Chapter 6: Effectiveness and Optimization of Stormwater Treatment Areas for Phosphorus Removal

Michael J. Chimney and M. Zaki Moustafa

Summary

The biotic integrity of the Everglades is endangered due to urban and agricultural development, a disruption of the system's hydroperiod and the introduction of nutrient-rich agricultural runoff. Everglades periphyton and plant communities are known to be sensitive to phosphorus (P) availability. Reducing the amount of total P (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 Interim 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 is almost completely vegetated with either emergent, floating or submersed 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.

Water loading to the ENR Project through the Inflow Pump Station varied by a factor of two among operational years (95,767 to 197,897 ac-ft). The combined volume of water from the Inflow and Seepage Return Pumps accounted for 84 to 90% of the total inflow water budget each operational year; rainfall and surficial seepage from WCA-1 accounted for the remainder of inflow to the system. The average hydraulic retention time in the ENR Project ranged from 17 to 24.9 days over the four years of operation.

The ENR Project is achieving its performance objectives based on an evaluation of 48 months of operational data (August 1994 through July 1998). All 12-month, rolling, flow-weighted TP concentrations at the project outflow were well below the mandated 50 µg P/L (cumulative outflow TP concentration = 22 µg P/L), and all 12-month rolling, TP load reduction estimates (inflow versus outflow) were greater than the 75% goal (cumulative total P load reduction = 82%). Since the start of operations, the ENR Project has removed 62.9 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 18.5 m/yr. Based on these results, from early in the lifespan of the Project the STA design settling rate of 10.2 m/yr appears to have been a reasonable, possibly conservative estimate.

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 P/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 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 and modeling efforts.

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

The upper 5 cm layer of sediment in Treatment Cell 1 has become P enriched; mean P concentrations increased from 251.6 mg P/kg in pre-construction samples to 650.0 mg P/kg by 1996; 81.7% of the 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.

Research will be 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 have been completed and preliminary water quality sampling was initiated in late FY98. Experimentation will begin shortly after the test cells have been characterized.

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.

STA-6 Section 1 is the first component of the District's Everglades Construction Project that has been completed; operation began in December 1997. All but one weekly TP measurement at the outflow from this STA during the first seven months of operation have been below the 50 µg P/L interim goal established for the project.

Background and Issues

Everglades Impacts and Stormwater Treatment Areas

The biotic integrity of the Everglades is endangered due to urban and agricultural development, a disruption of the system's hydroperiod and the introduction of nutrient-rich agricultural runoff. Everglades periphyton and plant communities are known to be sensitive to phosphorus (P) availability. Reducing the amount of total P (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) (**Figure 6-1**). The Everglades Forever Act (Act) requires the South Florida Water Management District (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 Interim Report will provide the information necessary to fulfill this mandate. Regional environmental issues and Act requirements are treated more fully in **Chapter 1** of this report.

