Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas

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SUMMARY

As part of Everglades restoration, the construction and operation of large freshwater treatment wetlands, known as the Everglades Stormwater Treatment Areas (STAs), are mandated by the Everglades Forever Act (EFA) (Section 373.4592, Florida Statutes). The total area of the STAs including infrastructure components is around 65,000 acres, with approximately 45,000 acres of effective treatment area currently operational. An additional 12,000 acres of treatment area have been completed in Compartments B and C. These areas have been created south of Lake Okeechobee to reduce excess total phosphorus (TP) from surface waters prior to discharging that water into the Everglades Protection Area (EPA) (**Figure 5-1**). Stormwater Treatment Areas 1 East, 1 West, 2, 3/4, 5, and 6 (STA-1E, STA-1W, STA-2, STA-3/4, STA-5*, and STA-6*, respectively) are managed by the South Florida Water Management District (District or SFWMD). This chapter and related appendices (Appendices 5-1 through 5-7 of this volume) summarize the short- and long-term STA performance analyses, evaluation of conditions relevant to STA performance, facility status, operational challenges, and enhancements during Water Year 2012 (WY2012) (May 1, 2011–April 30, 2012). A detailed analysis of the annual STA performance in terms of permit compliance is reported in Volume III, Appendix 3-1. A summary of individual components identified in the Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area (Long-Term Plan) (Burns and

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* Note: In this report, STA-5 and STA-6 are also referred to as STA-5/6, with the completion of construction of Compartment C in mid-2012. The Compartment C build-out will not be operational until permits for this expanded area are issued by the Florida Department of Environmental Protection.

McDonnell, 2003) is also covered in this chapter. More information on the STAs is also available at www.sfwmd.gov/sta. Highlights of WY2012 STA performance and optimization are presented below.

- WY2012 outflow concentrations in STA-1W, STA-2, and STA-5 improved compared to values observed in WY2011. In WY2012, the STAs received 712,331 acre-feet (ac-ft) of water and retained 80.7 metric tons of TP. This equates to an 83 percent TP load reduction and a decrease in flow-weighted mean (FWM) TP concentration from 111 to 19 parts per billion (ppb). STA-1E, STA-1W, STA-2, and STA-3/4 achieved outflow concentrations below 25 ppb; the lowest outflow concentration of 12 ppb was achieved in STA-2. As a result of the dryout and consequent loss in submerged aquatic vegetation (SAV), STA-3/4 outflow FWM TP concentration in WY2012 was 19 ppb, slightly higher than the previous year's outflow FWM concentration of 17 ppb. Partial diversion of water from STA-3/4 in July 2011 and restricted operation of the flow-ways between July and August 2011 were necessary to allow for STA-3/4 vegetation to re-establish. STA-5 achieved its lowest outflow FWM TP concentration of 32 ppb over its period of operation. STA-6 was the only STA that did not meet its interim effluent limit; the annual outflow concentration was influenced by an extreme TP spike that occurred once flow resumed in July and August 2011 after approximately eight months of dry conditions.

- The outstanding overall performance can be attributed to the lower hydraulic and TP loading during WY2011 and WY2012 compared to previous water years, effective operational management, and continued enhancements in various areas of the STAs. Further details on STA conditions, operational status, management activities, and enhancements are discussed within this chapter.

- STA-1E operation continued to be impacted by structural and elevation issues, vegetation impacts, and restriction of the Eastern Flow-way (former Periphyton Stormwater Treatment Area). Repairs of major structures, led by the U.S. Army Corps of Engineers (USACE), also continued in STA-1E, including S-367B, S-375, S-370C, S-373B, and S-374A. Flow to the Western Flow-way has also been restricted. The District implemented multiple vegetation enhancements and trials to maintain treatment until long-term repairs are completed by the USACE. These enhancements and trials are discussed in the *STA-1E* section of this chapter.

- Vegetation enhancements continued in other STAs, including vegetation conversion in STA-3/4 and STA-2, extensive bulrush (*Schoenoplectus californicus*) planting in areas that are too deep for cattail (*Typha* spp.) to thrive and in areas where short-circuiting is visible. In STA-3/4, the water level in Cell 1A was drawn down to encourage cattail reestablishment; vegetation in this area has been impacted by chronic deep water conditions. Details of the evaluation of the drawdown are included in the *Applied Science* section of this chapter.

- Many of the STA cells were adversely affected by the regional drought in WY2012. Approximately 46,158 ac-ft of water from Lake Okeechobee was delivered during the water year to hydrate priority cells in the STAs. However, due to high evapotranspiration rates, seepage loss, and delayed start of the wet season, some of the cells dried out in the early and later part of the water year. The worst impacts were observed in STA-3/4 and STA-6, where the entire STA dried out and consequently resulted in short-term TP spikes at the outflow. The SAV in STA-3/4 continues to recover and vegetation monitoring is planned to continue in WY2013. The dry condition resulted in new cattail recruitment and expansion, particularly in the open areas of STA-3/4 Cells 1A and 2A. Further information on the drought-related impacts is included in individual STA sections of this chapter.

- Construction of STA Compartments B and C continued in WY2012 and was completed in September 2012. Vegetation start-up for these areas, which were flow-capable in December 2010, continued in WY2012. While the District has not been issued permits to operate Compartments B and C, assessment of environmental conditions (soil, vegetation, and water quality) have been initiated.
- Avian protection surveys, specifically for black-necked stilt (*Himantopus mexicanus*) nesting, were conducted during calendar years 2011 and 2012 (CY2011 and CY2012) nesting seasons, as required under the Avian Protection Plan. Utilizing the survey results, operational priorities were adjusted, specifically affecting STA-1E, in early WY2012. CY2011 and CY2012 surveys are summarized in Appendix 5-4; impacts to STA operations are included under each STA section in this chapter.

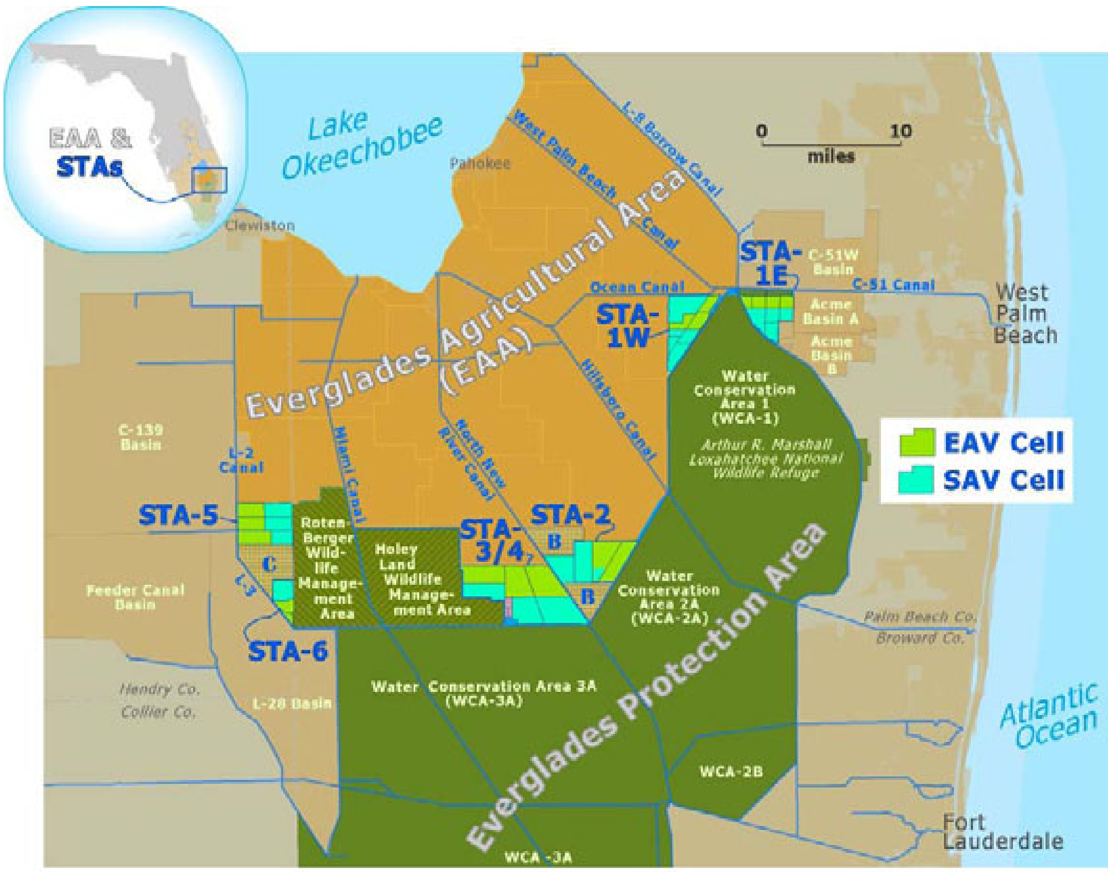


Figure 5-1. Location of the Everglades Stormwater Treatment Areas (STAs) 1 East (1E), 1 West (1W), 2, 3/4, 5, and 6 in relation to the Everglades Protection Area (EPA), their dominant vegetation community [emergent vegetation (EAV) or submerged aquatic vegetation (SAV)], and major basins south of Lake Okeechobee.

INTRODUCTION

As a major component of Everglades restoration, the Everglades Construction Project Stormwater Treatment Areas (STAs) were built and operated to remove excess total phosphorus (TP) from surface waters prior to those waters entering the Everglades Protection Area (EPA). STAs are constructed wetlands that retain nutrients through several mechanisms including plant nutrient uptake, settling and sorption, sedimentation, and microbial activities. This chapter describes the performance and condition of the Everglades STAs (STA-1E, STA-1W, STA-2, STA-3/4, STA-5, and STA-6, respectively) and the highlights and operational challenges as they relate to the treatment performance and capabilities of the STAs and individual flow-ways (**Figure 5-1**; Appendix 5-1). The South Florida Water Management District (District or SFWMD) manages these STAs, while the United States Army Corps of Engineers (USACE) continues to be responsible for structural maintenance and repairs in STA-1E.

Varying in size, configuration, and period of operation, the STAs are shallow freshwater marshes divided into treatment cells by interior levees (Appendix 5-1). Water flows through these systems via water control structures, such as pump stations, gates, or culverts. The dominant plant communities in the treatment cells are broadly classified as (1) emergent aquatic vegetation (EAV), (2) submerged aquatic vegetation (SAV), and (3) floating aquatic vegetation (FAV). Some cells have a mixture of these vegetation types, particularly cells that are undergoing vegetation conversion from emergent to SAV. Periphyton communities are interspersed among this vegetation where conditions are favorable.

Treatment performance, which varies temporally and among STAs, depends on several factors including (1) antecedent land use, (2) nutrient and hydraulic loading, (3) vegetation condition, (4) soil type, (5) cell topography, (6) cell size and shape, (7) hydrologic pattern (continuously flooded versus periodic dryout), (8) maintenance and enhancement activities, and (9) regional operations. District staff uses an adaptive approach in managing the STAs using weekly data and information, including examination of stage levels, outflow TP concentrations, hydraulic and TP loading, vegetation condition, and any wildlife restriction issues.

This chapter includes an assessment of each STA and individual flow-way performance, information on STA operational status, maintenance activities and enhancements, applied scientific studies relevant to the STAs, recreational facilities and activities, and implementation of the Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area (Long-Term Plan).

OVERVIEW OF WATER YEAR 2012 STA PERFORMANCE

Overall, the STAs performed well in Water Year 2012 (WY2012)(May 1, 2011–April 30, 2012) in terms of outflow TP concentrations and TP load removal (**Table 5-1** and **Figure 5-2**). During the water year, the STAs received a total of 712,331 acre-feet (ac-ft) of inflow and retained 80.7 metric tons (mt) of TP. This equates to an average of 83 percent TP load reduction and a decrease in flow-weighted mean (FWM) TP concentration from 111 to 19 parts per billion (ppb). STA-1E, STA-1W, STA-2, and STA-3/4 achieved outflow concentrations below 25 ppb. The lowest outflow concentration was from STA-2 (12 ppb). Despite almost a month-long dryout of all cells that resulted in vegetation loss, STA-3/4 maintained good long-term performance with an outflow TP FWM concentration of 19 ppb. The performance of STA-5 continued to improve, achieving the lowest concentration for its period of record (POR, 32 ppb). Due to an extended period of dryout and a resulting TP spike after resumption of flow, STA-6 outflow concentrations were the highest in its operational history (75 ppb). Details about the condition and operational issues related to observed performance are included under each individual STA section in this chapter.

While the WY2012 annual inflow TP concentration remained comparable to average levels observed over the POR for each STA, the mean outflow concentration for all STAs was among the lowest since 1995 (**Figure 5-3**). This can be attributed to factors such as a reduction in inflow TP load compared to WY2002–WY2010, improved STA management, including strategic flow distribution and supplemental water deliveries to keep priority cells hydrated even during drought periods, and various vegetation and physical enhancements over time. The performance summarized above was achieved despite the fact that several of the flow-ways were offline or under restricted operation during the water year (**Table 5-2**). Details about the offline status or restricted operation are included under the individual STA sections within this chapter.

