cells 2 and 4 which encompass 560 ha (1,384 acres) and were part of the former ENR project; or
- Treatment Cell 5 which is divided into two compartments: Cell 5a east of the Florida Power and Light levee (~ 243 ha [600 acres]) and Cell 5b west of this levee (~ 931 ha [2,300 acres]).

Treated outflow from STA-1W will be discharged into the L-7 perimeter canal of WCA-1.

Operational status

Construction of the Cell 5 portion of STA-1W was substantially complete by March 1999. Everglades Forever Act (EFA) and USEPA National Pollution Discharge Elimination System (NPDES) operating permits have been issued to the District for this facility. Cell 5 has been flooded and is in the process of stabilizing, although TP criteria that would allow discharge have not been met to date. However, the ENR Project portion of STA-1W continues to operate.

Modification to Operations Plan

Submerged Aquatic Vegetation. In recognition of the exceptional performance achieved in Treatment Cell 4 of the ENR Project, and the preliminary results observed in the SAV/Limerock project (see **Chapter 8**), Cell 5 of STA-1W is being managed to encourage emergent vegetation in Cell 5a followed by a SAV community in Cell 5b. It is anticipated that this can be accomplished through changes in operational management, supplemented with herbicide application and SAV stocking. Modifications to the operational plan include:

- Inundating Cell 5 to a depth of 3 feet for approximately 30 days to inhibit the growth of emergent vegetation (completed April 30, 1999);
- Selective herbicide application to control undesirable emergent species (initiated in the fall of 1999);
- Stocking Cell 5b with desirable SAV species (began in April 1999 and continuing throughout the year as needed), and

Holding water depth at 1.5 to 2 feet and initiating minimal flow through Cells 5a and 5b by recirculating water to the old ENR Project to encourage growth and dispersion of the vegetation (planned for the fall of 1999).

STA-1EAST

Operational status

STA-1E is currently being designed by the U.S. Army Corps of Engineers (Corps). There are no operational data to report at this time.

STA-2

Project description

STA-2 is located in south central Palm Beach County along the northwestern boundary of Water Conservation Area 2A (WCA-2A) and on the southeastern boundary of the EAA (Figure 6-1). This STA will provide a total of approximately 2,602 ha (6,430 acres) of wetland treatment area for the removal of P from stormwater runoff and other water sources before this effluent enters the EPA. Approximately 1,942 ha (4,800 acres) of STA-2, covering most of Cell 1 and Cell 2, was formerly the Browns Farm Wildlife Management Area, which had been maintained as Everglades habitat, albeit somewhat degraded, and was never subjected to agricultural activities. Inflows to STA-2 will be diverted from the S-6 pump station and distributed to three adjacent treatment cells:

- Cell 1 provides an effective treatment area of roughly 765 ha (1,890 acres);
- Cell 2 provides an effective treatment area of roughly 919 ha (2,270 acres); and
- Cell 3 provides an effective treatment area of roughly 919 ha (2,270 acres).

The STA-2 construction permit calls for treated outflow from this facility to be discharged into WCA-2A via 40 broad crested weirs to re-establish sheetflow that was disrupted with the construction of the Central and Southern Florida Flood Control Project in the 1950s.

Operational Status

Construction of the levees, canals, and associated interior works for STA-2 is substantially complete. Inundation of all cells is planned for the fall of 1999. EFA and NPDES operating permits for this facility have not been issued to the District as of this Report. There are no operational data from STA-2 to report at this time.

Modification to operations plan

Cell 3 Operations. Upon initial inundation, Cell 3 will be managed to encourage the growth of SAV. It is anticipated that SAV growth can be accomplished through changes in operational management, supplemented with herbicide application and SAV stocking. Modifications to the operational plan include:

- Inundating Cell 3 to a depth of 3 feet to inhibit the growth of emergent vegetation;
- Stocking the area with desirable SAV species; and
- Selective herbicide application to control establishment of undesirable emergent species.

Limerock demonstration sites. The present design scenario for the STAs is based on development of wetland vegetation, primarily cattail, on an organic peat substrate. Evidence suggests that vegetation growing on an inorganic substrate, such as limerock, may provide greater P removal than a peat-based wetland. While this concept is appealing as a potentially critical element for achieving Everglades restoration goals, it has not been demonstrated to be practical on a large scale. To demonstrate the influence of limerock substrate and water depth on vegetation establishment and growth at the field-scale, as well as to examine construction issues related to adding limerock on top of peat soils, the District built two 2-ha limerock pads in the westernmost cell (Cell 3) of STA-2. There is a 30-cm difference in the surface elevation of the two pads to provide different water depths for this demonstration.