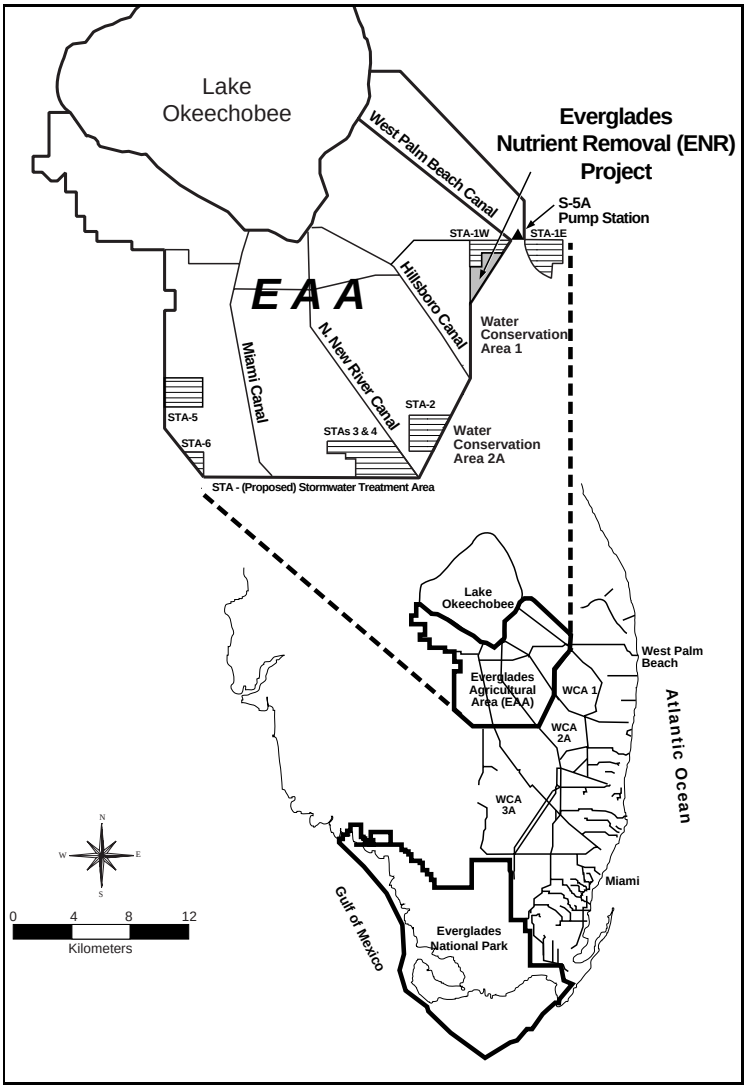

Figure 6-1. Location of the Everglades Nutrient Removal Project in relation to the Everglades Agricultural Area in south Florida.

Everglades Nutrient Removal Project – A Prototype STA

The Everglades Nutrient Removal (ENR) Project is a 1,545 ha (3,819 acres) treatment wetland built by the District on land previously farmed for sugar cane, corn and rice. The ENR Project serves as a prototype STA, and will be incorporated into STA-1W (**Figure 6-1**) which is currently under construction. The history of events leading up to the decision to construct this facility are summarized in SFWMD (1989, 1991). The project site is located 25 km (15.5 miles) west of the city of West Palm Beach in Palm Beach County and borders the northwest corner of WCA-1(26^{o} 38' N and 80^{o} 25' W). The soils at this location consist of a 0.8 to 1.8-m layer of poorly drained, highly organic peat (predominately Okeechobee muck)

with a near-surface water table that overlies a hard carbonate rock shelf (caprock). Beneath the caprock is a deep deposit of silty, clay-like sands with interbedded layers of limestone (Jammal & Associates, Inc., 1989). Surface ground elevations within the ENR Project site range from 7.1 to 10.9 m NGVD (National Geodetic Vertical Datum). The initial basis of design for the project was derived from the observation that cattail in nutrient enriched areas of WCA-2A had a phosphorus retention capacity of 1.67 g $P/m^2/yr$ (SFWMD, 1989, 1991). Based on the assumption that the ENR Project would have a footprint of 1,497 ha (3,700 acres) and that future annual water and P loadings to the Project would be similar to historic discharges from the EAA, it was projected that this treatment wetland would remove 25 metric tons (mt) P/ yr from runoff entering WCA-1. Subsequent design criteria, assumptions and performance goals developed from ENR Project conceptual designs are summarized in **Table 6-1**. Note that early designs considered the impact on the Project of having the EAA both with and without Best Management Practices (BMPs) in place. The ENR Project was built in two phases: Phase I was completed in July 1989 with flooding of the first 384 ha (950 acres) for the Project; Phase II, which included constructing the containment levees, pump stations and other major structural elements associated with the project, began in June 1991 and was completed by September 1993. Due to delays associated with obtaining regulatory discharge permits, flow-through operations did not begin until August 1994. An "operational year" for the ENR Project is defined as beginning on August 1 and running through July 31 of the following calendar year. The period of record for ENR Project operations covered in this Report extends from August 1994 through July 1998, which encompasses the first four operational years. Additional information about the design of the ENR Project is provided in Burns & McDonnell (1989, 1992c), CH2M Hill (1991), SFWMD (1991), Goforth et al. (1994) and Guardo et al. (1995).

The ENR Project is a once-through treatment system and has the capacity to process approximately 39 to 60% of the annual runoff that would otherwise be pumped directly into WCA-1 via the S-5A pump station (range of processing estimates based on ENR Project design inflow pumping rates (**Table 6-1**) and the mean annual discharge at S-5A for water years 1979 to 1988 [314,750 ac-ft; Burns & McDonnell, 1992b]; see Light and Dineen [1994] for a discussion of the water conveyance system and hydrology of the region). It was anticipated during design that the Project would be operated in a pulsed flooding mode with a range of water depths between 30 and 91 cm and a minimum hydraulic retention time (HRT) of 10 to 13 days (Burns & McDonnell, 1989; CH2M Hill, 1991; SFWMD, 1991). The primary source of inflow water to the ENR Project is the S-5A basin (595.7 km^2), 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 electric pumps with a combined capacity of 17 m^3/sec (600 cfs), into the Buffer Cell (54 ha) and then distributed via gravity flow to two parallel treatment trains that are separated by an interior, transverse 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). The direction of flow is from Treatment Cell 1 to 3 and from Treatment Cell 2 to 4. The Western Flow-way (560 ha) is 40% 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). Sixty-seven percent of the water pumped into the Buffer Cell was designed to enter the Eastern Flow-way via 10, 72-inch culverts in the G252 levee, while the remaining 33% 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