An analysis of the POR data indicates that at very low outflow concentrations ($\leq$20 ppb), there is no definitive relationship between outflow TP concentration and key operational factors, i.e., inflow concentration, phosphorus loading rate (PLR), or hydraulic residence time (HRT) (**Figure 5-4**). Data shows that there were cells that received inflow concentrations of 50–150 ppb that still produced outflow TP concentrations of 20 ppb or less. Correspondingly, there were cells that received loading rates higher than 1 gram per square meter per year ($g/m^2/yr$) that resulted in outflow concentrations of 20 ppb or less. This is consistent with previous findings reported in the *2012 South Florida Environmental Report* (SFER) – *Volume I, Chapter 5,* and suggests that other factors may influence an individual treatment cell's ability to produce low outflow TP concentrations (Ivanoff et al., 2012). Additional data analysis and research studies (e.g., the STA-3/4 Periphyton STA Project) will provide a better understanding of these factors and processes.

Table 5-1. STA performance for Water Year 2012 (WY2012) (May 1, 2011–April 30, 2012) and the period of record (POR) 1994–2012 [a].

Parameter	STA-1E	STA-1W	STA-2	STA-3/4	STA-5	STA-6	All STAs
Effective Treatment Area (acres)	5,132	6,670	8,240	16,543	6,095	2,257	44,937
Adjusted Effective Treatment Area (acres)[a]	5,099	6,670	6,338	16,543	6,095	836	41,581
Inflow							
Total Inflow Volume (ac-ft)	85,533	96,847	195,651	269,737	47,508	17,055	712,331
Total Inflow TP Load (mt)	11.520	17.117	21.044	36.327	9.160	2.624	97.792
Flow-weighted Mean Inflow TP (ppb)	109	143	87	109	156	125	111
Hydraulic Loading Rate (HLR) (cm/d)	1.40	1.21	2.58	1.36	0.65	1.70	1.43
TP Loading Rate (PLR) ($g/m^2/yr$)	0.56	0.63	0.82	0.54	0.37	0.78	0.58
Outflow							
Total Outflow Volume (ac-ft)	76,208	94,011	217,570	291,838	41,779	9,061	730,468
Total Outflow TP Load (mt)	2.010	2.598	3.278	6.670	1.659	0.833	17.048
Flow-weighted Mean Outflow TP (ppb)	21	22	12	19	32	75	19
Hydraulic Residence Time (d)	15	41	19	31	46	3	
TP Retained (mt)	9.509	14.519	17.766	29.657	7.501	1.791	80.744
TP Removal Rate (g/m2/yr)	0.46	0.54	0.69	0.44	0.30	0.53	0.48
Load Reduction (%)	83%	85%	84%	82%	82%	68%	83%
Period of Record Performance							
Start date	Sep-04	Oct-93	Jun-99	Oct-03	Oct-99	Oct-97	***1994-2012***
Inflow Volume (ac-ft)	648,071	3,256,934	2,764,250	3,719,561	1,226,542	687,681	12,303,039
TP Inflow to Date (ppb)	173	171	103	114	225	100	140
Standard Deviation TP Inflow (ppb)	*57*	*54*	*39*	*31*	*56*	*39*	*26*
TP Inflow Load to Date (mt)	139	689	350	522	341	85	2,125
TP Retained to Date (mt)	95	480	269	440	212	66	1,561
TP Outflow to Date (ppb)	57	51	22	18	93	34	37
Standard Deviation TP Outflow (ppb)	*121*	*32*	*9*	*4*	*46*	*23*	*13*

[a] Excludes G-388 outflow data
[b] Adjusted effective treatment areas excludes specific area where and time period when cells are temporarily offline for plant rehabilitation, infrastructure repairs, or Long-Term Plan enhancements (refer to **Table 5-2**)
[c] Data presented reflects current water year data added to that information presented in the 2012 SFER – Volume I – Chapter 5

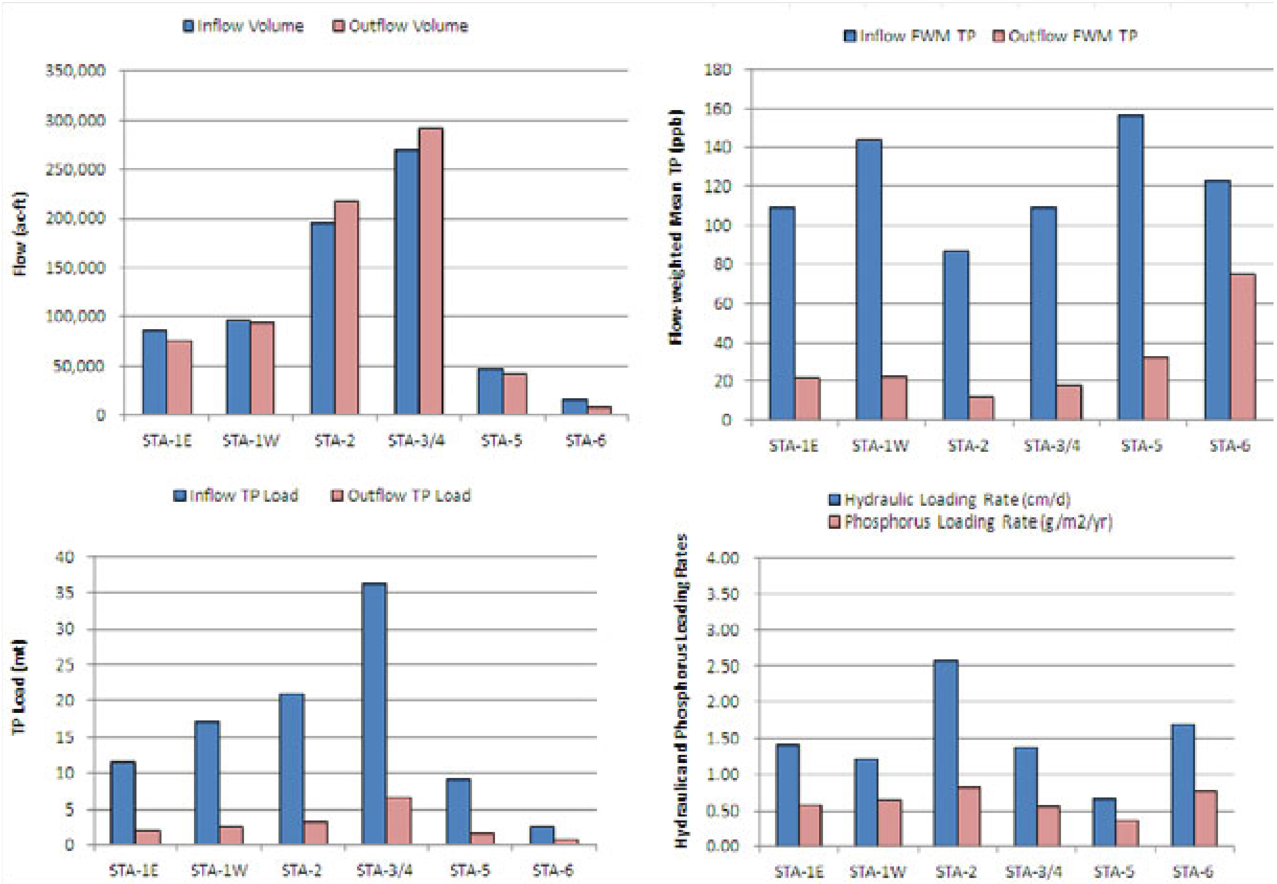


Figure 5-2. WY2012 hydraulic and phosphorus loading rates and total phosphorus (TP) concentrations in the STAs.

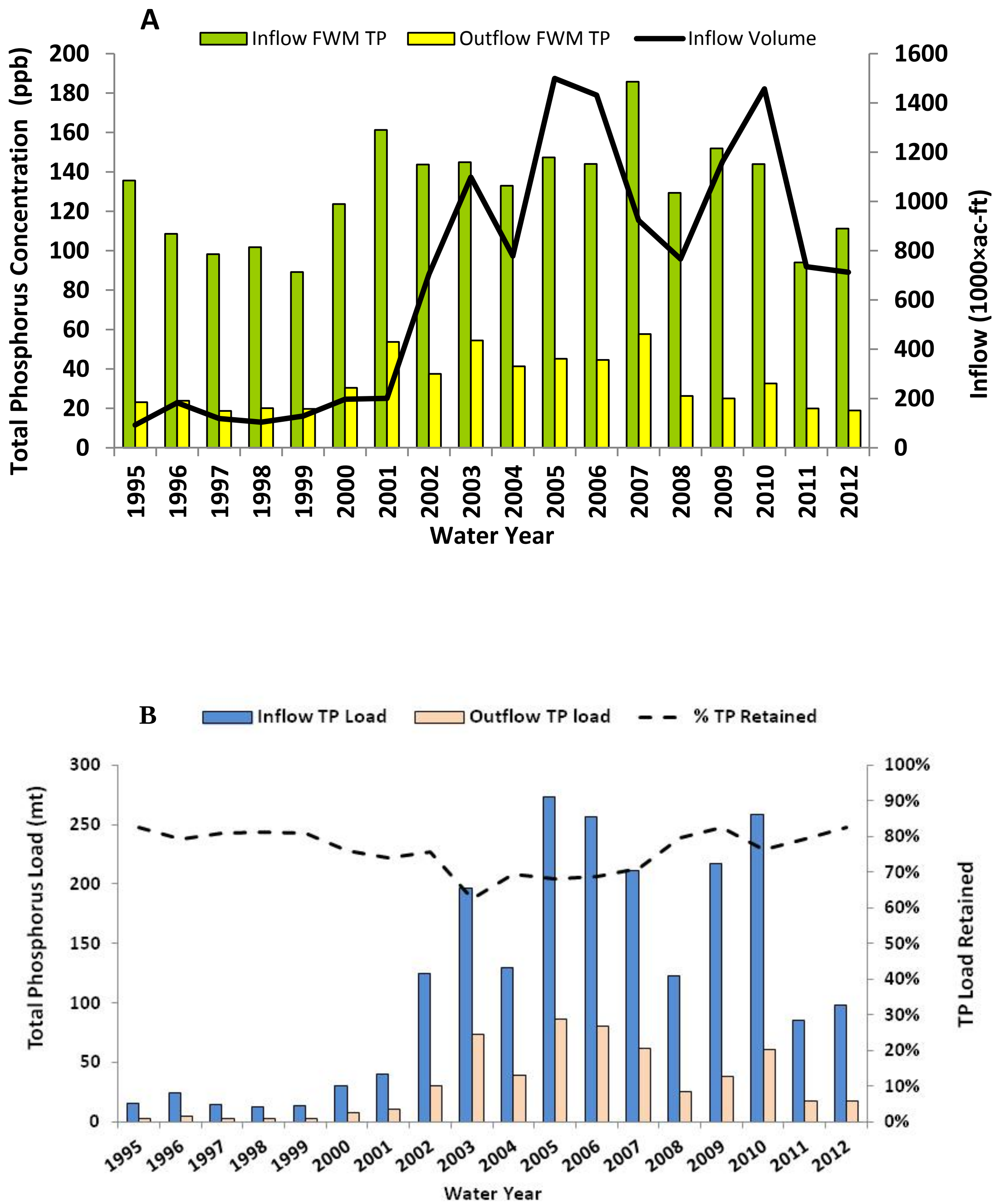


Figure 5-3. Annual inflow and outflow TP flow-weighted mean (FWM) concentrations and inflow volumes (A), and overall annual inflow and outflow TP loads and percent TP load retained by all the STAs (B) by water year since 1995.

FLOW-WAY OPERATIONAL STATUS

The performance summarized earlier in this chapter was achieved despite the fact that several flow-ways were offline or under restricted operation during the water year (**Table 5-2**). Flow through operation may be suspended (offline) or restricted (online with restrictions) for a cell or a flow-way based on environmental or vegetation condition that may affect its P uptake performance, for construction purposes, or for rehabilitation purposes. In WY2012, STA-2 Cell 4 and STA-6 Cell 2 were both offline for Compartments B and C construction, respectively. Details about the offline status or restricted operation are also included under the individual STA sections within this chapter.

ADJUSTMENT OF THE EFFECTIVE TREATMENT AREA VALUES

Effective treatment area values are used to calculate the performance data shown in **Table 5-1**, specifically for the following parameters that are reported in this chapter:

- Hydraulic Loading Rate (HLR)
- Phosphorus Loading Rate (PLR)
- TP Removal Rate

The treatment area is adjusted using to the following equation based on the operational time period of each cell or flow-way (**Table 5-2**):

$$WY2012\ Adjusted\ Effective\ Treatment\ Area = \ Total\ Area\ X \frac{\sum_{1}^{366} daily\ online\ percentage}{366}$$

Effective treatment areas were adjusted for STA-1E (Western Flow-way was offline from November 29, 2011, to December 19, 2011), STA-2 (Cell 4 was offline during the entire water year), and STA-6 (Cell 5 was offline from April 1, 2012, to April 30, 2012, and Cell 6-2 was offline during the entire water year.

VEGETATION MANAGEMENT

Routine vegetation management, which includes chemical control of FAV and woody species, was conducted throughout WY2012. Controlling FAV, such as water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichornia crassipes*), is necessary, particularly in SAV cells, because they form dense beds and negatively impact SAV cover and health through shading and competition. Woody species, such as *Ludwigia* sp. are also controlled because they tend to expand and negatively impact cattail (*Typha* spp.) communities. Also, the woody species do not provide the same litter-based treatment as cattail or sawgrass (*Cladium jamaicense*). Aside from routine management, preparation of new areas in Compartment B and C was also initiated. Details of this activity are included in the *STA-5/6* section of this chapter.