STA-3/4

STA-3/4 is currently in design. There are no operational data from STA-3/4 to report at this time.

STA-5

Project description

STA-5 is located in eastern Hendry County, east of the L-3 borrow canal, adjacent to the northwestern corner of the Rotenberger Wildlife Management Area, and on the western boundary of the EAA (**Figure 6-1**). STA-5 provides approximately 1,667 ha (4,120 acres) of wetland treatment area for the removal of P from stormwater runoff and other source waters. Inflow to STA-5 will be diverted from the C-139 basin and distributed to two parallel treatment paths:

- Cells 1a and 1b, comprising the northern flow path, provide an effective treatment area of approximately 287 ha (710 acres) and 546 ha (1,350 acres), respectively; and
- Cells 2a and 2b, comprising the southern flow path, provide an effective treatment area of approximately 287 ha (710 acres) and 546 ha (1,350 acres), respectively.

STA-5 was located and originally authorized to discharge into the Rotenberger Water Management Area (WMA). However, concerns of potential adverse impacts to the remnant Everglades habitat within the Rotenberger WMA led the Corps to restrict discharge from STA-5 until extensive monitoring, evaluation and a multi-agency operating agreement is executed. Once these conditions are met, a portion of the treated discharge from STA-5 will flow into the Rotenberger WMA via pump station G-410 and a 5.6 km spreader canal. The remaining STA-5 outflow will be collected along the eastern boundary of the project and conveyed to the Miami Canal via a discharge canal located along the north boundary of the Rotenberger WMA.

Operational status

STA-5 was completed in December 1998, and start-up operations began in January 1999. EFA and NPDES operating permits for this facility have not been issued to the District as of this Report. There are no operational data from STA-5 to report at this time.

Modification to operations plan

Submerged Aquatic Vegetation. In recognition of the exceptional performance achieved in Treatment Cell 4 of the ENR Project, and the preliminary results observed in the SAV/Limerock project (see **Chapter 8**), the northern flow-path of STA-5 will be managed to encourage emergent vegetation in Cell 1a followed by a SAV community in Cell 1b. It is anticipated that this goal can be accomplished through changes in operational management and without any structural modifications. Modifications to the operating plan include**:**

- Inundating Cell 1b to a depth of 3 feet to inhibit the growth of emergent vegetation (completed July 1, 1999);
- If needed, stocking the area with desirable SAV species; and
- If needed, selective application of herbicide to control the establishment of undesirable emergent species.

STA-6

Project description

STA-6 is located in southeast Hendry County, adjacent to the southwestern corner of the Rotenberger WMA, and on the southwestern boundary of the EAA (Figure 6-1). Section 1 of STA-6 provides approximately 352 ha (870 acres) of wetland treatment area for the removal of P from agricultural runoff before this effluent enters the EPA. STA-6, Section 1 has been operating since October 1997, and has discharged an average P concentration of approximately 20 µg/L. Inflow to STA-6, Section 1 is distributed into two parallel treatment cells:

- Cell 5 comprises the northern flow-path and provides an effective treatment area of approximately 253 ha (625 acres); and
- Cell 3 comprises the southern flow-path and provides an effective treatment area of approximately 99 ha (245 acres).

Treated outflow from this facility is collected along the eastern boundary of the project and conveyed to the L-4 canal via the discharge canal located along the western boundary of the Rotenberger WMA. In late 2001, design will begin on STA-6, Section 2, currently anticipated to be approximately 566 ha (1,400 acres) in size. STA-6, Section 2 will capture and treat excess C-139 basin runoff in two treatment cells. Construction of Section 2 is scheduled to be completed in 2004.

Stabilization period of operation

Specific Condition 7(a) of the EFA operating permit for STA-6, Section 1 (FDEP #262918309) specifies that following a start-up period of operation, discharge from this facility shall be allowed to continue only if, after a stabilization period, the District demonstrates that the following three conditions are met:

- STA-6, Section 1 is achieving the design objectives of the Everglades Forever Act for TP removal;
- For water quality parameters other than TP, outflow water quality is of equal or better quality than at the inflow; and
- Discharges do not pose a serious danger to the public health, safety, or welfare.

On December 9, 1997, DEP concurred with the District that the startup compliance criteria for STA-6, Section 1 had been achieved and authorized the District to begin flow-through operations. The initial flow-through phase of project operation

is referred to as the Stabilization Period. Furthermore, specific conditions 7(a) authorizes continued discharge from the project during the Stabilization Period, provided that the following criteria are met:

- 7(a)(i) - For all water quality parameters other than TP listed in **Table 6-15**, a water quality monitoring program must be conducted to demonstrate that either:

Table 6-15. Water quality parameters monitored in STA 6, Section 1.