Table 6-1. Design criteria, assumptions and performance goals for the Everglades Nutrient Removal Project with and without the use of Best Management Practices in the Everglades Agricultural Area.

Wetland Treatment Area[a]	1,497 ha	(= 3,700 acres)
Expected Total Phosphorus Removal[a]	1.67 g P/m^2/yr	
Inflow Total Phosphorus Concentration[a]		
No BMPs =	190 µg P/L	(= 190 ppb)
BMPs =	134 µg P/L	(= 134 ppb)
Inflow Pumping Rate (25 mt P/yr removal target)[a]		
Design maximum =	16.99 m^3/sec	(= 600 cfs; = 434,678 ac-ft/yr)
No BMPs (@ 190 µg P/L & 85% efficiency) =	4.81 m^3/sec	(= 170 cfs; = 123,159 ac-ft/yr)
BMPs (@ 260 µg P/L & 78% efficiency) =	7.36 m^3/sec	(= 260 cfs; = 188,360 ac-ft/yr)
Hydraulic Loading Rate[a]		
No BMPs (@ 170 cfs & 3,700 acres) =	2.8 cm/day	(= 1.1 in/day)
BMPs (@ 260 cfs & 3,700 acres) =	4.2 cm/day	(= 1.7 in/day)
Total Phosphorus Removal Rate (50 µg P/L outflow target)[a]		
No BMPs (@ 190 V 50 µg P/L; 170 cfs) =	1.42 g P/m^2/yr	(= 21.3 mt P/yr; = 46,901 lbs P/yr)
BMPs = (@ 134 V 50 µg P/L; 260 cfs) =	1.30 g P/m^2/yr	(= 19.5 mt P/yr; = 43,039 lbs P/yr)
Total Phosphorus Removal Efficiency (50 µg P/L outflow target)[a]		
No BMPs (@ 190 V 50 µg P/L; 170 cfs) =	74%	
BMPs (@ 134 V 50 µg P/L; 260 cfs) =	63%	
Water Depth		
Normal operating range[b] =	39.6 to 91.4 cm	(= 1.3 to 3.0 ft)
Normal operating range[a] =	30.5 to 91.4 cm	(= 1.0 to 3.0 ft)
Design maximum[a,b]=	137.2 cm	(= 4.5 ft)
Hydraulic Retention Time	≥13 days[b]	
	10 - 20 days[a]	

a. CH^2M Hill (1991) summarized from various design documents and memoranda
b. SFWMD (1991)

from the Inflow Pump Station to G255. Treatment Cells 1 and 2 were intended to remove the bulk of the nutrient load entering the ENR Project (the Buffer Cell also acts in this capacity), while Treatment Cells 3 and 4 would accomplish the final polishing of the water to lower nutrient concentrations. Water is discharged from the ENR Project at the Outflow Pump Station (G251), which has six electric pumps with a combined capacity of 12.7 m^3/sec (450 cfs), by pumping it over the L-7 levee into WCA 1. A perimeter canal collects groundwater seepage from along the western and northern boundaries of the ENR Project and returns it to a separate set of Seepage Return Pumps located at the Inflow Pump Station (three electric pumps with a combined capacity of 5.7 m^3/sec [200 cfs]) where it is pumped back to the headwaters of the project.