For EAV cells, the most common species that are desired are cattail (*Typha latifolia* and *Typha domingensis*), giant bulrush (*Schoenoplectus californicus*), and sawgrass. Other desirable native species that thrive in certain areas of the STAs are arrowhead (*Sagittaria latifolia*), duck potato (*Sagittaria lancifolia*), and spike rush (*Eleocharis* sp.), For SAV cells, the most common desired species are coontail (*Ceratophyllum demersum*), musk grass (*Chara* sp.), pond weed (*Potamogeton* sp.), and southern naiad (*Najas guadalupensis*). Another common species in the STAs is hydrilla (*Hydrilla* sp.); however, despite this species ability to take up phosphorus (P), it is not a desired species due to its instability. Hydrilla, which thrives primarily in areas with higher water column TP concentrations, is the most dominant SAV species in STA-1E and STA-5.

Another key vegetation management activity in WY2012 was the continued planting of giant bulrush, particularly in deep water areas where cattail do not thrive, and along emergent vegetation strips in SAV cells. Emergent vegetation strips are established in SAV areas to protect the SAV community against strong winds and flows. Details of bulrush planting are also included in the individual STA section in this chapter.

Table 5-2. Flow-way status and effective treatment area adjustment for WY2012.

STA	Flow-way	Total Area (acres)	Offline (OFF) or Online with Restriction (ONR) Schedule	Comments	% Time Online	Adjusted Treatment Area (acres)
STA-1E	STA	5,132			99	5,099
	Eastern	1,108		Online with restrictions due to structural constraints (USACE PSTA Project in Cell 2)	100	
	Central	1,986			100	
	Western	2,038	OFF: 11/29–12/19/ 2011 ONR: remainder of WY2012	OFF: Vegetation enhancements ONR: structural, vegetation, and performance issues	98	
STA-1W	STA	6,670			100	6,670
	Eastern	2,516			100	
	Western	1,299			100	
	Northern	2,855			100	
STA-2	STA	8,240			77	6,338
	Cell 1	1,798			100	
	Cell 2	2,270			100	
	Cell 3	2,270			100	
	Cell 4	1,902	OFF: Entire WY2012	Compartment B construction	0	
STA-3/4	STA	16,543			100	16,543
	Eastern	6,527	ONR: May 1–August 23, 2011	Vegetation enhancement (Cell 1A); vegetation recovery post dryout	100	
	Central	5,436	ONR: July 5–August 23, 2011	Vegetation recovery post dryout	100	
	Western	4,580	ONR: July 5–August 23, 2011	Vegetation recovery post dryout	100	
STA-5	STA	6,095			100	6,095
	Flow-way 1	2,055			100	
	Flow-way 2	2,055			100	
	Flow-way 3	1,985	ONR: entire WY2012	Topographic issues (Cell 3A) and Compartment C construction	100	
STA-6*	STA	2,257			37	836
	Cell 3	245			100	
	Cell 5	625	OFF: 4/1-4/30/2012	Redundant levee removal	95	
	Section 2	1,387	OFF: Entire WY2012	Compartment Construction	0	

* Under the new configuration, STA-6 Section 2 is now known as Cell 6-2, Cell 5 is Flow-way 7, and Cell 3 is Flow-way 8.

DROUGHT IMPACTS

One of the challenges of managing the STAs is periodic dryout. During the dry season, particularly during periods of drought, portions of or entire STA cells dryout. This is particularly problematic for areas that have higher elevation than surrounding areas (seepage issues) and areas that are not designed for efficient delivery of supplemental water. Dryout is known to impact STA performance and vegetation, as well as to encourage bird nesting that could limit operation of flow-ways. Dry conditions result in rapid organic matter oxidation and subsequent rewetting results in P spikes due to release of mineralized P into the water column (Bostic and White, 2007; DeBusk and Reddy, 2003; Martin et al., 1996). The impacts of dryout on outflow water TP are influenced by various factors such as the extent and duration of dryout, soil characteristics, type of vegetation, and the lag time between reflooding and cell discharge following the dryout period. Previous observations indicate that brief dryout periods in peat-based STA cells do not result in significant TP spikes, likely due to the ability of the peat material to retain water within the soil column. In areas where the substrate is more mineral, such as those found in STA-5 and STA-6, the upper soil column have been observed to dry out quickly upon depletion of standing water. The amount of P spikes resulting from varying durations of dryout for these two STAs is discussed within the *STA-5/6* section of this chapter. Concentrations exceeding 2 and 0.4 parts per million (ppm) have been observed in previous water years in STA-5 and STA-6, respectively. The impacts of annual cycles of dryout and reflooding in STA-6 have also been discussed in detail in the 2010 SFER – Volume I, Chapter 5 (Pietro et al., 2010).

While dryout conditions in SAV cells can be detrimental to the plant community, dryout in the EAV cells for short periods does not appear to negatively impact and may benefit the plant communities. Dryout was effective in encouraging dense new growth of cattails in STA-3/4 Cell 1A (see details in the *Applied Scientific Studies* section of this chapter). Extended periods of dryout, however, have visibly impacted the emergent plant communities in terms of die-off of standing vegetation and establishment of terrestrial plants. When cells are rewetted, EAV generally recovers quicker than SAV. In the STA operation plans, the minimum target stages for EAV and SAV cells during drought conditions are 6 inches below and 6 inches above the average ground elevation, respectively.

The District has been implementing a drought contingency plan since 2008 to minimize dryout during drought periods (SFWMD, 2008). The drought contingency plan includes raising stages higher before the end of the wet season to hold on to as much water as possible in the SAV cells, use of temporary pumps to deliver water from nearby sources if available, and the delivery of supplemental water (when available) from Lake Okeechobee. The plan also prioritizes hydration of SAV cells to minimize impacts to the SAV. The drought contingency plan is reviewed annually and lessons learned from previous years are incorporated into the plan for use during future droughts. Flow Equalization Basins (FEBs), to be built as part of the overall Everglades Restoration Strategies, will add to the potential supplemental water source for the STAs during dry seasons. The combination of FEBs and STA expansion will provide greater ability to hold water longer at the onset of the wet season without discharging from flow-ways that have dried out until treatment mechanism has stabilized in these areas. The impacts of WY2012 drought on each STA is discussed in the individual STA section within this chapter.

CONTINUING INVESTIGATION OF FACTORS AFFECTING STA PERFORMANCE

The STA phosphorus treatment process is affected by many biological, physical, and chemical factors and processes, including soil adsorption, precipitation, biota uptake, and peat accretion (Kadlec and Wallace, 2009; Richardson and Craft 1993; Reddy et al., 2005; Reddy and DeLaune, 2008). Extreme weather events, facility operation, and management activities also influence treatment performance (Ivanoff et al., 2012). Scientists and engineers continue to closely study the systems to gain a better understanding of the treatment mechanisms and enhance management strategies to keep the treatment performance optimized and sustainable. While there have been a numerous studies and publications discussing individual factors, a full understanding of the interactions of the different factors and mechanisms is still lacking and still a subject of current discussions. In the 2012 SFER – Volume I, Chapter 5, the relationship between inflow TP concentration and outflow TP concentration, and between PLR and outflow TP concentration was investigated at the STA and cell levels (Ivanoff et al., 2012). The 2012 report confirmed previous findings by other scientists that indicate a strong and direct correlation between inflow TP concentration and outflow TP concentration, and that PLR is also a strong influencing factor at loading rates greater than1 $g/m^2/yr$. At PLRs of less than 1 $g/m^2/year$, the variability in the results and lack of trend indicate that other factors may be influencing outflow TP concentrations in the STAs.

The analysis of the POR data continued in WY2012. One analysis was focused on determining the influence of inflow concentrations, PLR, and HRT on cells that achieve outflow TP concentrations of less than 20 ppb (**Figure 5-4**). The analysis also distinguished between dominant vegetation types, i.e. EAV and SAV, as well as the Periphyton-based Stormwater Treatment (PSTA). The type of dominant vegetation did not seem to influence the outcome of the analysis, which indicates no correlation between either the inflow TP concentration, PLR, or HRT and outflow TP concentration, confirming the findings reported in 2012 SFER – Volume I, Chapter 5 (Ivanoff et al., 2012). Certain cells received inflow concentrations up to 150 ppb and still produced outflow TP concentrations of 20 ppb or less. Correspondingly, there were cells with PLR slightly over 2.0 $g/m^2/yr$ that resulted in outflow concentrations of 20 ppb or less.

A multivariate data analysis effort was under way in WY2012 but was not completed in time for this report. Preliminary findings indicate that due to a large variability in the data gathered and a large number of factors influencing the outcome, generalizations across STAs or even among cells within an STA is challenging. Further studies that could isolate key variables and also provide a better understanding of the biogeochemical mechanism and processes may be needed to better understand the controlling factors that lead to very low outflow concentrations and P stability within the STAs. Some of these studies involved the STA-3/4 PSTA Project and are described in the *Applied Scientific Studies Section* of this chapter. Discussions of more elaborate scientific studies to fill information gaps and determine ways to further improve STA condition and performance are under way as part of a formal science plan development process.

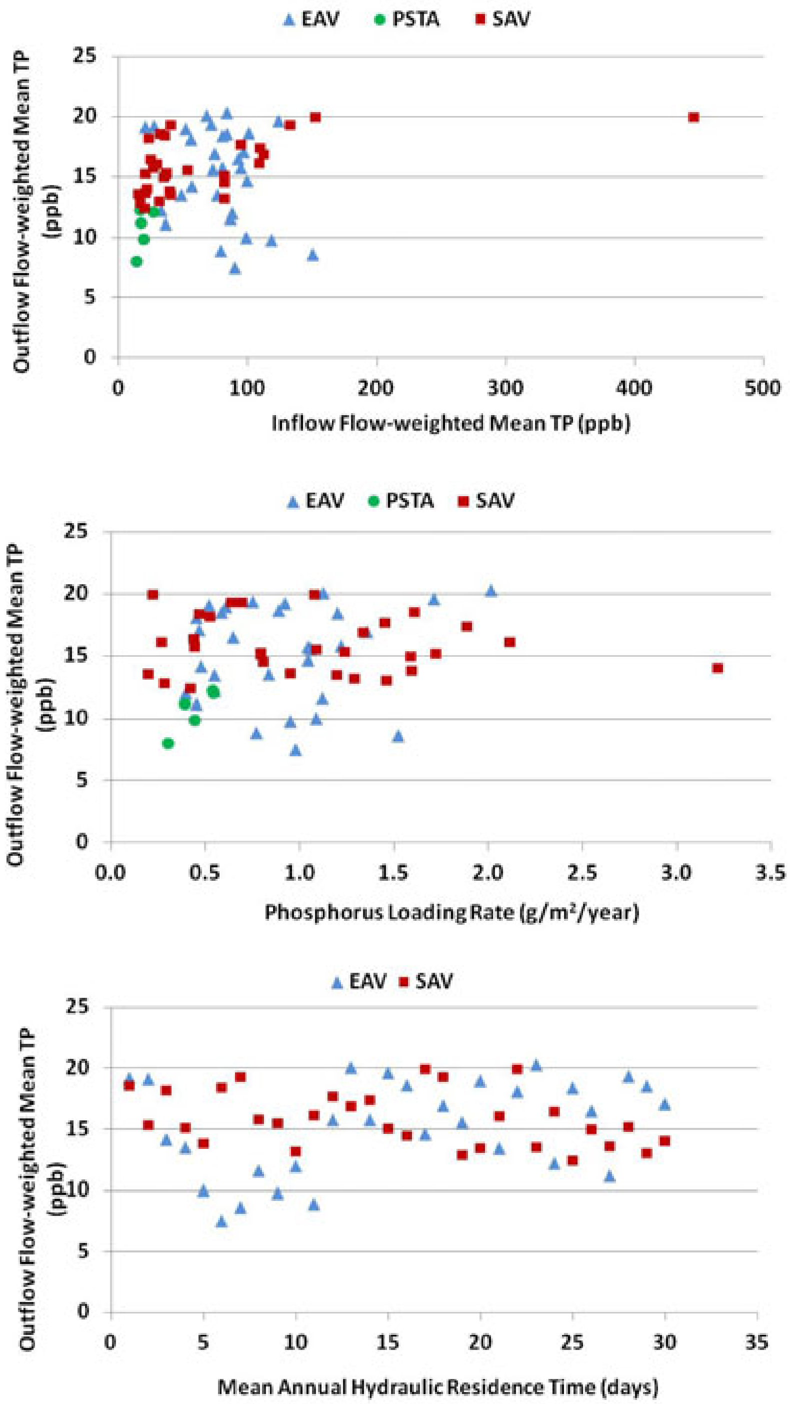


Figure 5-4. Relationship between inflow and outflow TP concentrations versus inflow TP concentrations (top), TP loading rate (middle), and hydraulic residence time (bottom) in cells that achieved 20 parts per billion (ppb) or less for all STAs since 1995.