	STORET Code	Water Quality Parameters	Unit of Measure
Physical Characteristics	10	Temperature	°C
	300	Dissolved Oxygen	mg/L
	94	Conductance	µmhos/cm
	400	pH	STD units
	82078	Turbidity	NTU
	80	Color	PCU
	530	Total Suspended Solids	mg/L
Nutrients - *Flow-Proportioned*	665	Total Phosphorus	mg/L
Nutrients - *Grabs*	612	Ammonia – unionized	mg/L
	625	Total Kjeldahl Nitrogen	mg/L
	660	Ortho-phosphorus	mg/L
Major Ions	74010	Iron - total	mg/L
	956	Silica	mg/L
	945	Sulfate	mg/L
	410	Alkalinity	mg $CaCO_3$/L
	940	Chloride - dissolved	mg/L
	929	Sodium - dissolved	mg/L
	937	Potassium - dissolved	mg/L
	916	Calcium - dissolved	mg/L
	927	Magnesium - dissolved	mg/L
Metals	1097	Antimony	µg/L
	1105	Aluminum	µg/L
	1012	Beryllium	µg/L
	1027	Cadmium - total	µg/L
	1042	Copper - total	µg/L
	1051	Lead – total	µg/L
	1067	Nickel – total	µg/L
	1147	Selenium	µg/L
	1077	Silver - total	µg/L
	1059	Thallium	µg/L
	1092	Zinc - total	µg/L
	900	Hardness	mg/L
Pesticides	82184	Ametryn	µg/L
	39033	Atrazine	µg/L
	38815	Hexazinone	µg/L
	78064	Norflurazon	µg/L

1. The four-quarter moving average value for each parameter at the outflow meets the State of Florida's Class III water quality standards, or
2. The four-quarter moving average value for each parameter at the outflow is better than or equal to the four-quarter moving average value at the inflow.

- 7(a)(ii) - Water quality monitoring must be conducted to evaluate progress toward achieving the design objectives for TP removal. Satisfactory progress will be demonstrated if either condition (1) or (2) below are met:

1. The rolling 12-month flow-weighted mean TP concentration at the outflow is less than or equal to 50 µg/L; or
2. The rolling 12-month flow-weighted mean TP concentration at the outflow is less than the concentration at the inflow and a trend toward achieving an average outflow concentration of 50 µg/L is indicated.

The District initiated a water quality monitoring program in STA-6, Section 1 in December 1997 for the purpose of demonstrating compliance with the above mentioned conditions of the operating permit. **Tables 6-15** and **6-16** summarize all water quality parameters, sampling frequencies and analytical methodologies that are part of this program.

Table 6-16. Sample locations, sampling frequency, and sample type for flow and water quality parameters monitored in STA 6, Section 1.

Sample Location	Parameters	Sampling Frequency	Sample Type
Inflow Pump Station (G600)	Flow	DAV	PR
	Physical Characteristics	Bi-W	G
	Nutrients - Flow-proportioned	W	FPC
	Nutrient - Grabs	Bi-W	G
	Major Ions	QTR	G
	Metals	QTR	G
	Pesticides	QTR	G
Outflow site (G607)	Flow	DAV	UVM
	Physical Characteristics	Bi-W	G
	Nutrients - Flow-proportioned	W	FPC
	Nutrient - Grabs	Bi-W	G
	Major Ions	QTR	G
	Metals	QTR	G
	Pesticides	QTR	G

Bi-W = biweekly (26 sample/yr)
DAV = daily average of continuous sampling
QTR = quarterly (4 samples/yr)
W = weekly (52 sample/yr)
FPC = flow-proportioned composite sample
G = grab sample
PR = based on pump records
UVM = ultrasonic velocity meter

Compliance with Stabilization Period Criteria

Water quality parameters other than total phosphorus. The four-quarter averages for all non-phosphorus parameters with Class III criteria were in compliance with state standards with the exception of beryllium, which has a limit of $\leq$ 0.13 µg/L (**Table 6-17**). The results for beryllium, although above the method detection limit (MDL)

Table 6-17. Summary of quarterly results for all water quality parameters other than total phosphorus and pesticides monitored in STA 6, Section 1.