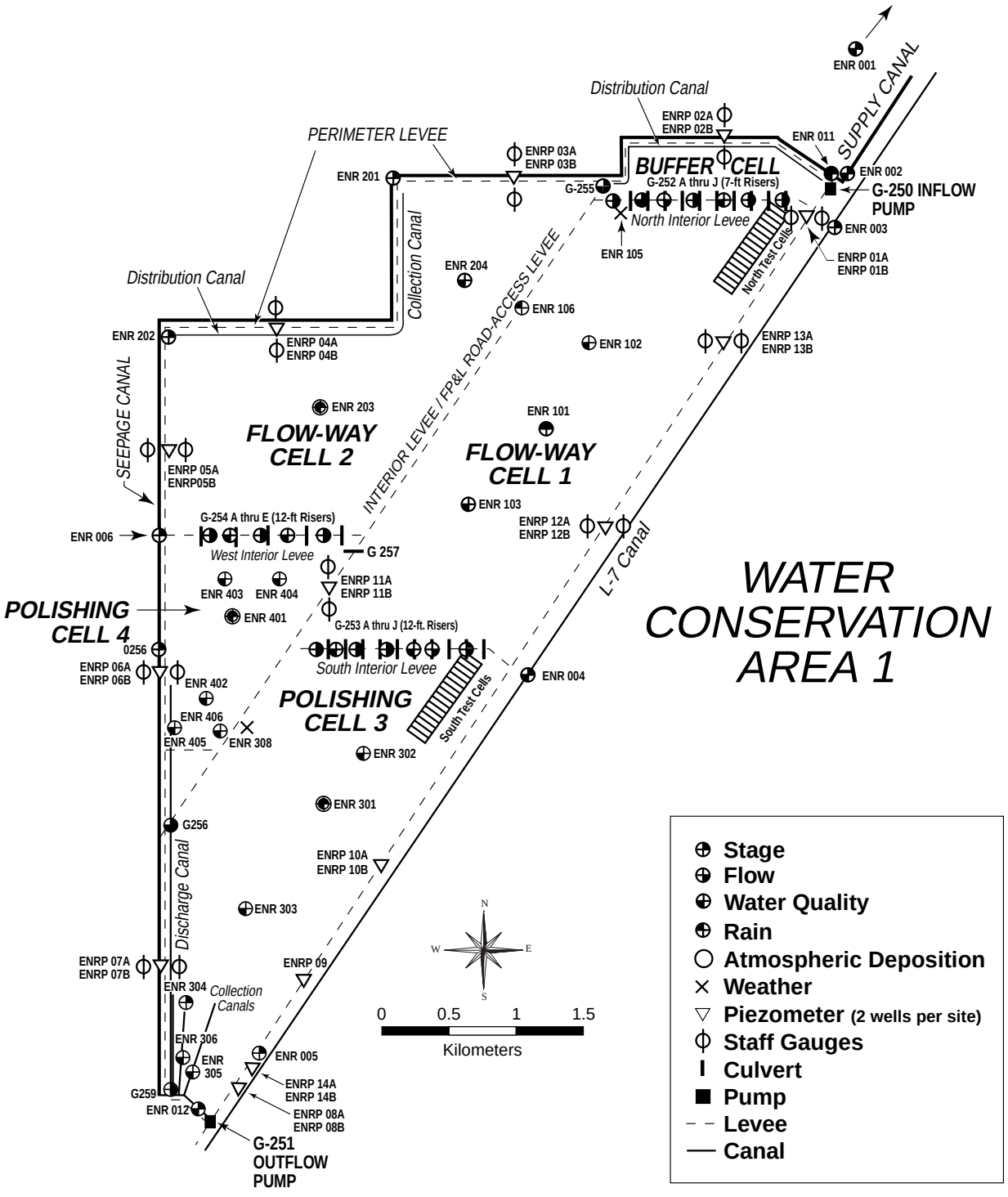

Figure 6-2. Site plan for the Everglades Nutrient Removal Project showing the location of stage, flow and water quality monitoring sites.

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* and *T. latifolia*). The plant community in Treatment Cell 3 is a mixture of naturally recruited cattail and areas (131 ha) that were planted with species common to south Florida, i.e., arrowhead (*Sagittaria latifolia* and *S. lancifolia*), Spikerush (*Eleocharis interstincta*), Maidencane (*Panicum hemitomon*), Pickerelweed (*Pontederia cordata*) and Sawgrass (*Cladium jamaicense*), and is referred to as a "mixed-marsh" plant community. Treatment Cell 4 has been actively maintained as a periphyton/submersed macrophyte community dominated by Coontail (*Ceratophylum demersum*) and Southern Naiad (*Najas quadalupensis*) through the 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 also support dense stands of submersed macrophytes (principally *C. demersum* and *N. quadalupensis*). Water Hyacinth (*Eichhornia crassipes*) and Water Lettuce (*Pistia stratiotes*) first appeared in northern areas of the project during construction (S. Newman, SFWMD, pers. obs.) and are becoming an increasingly important component of the plant community throughout the project (SFWMD, 1995a, 1996, 1997a, 1998a).