STA-1E

Stormwater Treatment Area 1 East (STA-1E) is located northeast of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge) and was first operated in WY2005 (**Figure 5-1**). The STA, which is comprised of the Eastern, Central, and Western flow-ways, consists of approximately 5,200 acres (**Figure 5-5**). The Eastern Flow-way was offline until WY2008 and then was online with restrictions through WY2012 due to limitation of the PSTA Demonstration Project. This STA receives inflow primarily from the C-51 West basin through the S-319 pump station and from the S-5A basin through the G-311 structure. In WY2008, STA-1E started receiving inflows from a new source, runoff from Wellington Acme Basin B. During dry months, supplemental water is delivered from Lake Okeechobee to maintain hydration of priority cells.

Several issues have adversely affected STA-1E conditions, operations, and performance, including high hydraulic loading during storm events (particularly in 2006), structural failures, topographic issues (particularly in Cells 5 and 7), dryout of some cells during drought periods and vegetation die off (e.g., Cell 7 cattail vegetation decline over time and Cell 6 hydrilla die off in WY2010). Through WY2012, STA-1E treated 648,071 ac-ft of water and retained approximately 95 metric tons (mt) of TP. The POR inflow FWM TP concentration was 173 ppb, while the POR outflow concentration was 57 ppb (**Table 5-1**).

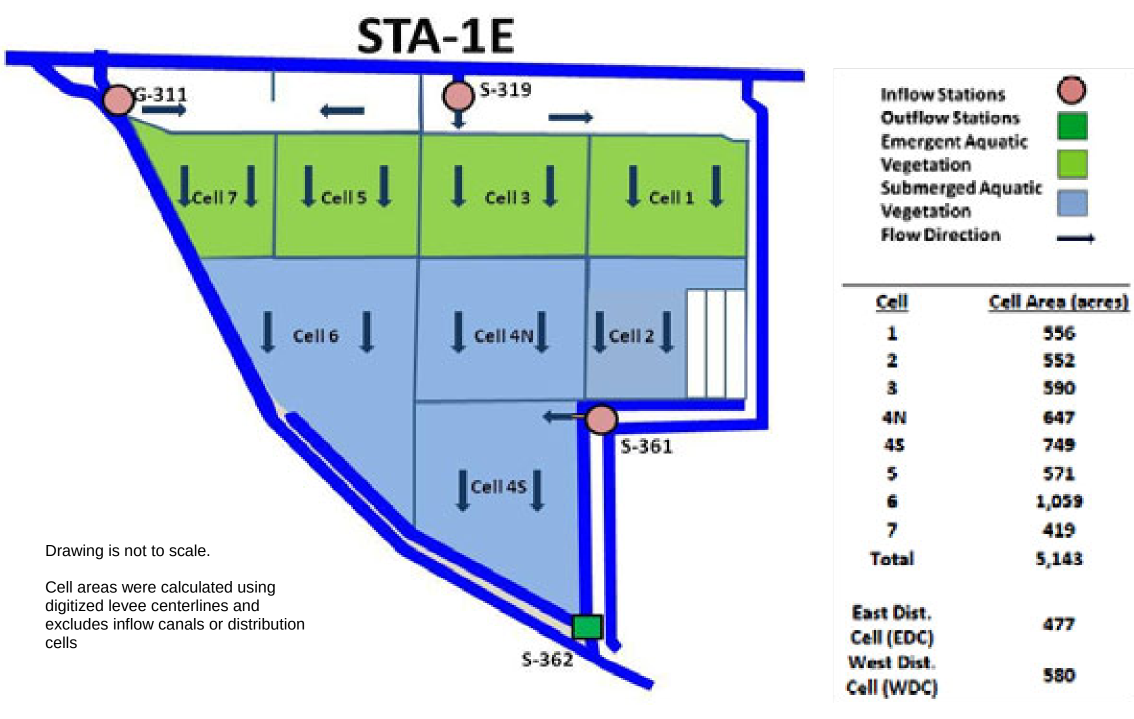


Figure 5-5. Simplified schematic of STA-1E showing major inflow and outflow structures, flow directions, and dominant/target vegetation types. (Note: A more detailed schematic is included in Appendix 5-1.)

STA PERFORMANCE

Despite some structural and vegetation issues, STA-1E performance was strong during WY2012, with a FWM TP outflow concentration of 21 ppb and TP load retention of 83 percent of inflow load. The water year outflow concentration was less than half of the POR outflow FWM TP concentration for this STA (57 ppb). It is important to note that operational adjustments were necessary (see the *Facility Status and Operational Condition* section of this chapter), and that the outflow concentration was also influenced by seepage coming from the Refuge. The 12-month average TP concentration plot for STA-1E shows a dramatic improvement since WY2011, as this STA recovered from the strong influence of TP spikes that occurred between May–June 2009 (hydrilla die off) and toward the end of WY2010 (**Figure 5-6**). The outflow FWM TP concentration continued to improve as vegetation in Cell 6 began to recover and while flow through the Western Flow-way was restricted toward the end of WY2011 and early WY2012.

Dramatic improvements in the outflow concentrations of the Central and Western flow-ways occurred between WY2011 and WY2012 (**Table 5-3**). The most notable improvement was in the Western Flow-way, where outflow concentrations dropped from 165 to 36 ppb. Operation of this flow-way was restricted part of the year, and the HLR was limited to 0.8 cm/day resulting in a total inflow volume of 19,433 ac-ft for WY2012. The Central Flow-way outflow concentration decreased from 45 ppb in WY2011 to 18 ppb in WY2012 likely a result of more normal hydraulic and phosphorus loading than occurred during the relatively dry WY2011.

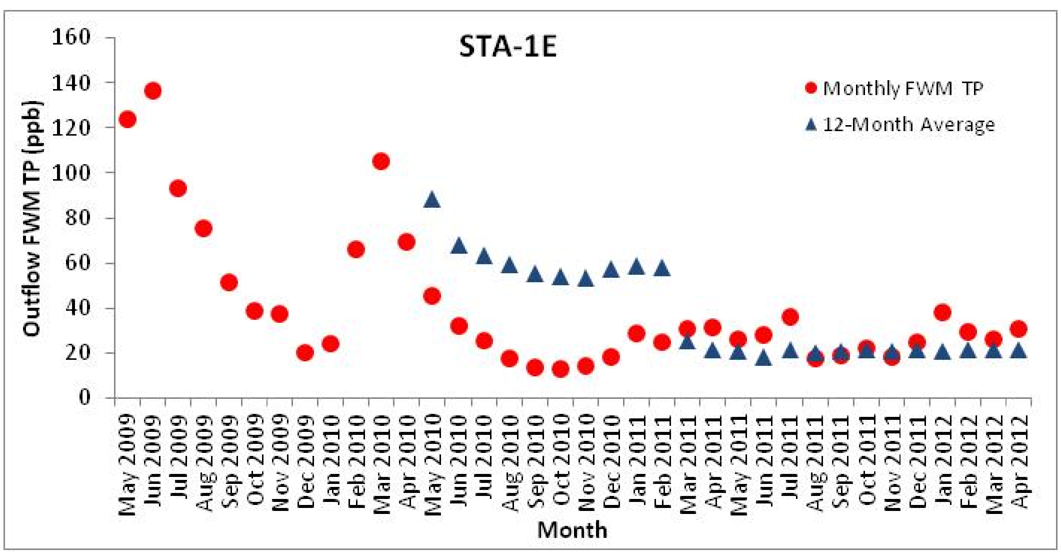


Figure 5-6. Monthly FWM TP phosphorus concentration and preceding 12-month average TP concentration in STA-1E.

Table 5-3. Comparison of flow-way performance in STA-1E between WY2011 and WY2012.

Flow-way/ Water Year	Area (acres)	PLR ($g/m^2/yr$)	HLR (cm/day)	Inflow Volume (ac-ft)	Inflow FWM TP (ppb)	Outflow FWM TP (ppb)	TP Retained (mt)	TP Retained (%)
Central Flow-way	1,986							
WY2011		0.1	0.3	6,857	120	45	0.4	42
WY2012		0.9	2.3	54,384	112	18	6.3	84
Western Flow-way	2,038							
WY2011		0.0	0.1	1,389	77	165	0.0	25
WY2012		0.4	0.8	19,422	125	36	2.1	70

Note: PLR = phosphorus loading rate; HLR = hydraulic loading rate

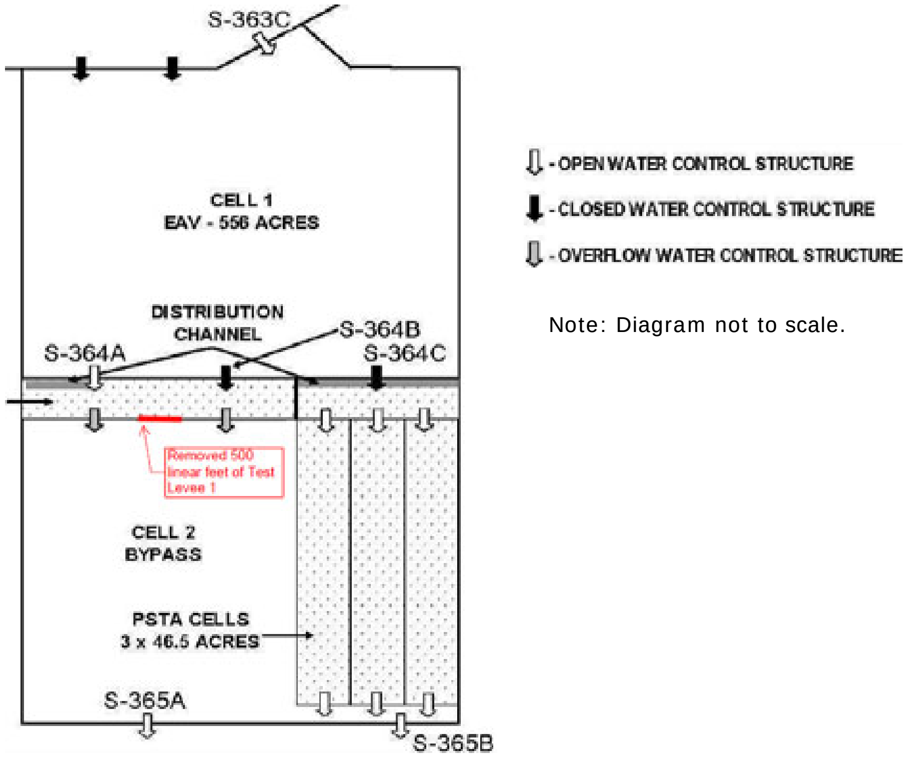
FACILITY STATUS AND OPERATIONAL ISSUES

The Eastern Flow-way of STA-1E remained online with restrictions in WY2012 due to structural constraints caused by the USACE PSTA Demonstration Project in Cell 2 (**Table 5-2**). As a result, Cells 1 and 2 were largely dry for most of the water year. The USACE PSTA Demonstration Project is scheduled to be deconstructed in November 2012, which will require that Cell 2 be completely dry no later than September 2012. Deconstruction of PSTA was decided upon by the USACE upon its review of the benefits of additional data collection for the project versus removal of flow restrictions to the Eastern Flow-way (USACE, 2012). The PSTA Project and its associated structures restrict the volume of water that can be treated by STA-1E and limit the flow capacity of the Eastern Flow-way. In the interim, approximately 500 linear feet of an earthen berm separating the upper SAV and the PSTA cell, was degraded to allow for more flow through the flow-way (**Figure 5-7**).

The Central Flow-way remained fully operational during the water year. Target stages in this flow-way were raised by six inches above the normal target stage of 1.25 feet during the dry season as a drought contingency measure. The Western Flow-way, which had been offline due to structural failures, vegetation decline, and TP removal performance issues, was online with restrictions for several months during the water year. It was offline briefly from November 29–December 19, 2011, for vegetation enhancements in Cell 7. Because the Western Flow-way was offline, the adjusted effective treatment area acreage was reduced to reflect the acreage that was operational (**Table 5-2**). Due to concerns about the condition and performance of Cells 6 and 7 early in the WY2012 wet season, temporary pumps were installed to route water from Cell 6 to Cells 4N and 4S. The USACE continued to repair structures in the Western and Central flow-ways. The repairs required taking one structure in each cell off line for construction, which resulted in limiting flow to each cell and flow-way.

As previously noted, structural repairs in STA-1E are under way, including S-367B, S-375, S-370C, S-373B, and S-374A. In March 2012, downstream coffer dams were constructed at S-370C, S-373B, and S-374A at the inflows of Cells 5, 6, and 7, respectively, for necessary repairs to these structures. Consequently, these structures have been taken offline until construction is completed.

a.



b.

Figure 5-7. Diagram of the Eastern Flow-way in STA-1E showing the location of the degraded berm in Cell 2 at the former Periphyton-based STA Demonstration Project site (a), and photo of the degraded berm (b) (photo by the SFWMD).

Drought Impacts

Despite delivery of supplemental water (approximately 4,111 ac-ft from Lake Okeechobee), drought and the delayed onset of the WY2012 wet season resulted in dryout in Cells 3 and 5; Cells 1 and 2 were already dry from the lack of flow during most of the water year (**Figure 5-8**). Dry and low water condition in some areas, particularly Cell 5, resulted in expansion of primrose willow (*Ludwigia peruviana*) in approximately 60 percent of the cell. This species is not desired in the STAs due to its less efficient role in phosphorus uptake. Upon resumption of flow and with systematic water management, such as the use of a temporary pump to deliver water from Cell 6 into Cell 4N and restricting flows through the Western Flow-way, the outflow concentration began to stabilize in both the Central and Western flow-ways. Due to various issues, such as uneven flow distribution, declining vegetation, and ongoing construction activities, assessment of the effects of the WY2012 drought in STA-1E is challenging.