Parameter	Sampling Event	Class III Standards		Outflow Exceeds Criterion?	Sampling Results	
		Inflow G600	Outflow G606		Inflow G600	Outflow G606
Temperature (°C)	2nd Quarter 1998	N/A		N/A	27.6	25.3
	3rd Quarter 1998				28.4	30.1
	4th Quarter 1998				24.5	25.2
	1st Quarter 1999				21.1	20.4
	4th Quarter Mean				25.4	25.2
Dissolved Oxygen (mg/L)	2nd Quarter 1998	Greater than or equal to 5.0 mg/L		YES	3.4	7.2
	3rd Quarter 1998				2.6	3.9
	4th Quarter 1998				3.2	5.1
	1st Quarter 1999				4.6	7.0
	4th Quarter Mean				3.5	5.8
Conductance (µmhos/cm)	2nd Quarter 1998	Not greater than 50% of background or greater than 1,275 µmhos/cm		NO	566	599
	3rd Quarter 1998				673	597
	4th Quarter 1998				713	616
	1st Quarter 1999				711	694
	4th Quarter Mean				666	626
pH	2nd Quarter 1998	Not less than 6.0 and not greater than 8.5		NO	7.4	7.7
	3rd Quarter 1998				7.1	7.3
	4th Quarter 1998				7.2	7.4
	1st Quarter 1999				7.5	7.5
	4th Quarter Mean				7.3	7.5
Turbidity (NTU)	2nd Quarter 1998	Less than or equal to 29 NTU above background conditions		NO	5.3	ND
	3rd Quarter 1998				4.1	1.8
	4th Quarter 1998				2.6	1.7
	1st Quarter 1999				1.8	1.5
	4th Quarter Mean				3.4	1.7
Color (PCU)	2nd Quarter 1998	N/A		N/A	64.7	ND
	3rd Quarter 1998				78.6	105.7
	4th Quarter 1998				80.5	84.2
	1st Quarter 1999				67.3	63.4
	4th Quarter Mean				72.8	84.4
Total Suspended Solids (mg/L)	2nd Quarter 1998	N/A		N/A	6	ND
	3rd Quarter 1998				5	<3
	4th Quarter 1998				5	<3
	1st Quarter 1999				3	<3
	4th Quarter Mean				5	<3
Ammonia - unionized (mg/L)	2nd Quarter 1998	Less than or equal to 0.02 mg/L		NO	0.003	ND
	3rd Quarter 1998				0.001	0.001
	4th Quarter 1998				0.002	0.002
	1st Quarter 1999				0.003	0.001
	4th Quarter Mean				0.002	0.001
Total Kjeldahl Nitrogen (mg/L)	2nd Quarter 1998	N/A		N/A	1.7	ND
	3rd Quarter 1998				1.8	1.8
	4th Quarter 1998				1.6	1.4
	1st Quarter 1999				1.4	1.4
	4th Quarter Mean				1.6	1.5
Ortho-phosphorus (mg/L)	2nd Quarter 1998	N/A		N/A	0.017	ND
	3rd Quarter 1998				0.015	0.007
	4th Quarter 1998				0.010	0.005
	1st Quarter 1999				0.008	<0.004
	4th Quarter Mean				0.013	0.005
Iron - total (µg/L)	2nd Quarter 1998	Less than or equal to 1,000 µg/L		NO	421	ND
	3rd Quarter 1998				388	615
	4th Quarter 1998				205	588

Table 6-17. Summary of quarterly results for all water quality parameters other than total phosphorus and pesticides monitored in STA 6, Section 1. (Continued)