As noted above, the original performance goal for the ENR Project (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. Design calculations accounted for the presence/absence of BMPs in the EAA on the inflow pumping and hydraulic loading rates (HLR) needed to achieve this target (see **Table 6-1**). Subsequent performance expectations for the Project focused more on achieving an effluent concentration of 50 µg P/L (= 50 parts per billion [ppb] P) rather than removing a specified TP mass. Assuming the same inflow TP concentrations and hydraulic loading rates, slightly lower TP removal rates than the original estimate were required to meet the outflow concentration target (1.30 – 1.42 g P/m^2/yr; **Table 6-1**). The current, primary performance objective for the ENR Project is to reduce the amount of total phosphorus (TP) discharged from the Outflow Pump station into WCA-1 by up to 75% relative to the inflow load and is mandated by specific condition 5 of the Florida Department of Environmental Protection (DEP) operating permit #502232569. The secondary performance objective, also mandated by the operating permit, is to discharge water with an annual, flow-weighted TP concentration no greater than 50 µg P/L.

Stormwater Treatment Area Optimization Research and Monitoring Program

The STA Optimization Research and Monitoring Program will assist in developing an operational strategy that maximizes performance of the STAs independent of other technologies (i.e., the District's Supplemental Technology Research Program is examining other treatment technologies that may be used in concert with the STAs to enhance overall nutrient removal performance; see **Chapter 8** of this Report). Information is being compiled from four distinct research efforts: (1) practical experience gained from operating the ENR Project and analysis of 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 nutrient fate and transport model for wetlands, the Wetland Water Quality Model, currently under development by the District. An annotated list of the research and monitoring activities being conducted in the ENR Project in support of this research program is provided in **Table 6-2** and sampling locations associated with these efforts are identified in **Figure 6-2**. The objective of this section of the Interim Report is to summarize key findings from research and monitoring efforts relative to P removal performance and/or compliance with water Class III quality standards. Discussion of ENR Project data is focused on considering the entire wetland as the best

predictor of future STA performance. Subsequent reports will include analyses of individual treatment cell performance and parameters other than P.

Everglades Nutrient Removal Project

Vegetation Coverage

Data Collection and Analysis

A vegetation monitoring program, required under the DEP operating permit for the ENR Project, has been implemented to document both the spatial and temporal changes that occur in the plant community within the treatment cells. Aerial photographs of the entire site are 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; starting in 1995, the overflight schedule was changed to semi-annual. The photographs acquired from each overflight (approximately 40 overlapping, separate images) are digitized to generate electronic images. These images are then rectified to known geographic markers to produce a composite image suitable for use as a GIS background image. Vegetation is classified into distinct "coverage types" through an interpretation of the photographs and verified by ground-truth surveys conducted after each overflight. A map has been generated for each overflight on which the different vegetation coverage types (**Table 6-3**) are 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 represents the dominant species within that grid element. Changes in the areal extent of each vegetation coverage type have been documented over time.

Status of Research and Monitoring

Eleven photographic overflights of the ENR Project have been conducted as of this writing (October 1993; February, May and October 1994; May and November 1995; April and November 1996; May and October 1997; April 1998). Annual reports on the status of the vegetation are provided in SFWMD (1995a, 1996, 1997a, 1998a). As of April 1998, 53.6%, 65.0% and 87.8% of the surface area of Treatment Cells 1, 2 and 3, respectively, was vegetated with either emergent or floating aquatic macrophytes; the Buffer Cell was 95.8% vegetated (**Table 6-3**). Much of the remaining area in Treatment Cells 1, 2, and 3 has been colonized by submersed aquatic vegetation. Cattail is the dominant emergent macrophyte species throughout the ENR Project (**Figures 6-3** and **6-4**). Sawgrass, Pickerelweed, Spikerush, Arrowhead and coverage types composed of a mixture of species also are important components of the vegetation community in Treatment Cell 3, while Treatment Cell 4 has been maintained as a periphyton/submersed macrophyte habitat.

Cattail reached 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 throughout 1996 in Treatment Cell 1 and throughout 1996 and 1997 and into 1998 in Treatment Cell 2. This loss was attributed to strong windstorms, which uprooted large mats of cattail in slightly deeper areas of these cells. Treatment Cell 1 next experienced a small increase in cattail coverage between November 1996 and May 1997, which coincided with a period when lower water depths were maintained in this cell than in previous years. Conversely, cattail loss accelerated