Impacts of Migratory Bird Nesting

Two nesting survey periods occurred during the WY2012 reporting period for all STAs: May–July 2011 and April 1–30, 2012 (Appendix 5-4). Nesting information for the remainder of 2012 (May–July 2012) is also included in Appendix 5-4. A total of 42 black-necked stilt (*Himantopus mexicanus*) nests were counted during STA-1E levee surveys between April and July 2011, the majority were observed in the Eastern Distribution Cell, and there were up to 9 nests in Cell 4S (May 2011). Necessary adjustments to flow-way prioritization were made weekly during this period, avoiding operation of the Eastern Distribution Cell and the Central Flow-way during the nesting period, to minimize impacts to nests. Toward the end of WY2012, nesting activities were limited, with a total of five nests observed only at Cell 5 (April 2012). There were no noted impacts to operations in April 2012, primarily due to low inflows to the STA.

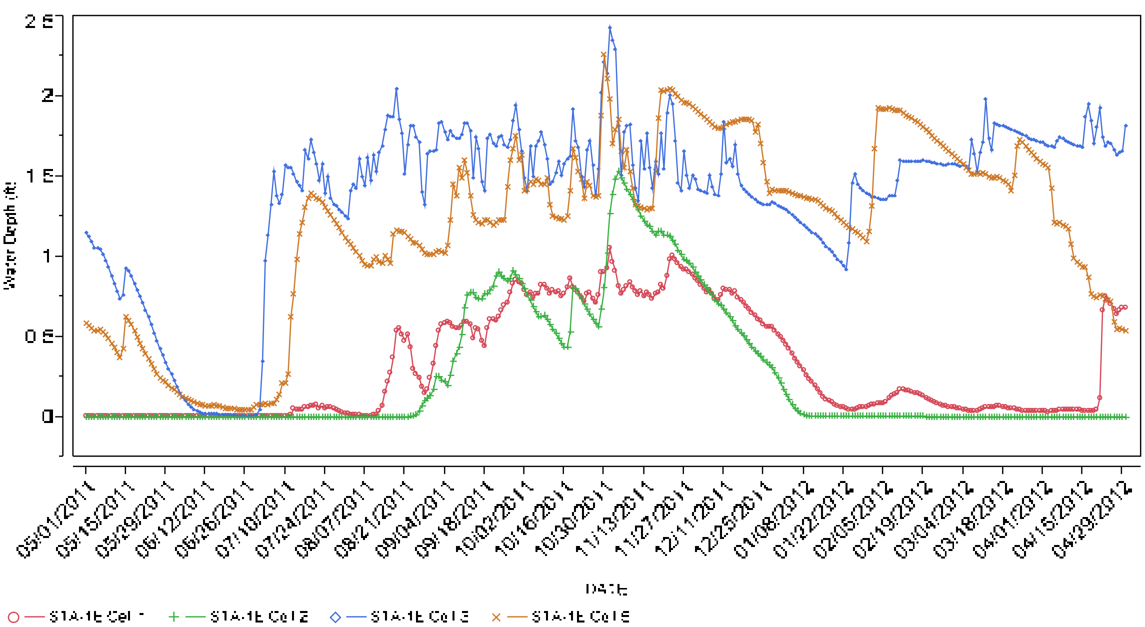


Figure 5-8. Daily average water depths in STA-1E Cells 1, 2, 3, and 5 in WY2012.

MAINTENANCE AND ENHANCEMENTS

Routine vegetation management in STA-1E included control of FAV in inflow distribution canals and in outflow collection canals to provide an even distribution of flow across each cell, and to ensure the efficiency of discharge structures. Within the cells, water lettuce and other floating plants such as water hyacinth and frog's bit (*Limnobium spongia*) were routinely treated to promote growth of submerged beds of aquatic vegetation in SAV cells. Routine maintenance and optimization of emergent cells primarily involved herbicide treatments of coastal plain willow (*Salix caroliniana*) and primrose willow. A summary of herbicide use in the STAs is included in Volume III, Appendix 3-1, Attachment E.

Due to topographic deficiencies and soil characteristics, cattail cover in Cell 7 of STA 1E has been in steady decline and now exists primarily as floating tussocks. Parallel projects to replace the floating tussocks with more effective water quality treatment processes were initiated in November–December 2011. A mechanical harvester was used to remove 15 acres of floating tussocks in the northwest corner of the cell while another 15 acres of floating tussocks in the south end of the cell were treated with herbicides. In April 2012, giant bulrush was planted throughout the harvested area and the treated area will be similarly planted in May–June 2012. These two projects will allow for comparative analyses of the effectiveness and costs of these measures and their potential utility for implementation in a larger scale.

In Cell 5, shallower water depths, caused by topographic issues and the extended dry season, resulted in colonization and spread of primrose willow, which covered over 60 percent of the cell. Primrose willow is an invasive exotic shrub that forms dense thickets with little or no understory cover and is not a desired species for effective water quality treatment in emergent cells. In November 2011, a pilot project to establish more effective vegetation was implemented in a 60-acre area in the east central portion of the cell. Herbicide treatments were applied to kill the primrose willow, followed by manual cutting in February 2012. While field observations indicate extensive cattail colonization, and recruitment has occurred within the treated area, there are also indications of new primrose willow growth in the pilot area. Unvegetated areas were planted with giant bulrush in June–July 2012 and additional selective primrose willow treatments will be undertaken in WY2013 when target water stages are achieved. Additional bulrush planting was also done on new emergent vegetation strips in Cells 4S and 6, to further protect SAV from wind action or high flow events.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

Based on an annual imagery flight, area coverage of EAV and SAV+open area was estimated for each STA (**Table 5-4**; Appendix 5-5). Vegetation coverage for CY2011 (conducted in May 2011) is presented in this chapter; a comparison with the previous year (conducted in April 2010) is also included. The image resolution and mapping units were 1 foot. For STA-1E, data shows that there was little change in terms of vegetation coverage; the biggest changes were observed in Cell 1 and Cell 7, with a 7 percent decrease and a 10 percent increase, respectively. It is important to note that area coverage estimates does not consider vegetation density. In Cell 7, for example, while coverage data indicates a 10 percent increase, visual observations indicate a drastic decline of cattail vegetation density in the past three years. Chronic deep water condition in this cell, due to very low ground elevation compared to surrounding areas, has impacted the cattail community in terms of mortality and formation of floating tussocks (**Figure 5-9**).

Table 5-4. Summary of vegetation coverage in STA-1E.
(Note: Numbers shown are expressed as percentage of total cell area.)

	Cover Category		
Area	**% EAV**	**% SAV+ Open Area**	**% Change in EAV Cover from 2010 to 2011**
Cell 1	86	14	-7
Cell 2	68	32	N/A
Cell 3	79	21	-6
Cell 4N	41	59	1
Cell 4S	11	89	0
Cell 5	89	11	4
Cell 6	14	86	-2
Cell 7	65	35	10

N/A=not available; negative numbers indicate a decrease in EAV coverage in 2011.

Figure 5-9. A portion of STA-1E Cell 7 showing vegetation mortality and sparse live cattail (*Typha* sp.) density, typical for the entire cell, as a result of chronic deepwater condition in the cell (photo by the SFWMD).

Ground Survey for Submerged Aquatic Vegetation

An SAV ground survey of Cells 4N, 4S, and 6 of STA-1E on May 5, 2011, indicates that hydrilla continued to be the dominant submerged vegetation in this STA, followed by coontail (**Figure 5-10**). Although the data indicate improvement in Cell 6 from the previous water year, most of the SAV was observed in the inflow region of the cell, with sparse vegetation in the outflow region. Within both cells of the central flow path (Cells 4N and 4S), hydrilla was also the dominant SAV observed. Some southern naiad, musk grass, and hornwort (*Ceratophyllum demersum*) were also observed within Cell 4N. Similar to Cell 6, there were areas in both Cells 4N and 4S that were devoid of SAV.

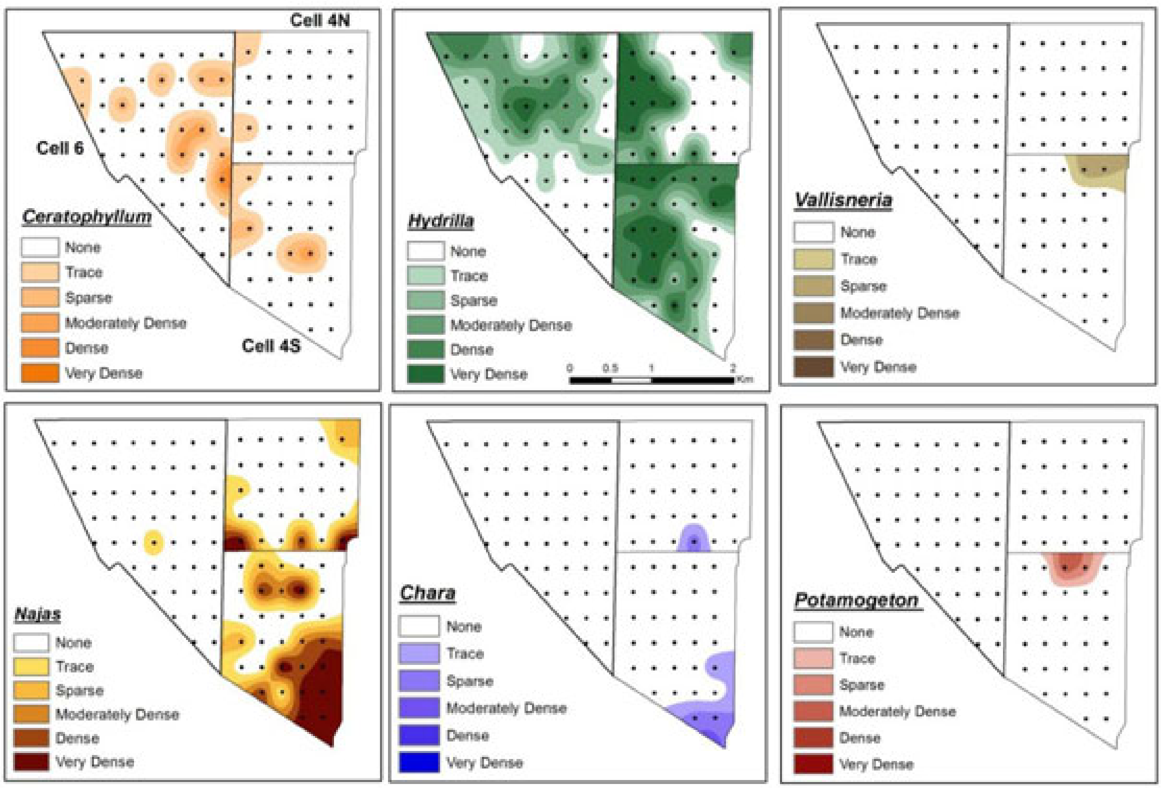


Figure 5-10. Vegetation survey results depicting the spatial coverage of hornwort (*Ceratophyllum demersum*), hydrilla (*Hydrilla verticillata*), eelgrass (*Vallisneria* sp.), southern naiad (*Najas guadalupensis*), musk grass (*Chara* sp.), and pond weed (*Potamogeton* sp.) in STA-1E Cells 4N, 4S, and 6 on May 5, 2011.

STA-1W

Stormwater Treatment Area 1West (STA-1W), which began operation in 1994 (WY1995), is northwest of the Refuge (**Figure 5-1**). It consists of three flow-ways totaling 6,670 acres of effective treatment area: Eastern Flow-way (Cell 1A, Cell 1B, and Cell 3), Western Flow-way (Cell 2A, Cell 2B, and Cell 4), and Northern Flow-way (Cell 5A and Cell 5B) (**Figure 5-11**; Appendix 5-1). The Eastern and Western flow-ways were formerly known as the Everglades Nutrient Removal Project; the Northern Flow-way was added in 1999 (WY2000). Compartmentalization of the original Cell 1 and Cell 2 was completed in 2007, creating Cells 1A, 1B, 2A, and 2B. This STA receives inflow primarily from S-5A drainage basins. During dry months, supplemental water was also delivered from Lake Okeechobee to maintain hydration on priority cells.

Since it became operational in WY1995 through WY2012, STA-1W has treated aaproximately 3.3 million ac-ft of water and retained approximately 480 mt of TP. The POR mean inflow FWM TP concentration was 171 ppb while the POR mean outflow concentration was 51 ppb (**Table 5-1**). Over its period of operation, STA-1W has been impacted by extreme weather events (regional drought and storm events), construction enhancement activities that included water level drawdown and earthwork, and high hydraulic and nutrient loadings. The conditions in STA-1E, which resulted in flow-ways being offline or under restricted operation, as discussed previously, also impacted the hydraulic and nutrient loadings in STA-1W. A series of major rehabilitation activities were implemented between 2005 and 2007 to improve cell condition and restore the treatment capability of the cells.

STA PERFORMANCE

The performance of STA-1W continues to improve; the STA achieved a FWM TP outflow concentration of 22 ppb, which was slightly lower than WY2011 (25 ppb), and retained 85 percent of the inflow TP load (**Table 5-1**; **Figure 5-2**). A total of 96,847 ac-ft of inflow was treated, with an annual average inflow FWM TP concentration of 143 ppb. The 12-month average plot for STA-1W shows a significantly decreasing trend between WY2011 and the end of WY2012 (**Figure 5-12**).