Parameter	Sampling Event	Class III Standards		Outflow Exceeds Criterion?	Sampling Results	
		Inflow G600	Outflow G606		Inflow G600	Outflow G606
	1st Quarter 1999				262	221
	4th Quarter Mean				319	475
Silica (mg/L)	2nd Quarter 1998	N/A		N/A	8.8	ND
	3rd Quarter 1998				9.1	12.3
	4th Quarter 1998				10.5	9.3
	1st Quarter 1999				8.2	4.7
	4th Quarter Mean				9.1	8.8
Sulfate (mg/L)	2nd Quarter 1998	N/A		N/A	15.8	ND
	3rd Quarter 1998				15.6	22.3
	4th Quarter 1998				20.7	10.5
	1st Quarter 1999				23.3	20.3
	4th Quarter Mean				18.8	17.7
Alkalinity (mg $CaCO_3$/L)	2nd Quarter 1998	Not less than 20 mg/L		NO	250.4	ND
	3rd Quarter 1998				205.1	205.1
	4th Quarter 1998				269.5	219.9
	1st Quarter 1999				276.7	246.2
	4th Quarter Mean				250.4	223.7
Chloride - dissolved (mg/L)	2nd Quarter 1998	N/A		N/A	56.8	ND
	3rd Quarter 1998				49.9	54.2
	4th Quarter 1998				69.2	47.9
	1st Quarter 1999				67.9	73.3
	4th Quarter Mean				61.0	58.5
Sodium - dissolved (mg/L)	2nd Quarter 1998	N/A		N/A	44.5	ND
	3rd Quarter 1998				35.5	36.6
	4th Quarter 1998				52.4	36.3
	1st Quarter 1999				51.2	54.0
	4th Quarter Mean				45.9	42.3
Potassium - dissolved (mg/L)	2nd Quarter 1998	N/A		N/A	3.8	ND
	3rd Quarter 1998				4.1	5.0
	4th Quarter 1998				3.1	3.1
	1st Quarter 1999				3.2	3.2
	4th Quarter Mean				3.6	3.8
Calcium - dissolved (mg/L)	2nd Quarter 1998	N/A		N/A	100.0	ND
	3rd Quarter 1998				80.9	82.1
	4th Quarter 1998				98.8	80.6
	1st Quarter 1999				109.0	92.8
	4th Quarter Mean				97.2	85.2
Magnesium - dissolved (mg/L)	2nd Quarter 1998	N/A		N/A	7.4	ND
	3rd Quarter 1998				6.7	7.3
	4th Quarter 1998				7.3	6.4
	1st Quarter 1999				8.0	7.7
	4th Quarter Mean				7.4	7.1
Antimony (µg/L)	2nd Quarter 1998	Less than 4,300 µg/L		NO	<2.2	ND
	3rd Quarter 1998				4.4	5.2
	4th Quarter 1998				<2.2	<2.2
	1st Quarter 1999				<2.2	<2.2
	4th Quarter Mean				2.7	3.2
Aluminum (µg/L)	2nd Quarter 1998	N/A		N/A	28.4	ND
	3rd Quarter 1998				32.9	45.4
	4th Quarter 1998				33.9	56.1
	1st Quarter 1999				12.5	4.0
	4th Quarter Mean				26.9	35.2
Beryllium (µg/L)	2nd Quarter 1998	Less than or equal to 0.13 µg/L as an annual average		Unknown values between MDL and PQL	<0.1	ND
	3rd Quarter 1998				0.2	0.3
	4th Quarter 1998				0.2	<0.1

Table 6-17. Summary of quarterly results for all water quality parameters other than total phosphorus and pesticides monitored in STA 6, Section 1. (Continued)

Parameter	Sampling Event	Class III Standards		Outflow Exceeds Criterion?	Sampling Results	
		Inflow G600	Outflow G606		Inflow G600	Outflow G606
	1st Quarter 1999				<0.1	<0.1
	4th Quarter Mean				0.1	0.2
Cadmium - total (µg/L)	2nd Quarter 1998	2.5	ND	NO	0.3	ND
	3rd Quarter 1998	2.2	2.2		<0.3	<0.3
	4th Quarter 1998	2.5	2.2		<0.3	<0.3
	1st Quarter 1999	2.7	2.4		<0.3	<0.3
	4th Quarter Mean	**2.7**	**2.4**		0.3	<0.3
Copper - total (µg/L)	2nd Quarter 1998	28.5	ND	NO	3.0	ND
	3rd Quarter 1998	24.1	24.5		<1.2	<1.2
	4th Quarter 1998	28.2	23.9		<1.2	<1.2
	1st Quarter 1999	30.7	27.0		<1.2	<1.2
	4th Quarter Mean	**27.9**	**25.2**		1.7	<1.2
Lead - total (µg/L)	2nd Quarter 1998	11.8	ND	NO	<0.8	ND
	3rd Quarter 1998	9.2	9.4		<0.8	<0.8
	4th Quarter 1998	11.6	9.1		<0.8	<0.8
	1st Quarter 1999	13.2	10.9		<0.8	<0.8
	4th Quarter Mean	**11.4**	**9.8**		<0.8	<0.8
Nickel - total (µg/L)	2nd Quarter 1998	377	ND	NO	<0.5	ND
	3rd Quarter 1998	319	325		1.5	1.4
	4th Quarter 1998	373	317		<0.5	<0.5
	1st Quarter 1999	405	357		1.6	1.1
	4th Quarter Mean	**369**	**333**		1.0	1.0
Selenium (µg/L)	2nd Quarter 1998	Less than or equal to 5.0 µg/L		NO	1.0	ND
	3rd Quarter 1998				<1	<1
	4th Quarter 1998				<1	<1
	1st Quarter 1999				<1	<1
	4th Quarter Mean				1.0	<1
Silver - total (µg/L)	2nd Quarter 1998	Less than or equal to 0.07 µg/L		Unknown MDL>STD	<0.5	ND
	3rd Quarter 1998				<0.5	<0.5
	4th Quarter 1998				<0.5	<0.5
	1st Quarter 1999				<0.5	<0.5
	4th Quarter Mean				<0.5	<0.5
Thallium (µg/L)	2nd Quarter 1998	Less than or equal to 6.3 µg/L		NO	<0.5	ND
	3rd Quarter 1998				ND	ND
	4th Quarter 1998				<0.5	<0.5
	1st Quarter 1999				0.6	<0.5
	4th Quarter Mean				0.5	<0.5
Zinc - total (µg/L)	2nd Quarter 1998	254	ND	NO	<4	ND
	3rd Quarter 1998	215	219		<4	<4
	4th Quarter 1998	251	213		<4	<4
	1st Quarter 1999	273	240		<4	<4
	4th Quarter Mean	**248**	**224**		<4	<4
Hardness (mg/L)	2nd Quarter 1998	N/A		N/A	280	ND
	3rd Quarter 1998				230	235
	4th Quarter 1998				277	228
	1st Quarter 1999				305	263
	4th Quarter Mean				273	242