For each flow-way the WY2012 TP outflow concentrations (20, 23, and 19 ppb for the Eastern, Western, and Northern flow-ways, respectively) are slightly but consistently lower than WY2011 outflow concentrations (24, 25, and 21 ppb, respectively) (**Table 5-5**). In terms of PLR, which is calculated as total mass loading per unit area, values for the Eastern Flow-way have been consistently about half of those for either the Western or Northern flow-ways. This can be attributed to the target stage and average ground elevation of the Western Flow-way being lower than the Eastern Flow-way, hence, water flows easier into the Western Flow-way. Controlling the flow to the Western Flow-way to allow more water into the Eastern Flow-way would require manipulation of the G-255 gate (inflow structure for the Western Flow-way) opening. Since the outflow TP concentrations have been comparable among the three flow-ways over the last two water years, no special efforts were made in WY2012 to adjust the G-255 gate openings.

The most change in TP load retention was in the Eastern Flow-way, with 79 percent in WY2011 and 85 percent in WY2012; percent TP retention for the Western and Northern flow-ways were 84 percent, which were similar to WY2011. The moderate hydraulic and TP loading, absence of any major activities or weather disturbance to impact STA performance, improved strategies in water management (e.g., better distribution of flows among flow-ways, increasing stages during the dry season, and delivering supplemental water when necessary), and continuing vegetation improvements all contributed to the good performance observed in these flow-ways.

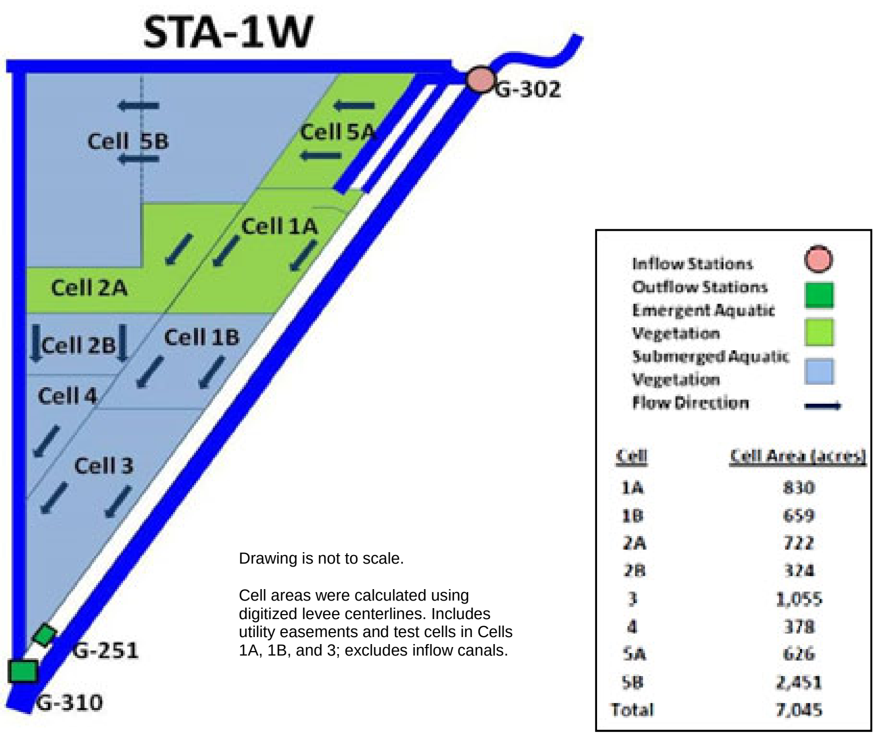


Figure 5-11. Simplified schematic of STA-1W showing major inflow and outflow structures, flow directions, and dominant/target vegetation types. (Note: A more detailed schematic is included in Appendix 5-1.)

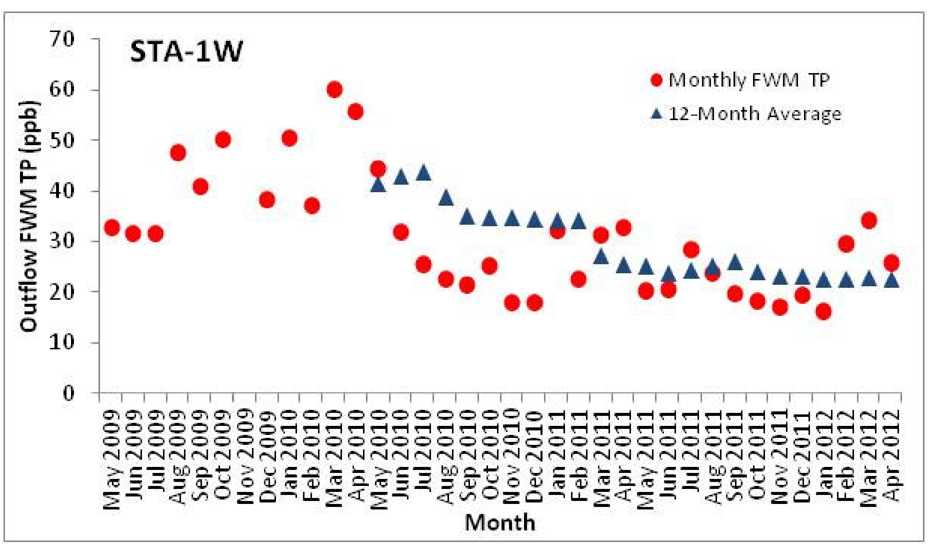


Figure 5-12. Monthly flow-weighted mean TP concentration and preceding 12-month average TP concentration in STA-1W.

Table 5-5. Comparison of flow-way performance in STA-1W between WY2011 and WY2012.

Flow-way/ Water Year	Area (acres)	PLR (g/m2/yr)	HLR (cm/day)	Inflow Volume (ac-ft)	Inflow FWM TP (ppb)	Outflow FWM TP (ppb)	TP Retained (mt)	TP Retained (%)
Eastern Flow-way	2516							
WY2011		0.5	1.0	30,896	125	24	3.8	79
WY2012		0.4	0.9	27,485	131	20	3.8	85
Western Flow-way	1299							
WY2011		1.1	2.1	32,590	148	25	5.2	87
WY2012		0.9	2.1	31,964	116	23	3.9	84
Northern Flow-way	2855							
WY2011		1.1	2.0	69,759	148	21	10.8	85
WY2012		0.7	1.2	42,017	152	19	6.7	84

FACILITY STATUS AND OPERATIONAL ISSUES

In WY2012, all flow-ways in STA-1W were operational (**Table 5-2**).

Drought Impacts

By implementing drought contingency strategies, the WY2012 drought had no observable impact on STA-1W performance or condition. To prepare for the anticipated drought season, water levels were held at the drought contingency stages (6 inches above the normal target stages) during the WY2012 dry season. Also, approximately 3,368 ac-ft of supplemental water from Lake Okeechobee was delivered to STA-1W in WY2012. These combined measures enabled STA-1W to stay hydrated through the drought periods of the water year.

Impacts of Migratory Bird Nesting

Between May and July 2011, 105 nests were observed from levee surveys in STA-1W, all of which were located in the Western Flow-way (Appendix 5-4). Due to a regional drought and lack of flows to the STA, the impact to STA-1W operation was minimal. By the beginning of the wet season in early July 2011, there were no observed active nests. There were also no nests observed in April 2012. Nesting information on the remainder of CY2012 is included in Appendix 5-4.

MAINTENANCE AND ENHANCEMENTS

In May 2011, additional bulrush planting was conducted in Cell 5A. Some regions of this cell have remained devoid of cattail, likely a result of the chronic deep water condition; however, previously planted bulrush (WY2010) has shown good establishment and continues to expand. Additional bulrush vegetation strips were created in Cell 5B during October–November 2011 and in March–April 2012 (**Figure 5-13**). Additional strips are expected to provide more protection against strong winds and flows to maintain good SAV establishment. Looking ahead, construction is planned to begin in June 2012 on a new trash rake at G-251. This structure will be offline while construction is ongoing.

Figure 5-13. New vegetation strip in STA-1W Cell 5B (April 2012). Additional strips are anticipated to provide increased protection to the existing SAV community against strong winds and flows (photo by the SFWMD).

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

EAV coverage has been stable in STA-1W, most likely because the stages were maintained at target levels that are optimal for the desired vegetation. For most cells, EAV coverage was similar to what was observed in CY2010 (**Table 5-6**; Appendix 5-5). The biggest change was in Cell 2A, where EAV coverage declined by approximately 9 percent. This analysis does not take into account vegetation density, which is an equally important parameter to consider when assessing cell condition relevant to nutrient removal.

Ground Survey for Submerged Aquatic Vegetation

Based on a survey conducted on July 29, 2011, musk grass was the dominant SAV in Cells 2B and 4 (**Figure 5-14**). Both hornwort and southern naiad were also present along the northern and eastern levees, in regions where musk grass was less dense. Musk grass was also the dominant SAV present in Cells 1B and 3 based on a February 24, 2012, survey (**Figure 5-15**). Southern naiad was present in a few areas of Cell 3 and trace amounts of hornwort were observed in the inflow and eastern regions of Cell 1B. Except for the inflow region, southern naiad was the dominant SAV within Cell 5B on April 4, 2012 (**Figure 5-16**). Within the inflow region, some areas were devoid of vegetation and hornwort was observed in others. Musk grass was also observed in the mid-to-outflow region of the cell.

Table 5-6. Summary of vegetation coverage in STA-1W based on May 2011 aerial imagery. [Note: Numbers shown are expressed as percentage of total cell area.]

	Cover Category		
Area	% EAV	% SAV+ Open Area	% Change in EAV Cover from 2010 to 2011
Cell 1A	82	18	2
Cell 1B	27	73	6
Cell 2A	86	14	-9
Cell 2B	8	92	4
Cell 3	44	56	-2
Cell 4	16	84	-3
Cell 5A	50	50	-4
Cell 5B	11	89	0

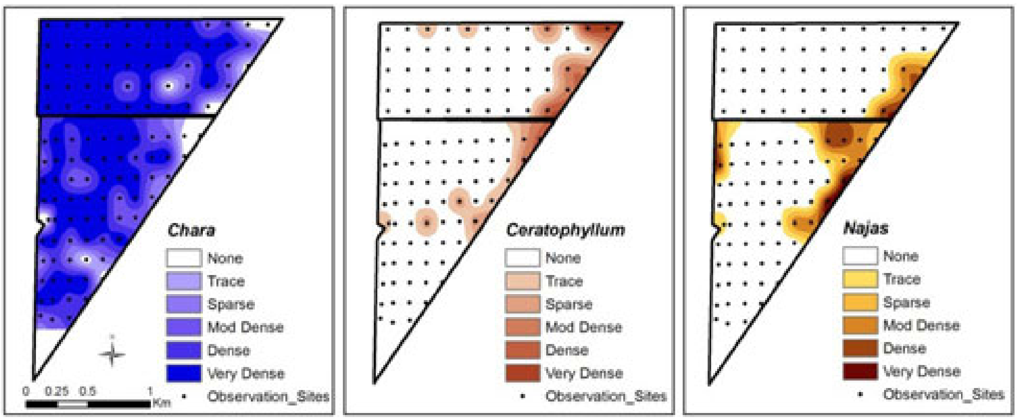


Figure 5-14. Vegetation survey results depicting the spatial coverage of *Chara, Ceratophyllum,* and *Najas* in STA-1W Cells 2B and 4 on July 29, 2011.

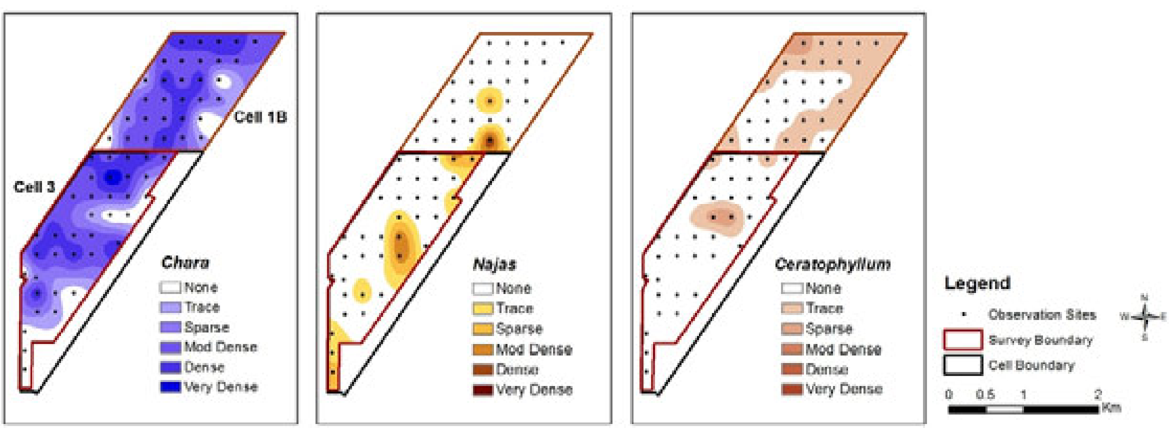


Figure 5-15. Vegetation survey results depicting the spatial coverage of *Chara, Najas*, and *Ceratophyllum* in STA-1W Cells 1B and 3 on February 24, 2012.

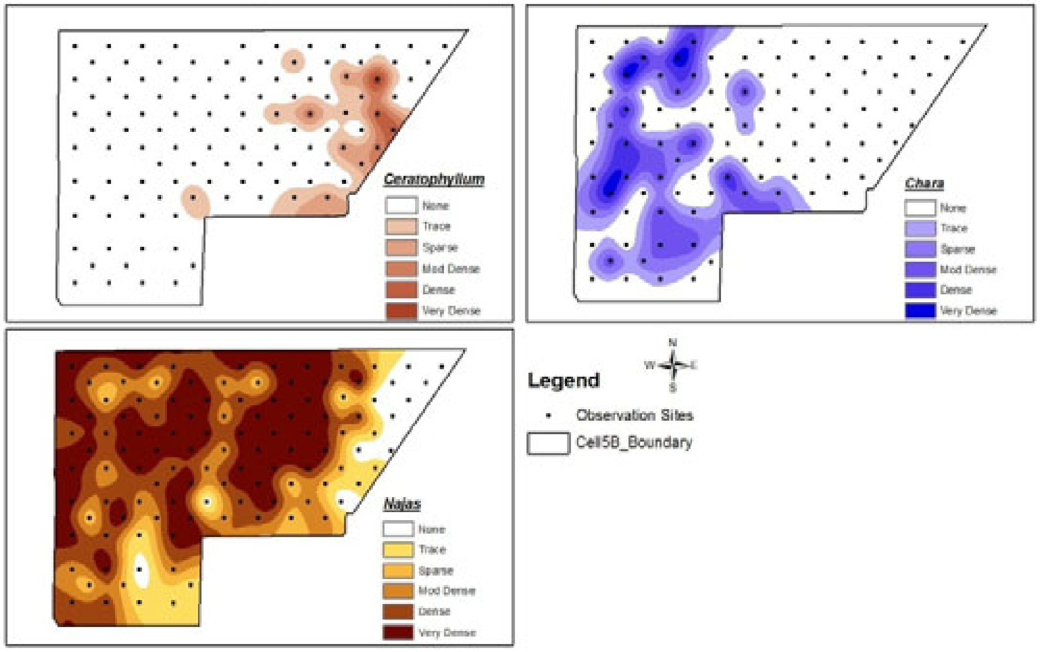


Figure 5-16. Vegetation survey results depicting the spatial coverage of *Ceratophyllum*, *Chara*, and *Najas* in STA-1W Cell 5B on April 4, 2012.

STA-2

Stormwater Treatment Area 2 (STA-2) is located in western Palm Beach County immediately west of Water Conservation Area 2A (WCA-2A) (**Figure 5-1**). The original STA-2 consisted of three treatment cells (1, 2, and 3) with 6,338 acres of effective treatment area and began operation in 2000. The treatment area was expanded by 1,902 acres with the construction of Cell 4, which was flow capable by December 2006, but this cell went offline in WY2010 for Compartment B construction. Upon completion of Compartment B (approximately 6,817 acres of treatment area), STA-2 will have eight treatment cells, five flow-ways, and a total area of approximately 15,933 acres (**Figure 5-17**).

The primary source of STA-2 inflow water is the Hillsboro Canal, which collects flows from various sources including agricultural runoff and discharges from the S-6/S-2 basin, a portion of runoff from the S-5A basin, and runoff from Chapter 298 Drainage Districts (Brown and Caldwell, 2011). During dry months, supplemental water is also delivered from Lake Okeechobee and other sources to maintain hydration of priority cells.

During WY2000–WY2012, STA-2 has treated aproximately 2.8 million ac-ft of water and retained approximately 269 mt of TP. The POR inflow FWM TP concentration is 103 ppb while the POR outflow concentration is 22 ppb, which is the second lowest average POR value achieved in the STAs (**Table 5-1**). One attribute of STA-2 that leads to consistently good performance is that over half of its current operational areas were never farmed prior to becoming a treatment area. Like the other STAs, STA-2 has also been impacted by extreme weather events (regional drought and storm events) over its period of operation. Parts of or the entire area of Cells 1 and 2 have dried out previously during drought periods or extended dry seasons when supplemental water was limited. The District continuously improves its operational management strategies to minimize impacts of extreme weather events. During both WY2011 and WY2012, methodical water management, including an increase in dry season target stages and delivery of supplemental water from Lake Okeechobee, prevented or minimized the impacts of drought in STA-2. In WY2009, conversion from cattail to SAV of approximately 300 acres at the southern portion of Cell 2 was initiated to further improve the performance of this cell.

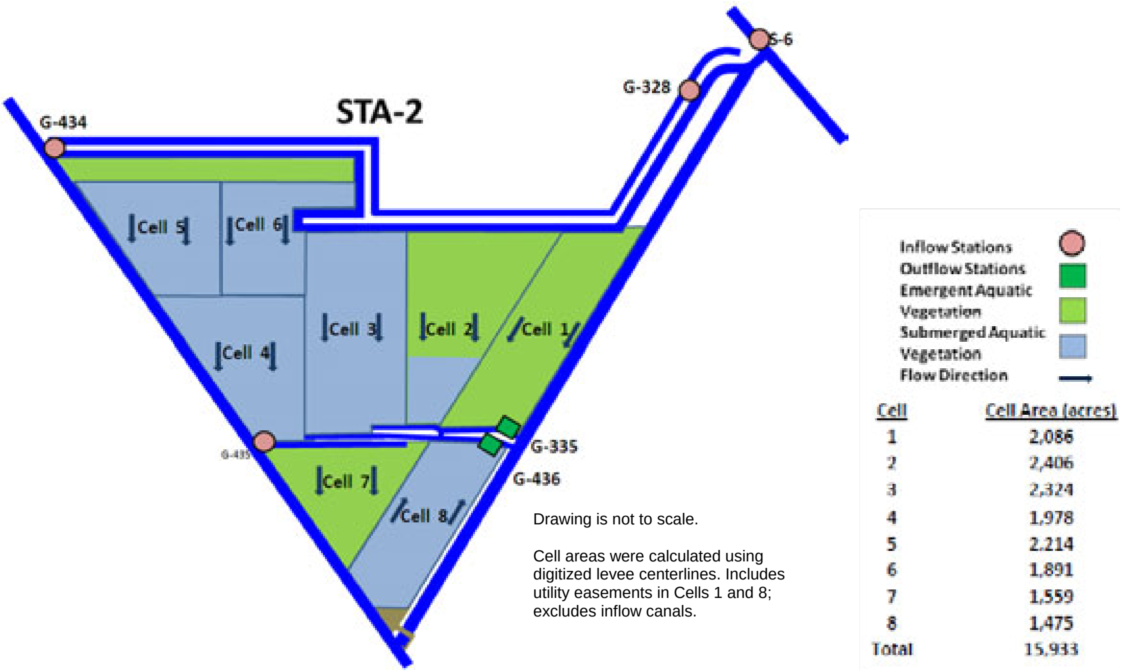


Figure 5-17. Simplified schematic of STA-2 showing major inflow and outflow structures, flow directions, and dominant/target vegetation types. The southern portion of Cell 2 was converted from emergent to submerged aquatic vegetation in April 2009. (Note: A more detailed schematic is included in Appendix 5-1.)

STA PERFORMANCE

In WY2012, STA-2 treated 195,651 ac-ft of inflow and retained approximately 18 mt of TP. In comparison to the other STAs, STA-2 had the lowest outflow TP concentration (12 ppb FWM) and its HLR and PLR were the highest at 2.58 cm/d and 0.82 g/m^2/yr, respectively (**Table 5-1**). The 12-month average plot shows a very slight decreasing trend in outflow TP concentration through the end of WY2012 (**Figure 5-18**). As previously noted, this strong performance is largely attributed to the fact that a large portion of this STA was never farmed, its excellent vegetation coverage, and the successful operational management strategies, including moderate loading. Previously farmed wetland areas have been shown to be either a source or a poor sink of P (Pant and Reddy, 2003; Aldous et al., 2005; Steinman and Ogdahl, 2011). A more in-depth investigation of the factors influencing consistently low outflow TP concentrations, particularly in Cell 1 is needed.

Of the flow-ways, Cell 1 produced the lowest outflow TP concentration (8.9 ppb FWM) compared to Cells 2 and 3 (15 and 14 ppb FWM, respectively) (**Table 5-7**). All flow-ways showed lower outflow concentrations compared to WY2011, where Cells 1, 2, and 3 achieved 12, 19, and 15 ppb FWM TP concentration, respectively. Although Cell 1 received less volume of inflow (57,632 ac-ft) than Cells 2 and 3 (78,193 and 73,549 ac-ft, respectively) in WY2012, the

HLR for the three cells was comparable (2.7–2.9 cm/day). Cells 1 and 3 had the same PLR (0.8 g/m^2/yr), while Cell 3 had a slightly higher PLR (1 g/m^2/yr).

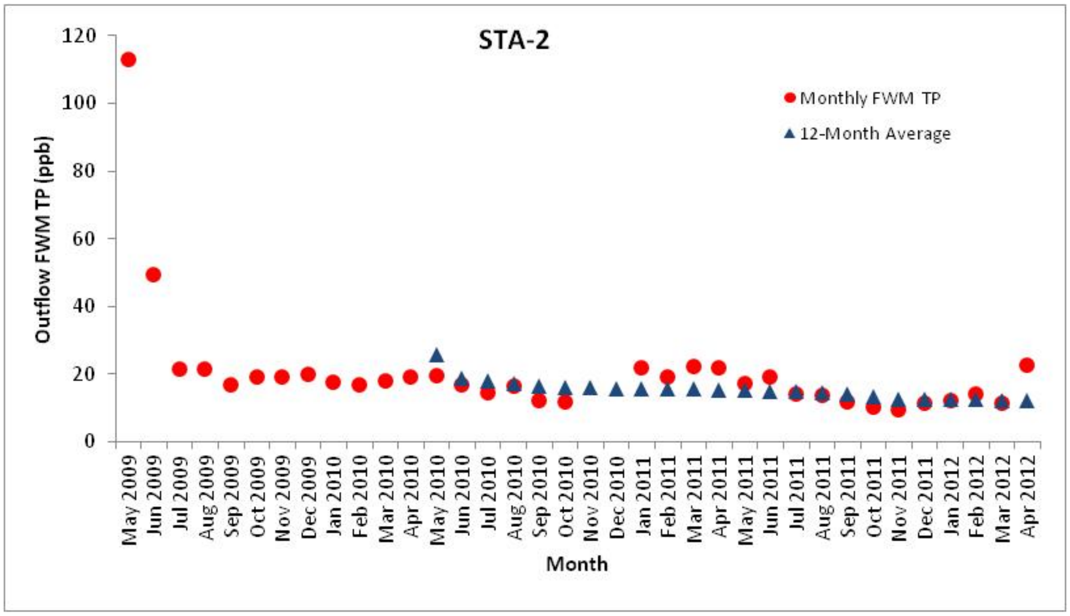


Figure 5-18. Monthly flow-weighted mean TP concentration and preceding 12-month average TP concentration in STA-2.

Table 5-7. Comparison of flow-way performance in STA-2 between WY2011 and WY2012.

Flow-way/ Water Year	Area (acres)	PLR (g/m2/yr)	HLR (cm/day)	Inflow Volume (ac-ft)	Inflow FWM TP (ppb)	Outflow FWM TP (ppb)	TP Retained (mt)	TP Retained (%)
STA-2, Cell 1	1798							
WY2011		0.4	1.2	26590	88	12	2.5	86
WY2012		0.8	2.7	57632	79	8.9	5.1	91
STA-2, Cell 2	2270							
WY2011		0.9	2.4	65696	101	19	6.6	80
WY2012		1.0	2.9	78193	99	15	8.0	83
STA-2, Cell 3	2270							
WY2011		0.8	2.7	72493	82	15	6.0	81
WY2012		0.8	2.7	73549	82	14	5.8	77

FACILITY STATUS AND OPERATIONAL ISSUES

Cells 1, 2, and 3 were fully operational, while Cell 4 remained offline due to construction activities in Compartment B (**Table 5-2**). Because Cell 4 was offline, the adjusted effective treatment area acreage was reduced to reflect the acreage that was operational. In March 2011, one of the three pumps in S-6 failed, limiting the structure's pumping capacity. Subsequently, temporary pumps were put in place to deliver water to STA-2 during pump repairs, which were completed and allowed S-6 to be fully operational on September 27, 2011.

Compartment B Build-out

The Compartment B Build-out Project is west and south of the existing STA-2 (**Figure 5-1**). Construction of Compartment B and the three associated pump stations began in WY2010 and the system was flow-capable by December 2010. Construction of two inflow canal bridges was completed in May 2011, while construction of the G-435 pump station was completed on January 24, 2012. Compartment B North and South build-outs were completed on October 22 and November 8, 2011, respectively. Construction of the G-434 and G-436 pump stations was completed in September 2012. Operation of the Compartment B Build-out Project depends on the acquisition of state and federal discharge permits.