= Value exceeded Class III Criteria

N/A = Not applicable

ND = No Data

of the District's laboratory, were below the practical quantitative limit for environmental samples. This may be an analytical artifact or simply represent variation within the experimental error of the analytical method.

For non-phosphorus parameters without Class III standards, all four-quarter averages at the outflow were less than at the inflow except for color, dissolved potassium, and aluminum (**Table 6-17**). The difference between inflow and outflow values for dissolved potassium was not statistically significant.

Total phosphorus. Specific condition 7(b) of the STA-6, Section 1 operating permit states that the project will be considered stabilized and operations will move to the post-stabilization phase when the rolling 12-month flow-weighted average TP concentration at the outflow is less than or equal to 50 µg/L for 12 consecutive periods. Since this Report presents only the first six rolling 12-month mean TP values (**Figure 6-63**), an evaluation of compliance with this criterion cannot be made at this time. By the time the next Report is submitted, sufficient data will have been collected to make this evaluation. The first six rolling 12-month TP values that have been calculated to date are well below the 50 µg/L limit.

Although not a permit requirement, it is significant to note that the individual monthly TP concentrations at the outflow consistently have been below inflow concentrations and less than the target value of 50 µg/L since discharge operations began in December 1997 (**Figure 6-63**). The lack of rain from mid-April through mid-July 1998 and in March and April of 1999 prevented discharges from STA-6, Section 1 during these periods. Accordingly, we were unable to calculate monthly flow-weighted means for these months.

Pesticides. **Table 6-18** lists the four herbicides that were analyzed in surface waters from STA-6, Section 1. The four-quarter average at the outflow for all compounds was lower than the corresponding inflow concentrations. Although not a permit requirement, it is significant to note that in all but two quarters, herbicide concentrations at the outflow were less than at the inflow. The exceptions were ametryn and atrazine in the first quarter of 1999. The atrazine concentration of 7.9 µg/L detected at the inflow site during the second quarter of 1998 exceeded the 3 µg/L threshold for inhibition of algal cell growth (Verschueren, 1983) and the Florida Ground Water Guidance Concentration of 3 µg/L established by FDEP. However, none of the quarterly concentrations for atrazine at the outflow approached this threshold concentration. Hexazinone was not detected above the minimum quantitation limit during any quarter. The herbicides detected during this study are typical of areas with nearby intensive agricultural activity but are not used for vegetation management at STA-6, Section 1.

Water Quality Data. Specific Conditions 14(b) and 14(f) of the DEP permit require the submittal of all sample collection data. This information is being provided to the DEP as part of this Report and is available to other interested parties upon request.

Specific Condition 14(c) of the permit requires a statement describing the methods used in collection, handling, storage and analysis of the samples. All samples are collected, handled and stored in accordance with Sections 6.0 and 7.0 of the 1998 FDEP-approved District Comprehensive Quality Assurance Plan (CompQAP) number 870166G.

Specific Condition 14(d) of the permit requires a statement by the individual responsible for implementation of the sampling program concerning the authenticity, precision, accuracy of the data, and minimum detection limits. The individual responsible for implementation of the program is Maxine Cheesman, Director, Water Quality Monitoring Division, Department of Water Quality & Hydrology, SFWMD. A statement prepared and signed by Maxine Cheesman is included as **Appendix 6-2**.

Specific Condition 14(e) of the permit requires documentation that the laboratory performing the

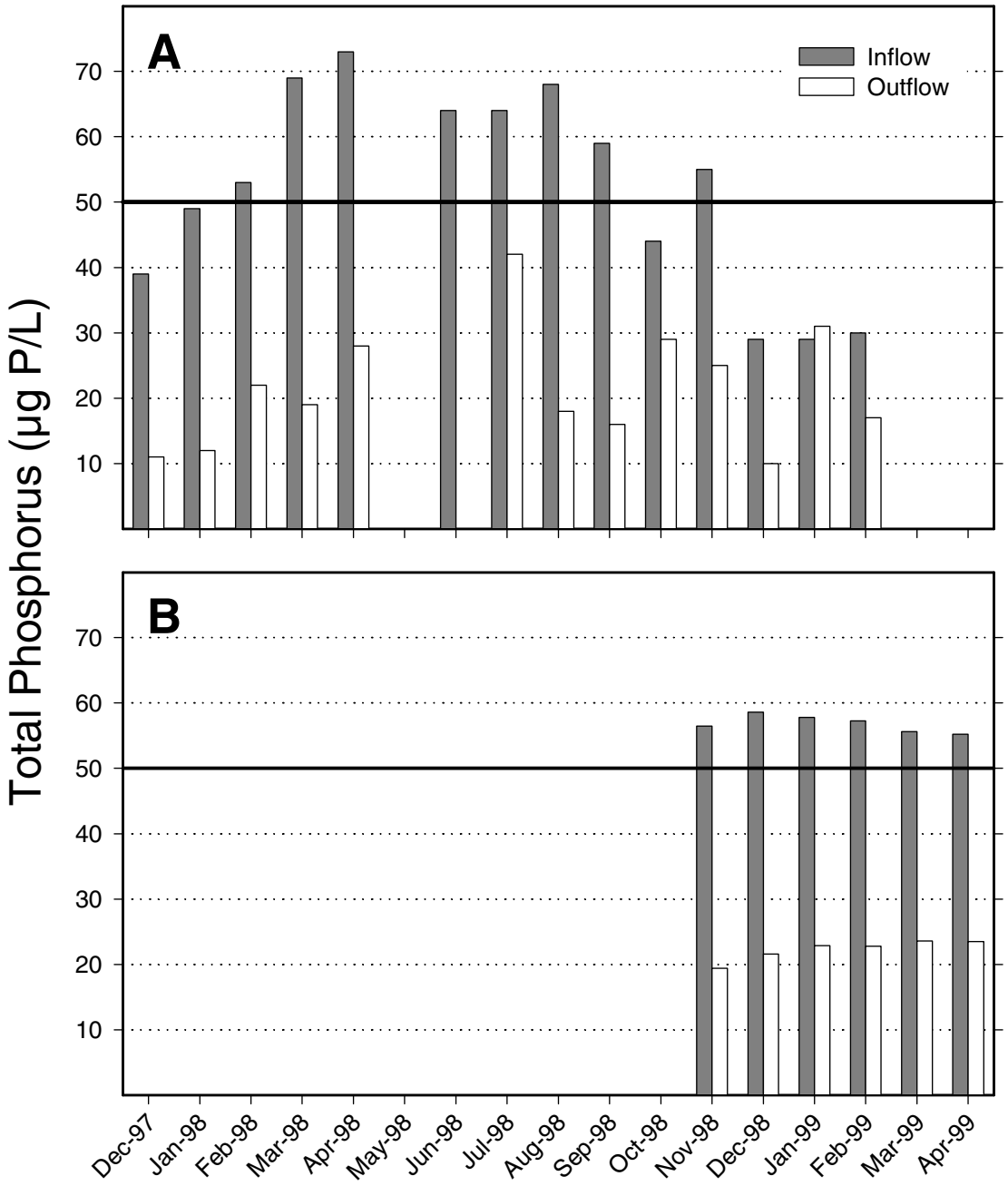

Figure 6-63. Total phosphorus concentrations (µg/L) at the inflow and outflow of STA 6, Section 1. Panel A: individual monthly flow-weighted mean concentrations. Panel B: rolling 12-month flow-weighted mean concentrations. See text for discussion of missing data points. Heavy solid line indicates the target total phosphorus target concentration of 50 µg/L.

Table 6-18. Summary of results from quarterly pesticide monitoring program conducted in STA 6, Section 1.

		Pesticide Concentration	
Parameter	**Sampling Event**	**Inflow – G600**	**Outflow –G606**
ametryn	2nd Quarter 1998	0.053	<0.010
	3rd Quarter 1998[a]	ND[b]	ND
	4th Quarter 1998	0.034[c]	0.012[c]
	1st Quarter 1999	0.017[c]	0.018[c]
	4th Quarter Mean	**0.035**	**0.013**
atrazine	2nd Quarter 1998	7.90	0.27
	3rd Quarter 1998[a]	ND	ND
	4th Quarter 1998	0.48	0.04[c]
	1st Quarter 1999	0.24	0.31
	4th Quarter Mean	**2.87**	**0.21**
hexazinone	2nd Quarter 1998	<0.019	<0.019
	3rd Quarter 1998[a]	ND	ND
	4th Quarter 1998	<0.019	<0.019
	1st Quarter 1999	<0.019	<0.019
	4th Quarter Mean	**<0.019**	**<0.019**
norflurazon	2nd Quarter 1998	0.031[c]	<0.029
	3rd Quarter 1998[a]	ND	ND
	4th Quarter 1998	0.035[c]	<0.029
	1st Quarter 1999	0.033[c]	<0.029
	4th Quarter Mean	**0.033**	**<0.029**

a. Data are unavailable for the 3rd quarter 1998 sampling event. Samples were inadvertently sent to an outside laboratory without full pesticide analysis capability and were analyzed for different parameters.
b. ND = no data available
c. Value reported is less than the minimum quantitation limit, and greater than or equal to the minimum detection limit.

sampling and analysis has an approved CompQAP on file with the DEP. The District performs the sampling and analysis and has an approved CompQAP number 870166G on file with the DEP.

Summary. The data presented demonstrate compliance of STA-6, Section 1 with the Stabilization Period criteria established in the operating permit. Outflow water quality was consistently better than at the inflow (**Table 6-17**). Similarly, both the frequency of detection and the concentration of pesticides at the outflow station were far below levels warranting concern (**Table 6-18**). The District will continue its water quality monitoring program and is working closely with FDEP to implement long-term operating strategies to bring STA-6, Section 1 into full compliance with all water quality standards. STA-6, Section 1 discharges are providing significant benefits to the Everglades ecosystem and do not pose any serious danger to public health, safety, or welfare. Since compliance with specific conditions 7(a)(i) and

7(a)(ii) has been achieved, information required in specific condition 7(a)(iii) is not required at this time.

Modification to operations plan

At this time, no operational modifications are recommended for STA-6, Section 1.

FINDINGS ON THE EFFECTIVENESS OF THE STAS

Based on the data presented in the chapter, we would conclude the following relative to the effectiveness of the STAs:

- The ENR Project achieved its mandated performance objectives for TP removal based on analysis of 57 months of operational data;
- Since the start of operations in August 1994 through April 1999, the ENR Project has removed 70.3 metric tons of phosphorus that would have otherwise have entered WCA-1;
- The performance of the ENR Project to date supports validity of the basic assumptions and design parameters used in planning and constructing the STA; and
- STA-6, Section 1 is achieving its mandated TP removal performance goals

Important aspects of STA effectiveness that current investigations can address in only a limited fashion involve meeting threshold TP levels, long-term performance and the useful operational life of these systems.

The District's Advanced Treatment Technology Research Program is examining other treatment methodologies that may be used in concert with the STAs to enhance overall nutrient removal performance (see **Chapter 8**). One or more of these technologies may be employed should the STAs alone be unable to achieve outflow TP concentrations necessary to protect the Everglades. The threshold TP concentration for the Everglades has not been established as of this Report.

References in this Report to ENR Project performance as "long-term" are based on usage in the FDEP operating permit, i.e., a 12-month basis. In reality, our 57 months of experience with this project is only a fraction of the time that the STAs must operate effectively to protect the Everglades. The long-term TP removal mechanism in the STAs will be burial of plant biomass in the sediment. In theory, this process is self-sustaining indefinitely, provided that the STAs do not dry out and allow the sediment to oxidize. One question is whether the equilibrium between nutrient removal and flux from the sediment will change causing an increase in the water column TP concentrations. Data from other regional peat-based wetlands with inflow nutrient concentrations similar to those anticipated for the STAs suggest that nutrient removal performance can be sustained over time. Boney Marsh on the Kissimmee River operated without any marked decrease in performance throughout its entire 9-year operational life (Moustafa et al. 1996). Discharge of nutrient-rich water into WCA-2A began in 1962 and this wetland is still removing nutrients almost four decades later.

As noted above, protecting the Everglades will require that the STAs operate for many decades. With proper maintenance, the levees, pump stations and other structures should have a service life of at least 50 years. Hydraulic capacity in these systems will be gradually lost over time due to sediment accretion. The District will have to consider dredging to remove sediment and/or changes in operation of these systems to compensate for the gradual rise in the bottom elevation.

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