Vegetation start-up measures were initiated in Compartment B. In Cell 4, the SAV cover that was previously present died back as a result of draining this cell for Compartment B construction. The low water condition also led to extensive colonization of cattail. Efforts to reverse this cattail encroachment and reestablish SAV were initiated in January 2012 when 700 acres of cattail were treated with an aerial herbicide application. Within the new cells, extensive coverage of willow and primrose willow present a similar impediment for establishing the desired wetland species. In November 2011, crews treated, cut, and piled some of the smaller patches of willow and primrose willow in Cell 6. Aerial herbicide treatment of the remaining tree and shrub cover is scheduled for the beginning of WY2013. Additional startup measures to be completed in WY2013 include conversions of Cell 8 and downstream portions of Cells 5 and 6 to SAV, including aerial inoculations to establish founder beds of SAV in these cells.

Backflow from G-368 into Cell 4 occurred, as needed, during March and April 2012 to stimulate SAV growth through increased hydration. Water was added to Cells 5 and 6 via S-6 and G-337A beginning on April 23, 2012, to facilitate vegetative growth.

Drought Impacts

During the early part of WY2012, water level of the EAV cells (Cells 1 and 2) receded quickly; Cell 1 eventually dried out by the last week of June 2011 (**Figure 5-19**). However, with the onset of the CY2011 wet season, the cells were rehydrated quickly and remained wet for the rest of the water year. By implementing drought contingency strategies, the WY2012 drought had no significant impact on STA-2 condition or performance, aside from visible browning of cattail leaves in Cells 1 and 2 (**Figure 5-20**). To prepare for the anticipated drought season, water levels were held at the drought contingency stages (additional 6 inches) during the WY2012 dry season. Also, 10,992 ac-ft of supplemental water from Lake Okeechobee was delivered to STA-2 in WY2012. These combined measures enabled the cells in this STA to stay hydrated through the dry months during the water year. In June 2011, the Cell 1 water level receded to below the minimum target, but quickly resumed to target levels at the onset of the 2011 wet season. Cell 3 remained hydrated through the dry season.

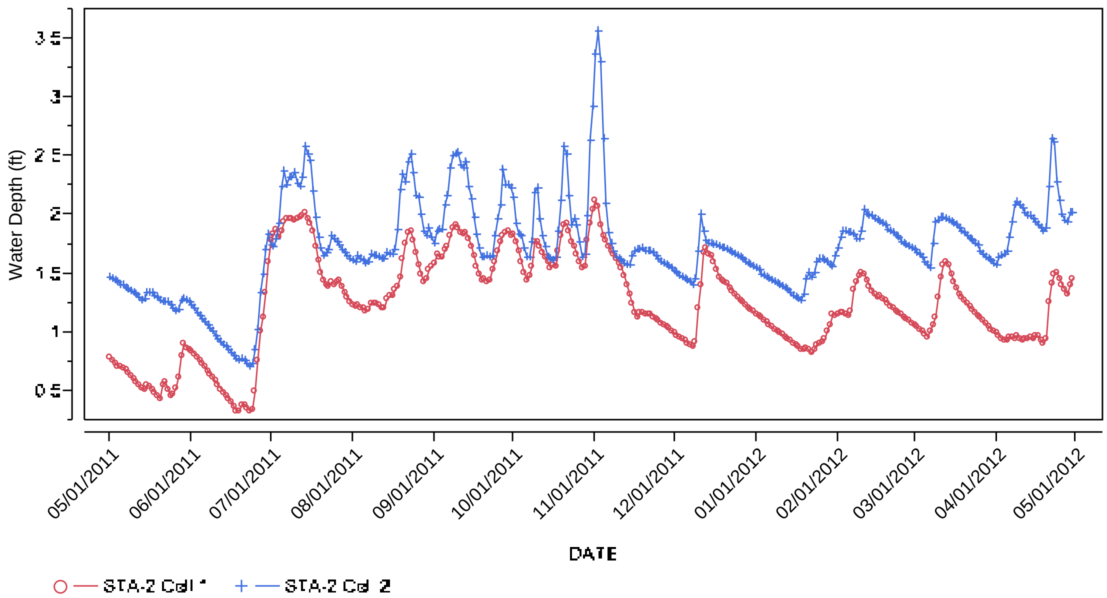


Figure 5-19. Daily average water depths in STA-2 Cells 1 and 2 during WY2012. Cell 3 water depths are not included; this cell remained hydrated through the water year.

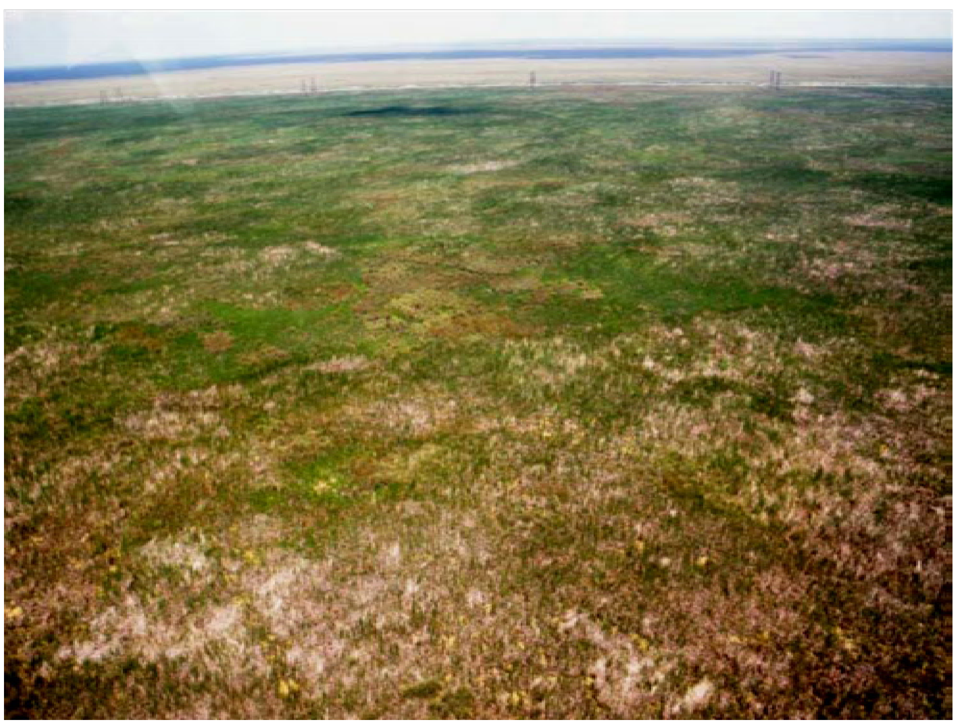


Figure 5-20. Dry condition in STA-2 Cell 1 as a result of low water conditions and brief dryout period in June 2011 (photo by the SFWMD).

Impacts of Migratory Bird Nesting

STA-2 operations were not impacted by migratory bird nesting in WY2012. Between May and July 2011, 39 black-necked stilt nests were observed via levee surveys in the STA, all of which were in non-operational cells (Cells 4 and 6) (Appendix 5-4). No nests were found in STA-2 in April 2012.

MAINTENANCE AND ENHANCEMENTS

Routine vegetation management included control of FAV in inflow distribution canals and in outflow collection canals to provide an even distribution of flow across each cell, and to ensure the efficiency of discharge structures. Within the cells, water lettuce and other floating plants such as water hyacinth and frog's bit were routinely treated to promote growth of submerged beds of aquatic vegetation in SAV cells. A summary of herbicide use in the STAs is included in Volume III, Appendix 3-1, Attachment E.

The partial conversion of the southern portion (approximately 300 acres) of Cell 2 from cattail to SAV is considered complete based on establishment of musk grass throughout the cell. In July 2011, the southern portion of the cell was inoculated with southern naiad to diversify the SAV of the area. The most recent survey, as mentioned earlier, shows an indication of southern naiad establishment along with a widespread cover of musk grass. Cattail expansion in the conversion area was controlled as part of routine vegetation management in STA-2.

During the water year, one of the pumps at the S-6 pump station underwent emergency repairs on November 21, 2011, limiting the structure's pumping capacity. Gate 2 of G-339 was removed for overhaul repairs and stop gates were installed, halting flow through this structure from February 21 to March 29, 2012, when the gate was successfully replaced.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

Based on an annual imagery flight, area coverage of EAV and SAV+open area is estimated for each STA. Imagery for CY2011 (conducted in May 2011) and comparison with the previous year (conducted in April 2010) is included in this report (**Table 5-8**; Appendix 5-5). For STA-2, data shows that there is little change in terms of vegetation coverage in Cells 1-3, while Cell 4 had 36 percent increase in EAV coverage as a consequence of the dry condition in the cell due to Compartment B construction (**Table 5-8**). Field observations in Cells 1 and 2 indicate healthy, dense cattail stands and sparse areas of sawgrass.

Table 5-8. Summary of vegetation coverage in STA-2 based on May 2011 aerial imagery. Numbers shown are expressed as percentage of total cell area.

	Cover Category		
Area	% EAV	% SAV+ Open Area	% Change in EAV Cover from 2010 to 2011
Cell 1	97	3	0
Cell 2	65	35	3
Cell 3	31	69	3
Cell 4	48	52	36

Ground Survey for Submerged Aquatic Vegetation

At the vegetation conversion area in the southern portion of Cell 2 (i.e., converted from cattail to SAV) survey data shows a good coverage of musk grass. On June 1, 2011 (post-drought assessment), and July 8 and 12, 2011, SAV surveys were performed in the southern and northern SAV regions of this cell, respectively. Within the northern region, a mixture of hydrilla and hornwort was the dominant SAV (**Figures 5-21** and **5-22**). Pond weed and southern naiad were present, but at much lower density within this region. The conversion area in the southern region of the cell was dominated by musk grass with some southern naiad present. Medium density and good coverage of bladderwort (*Utricularia* sp.) was also observed in the June 2011 survey.

SAV surveys performed in Cell 3 on August 5, 2011 and February 29, 2012, indicate stable vegetation coverage during the water year (**Figure 5-23**). A mixture of southern naiad, hornwort, and hydrilla was observed in the inflow region of the cell, while the middle to outflow region was dominated by musk grass, with some pond weed and southern naiad.

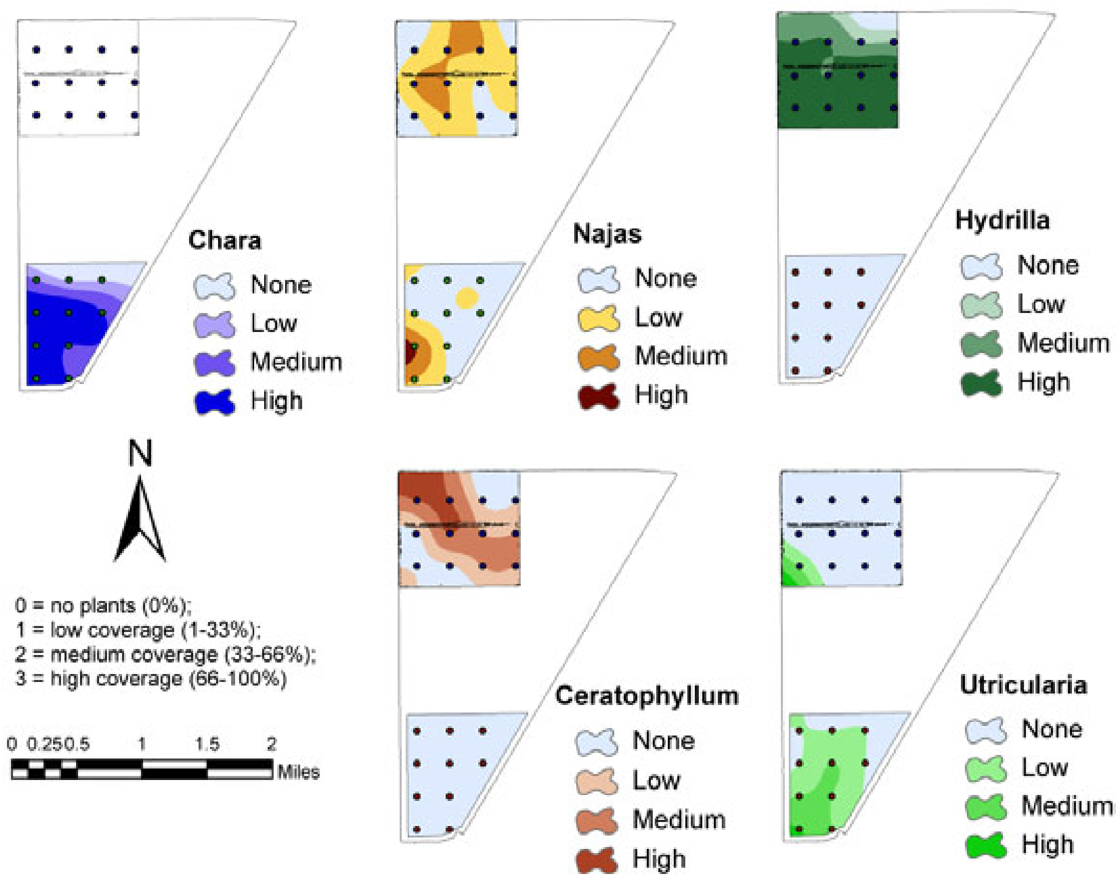


Figure 5-21. Post-drought SAV survey in STA-2 Cell 2; plots depict the spatial distribution and relative density of *Chara*, *Najas*, *Hydrilla*, *Ceratophyllum*, and bladderwort (*Utricularia* sp.) in STA-2 Cell 2 on June 1, 2011.

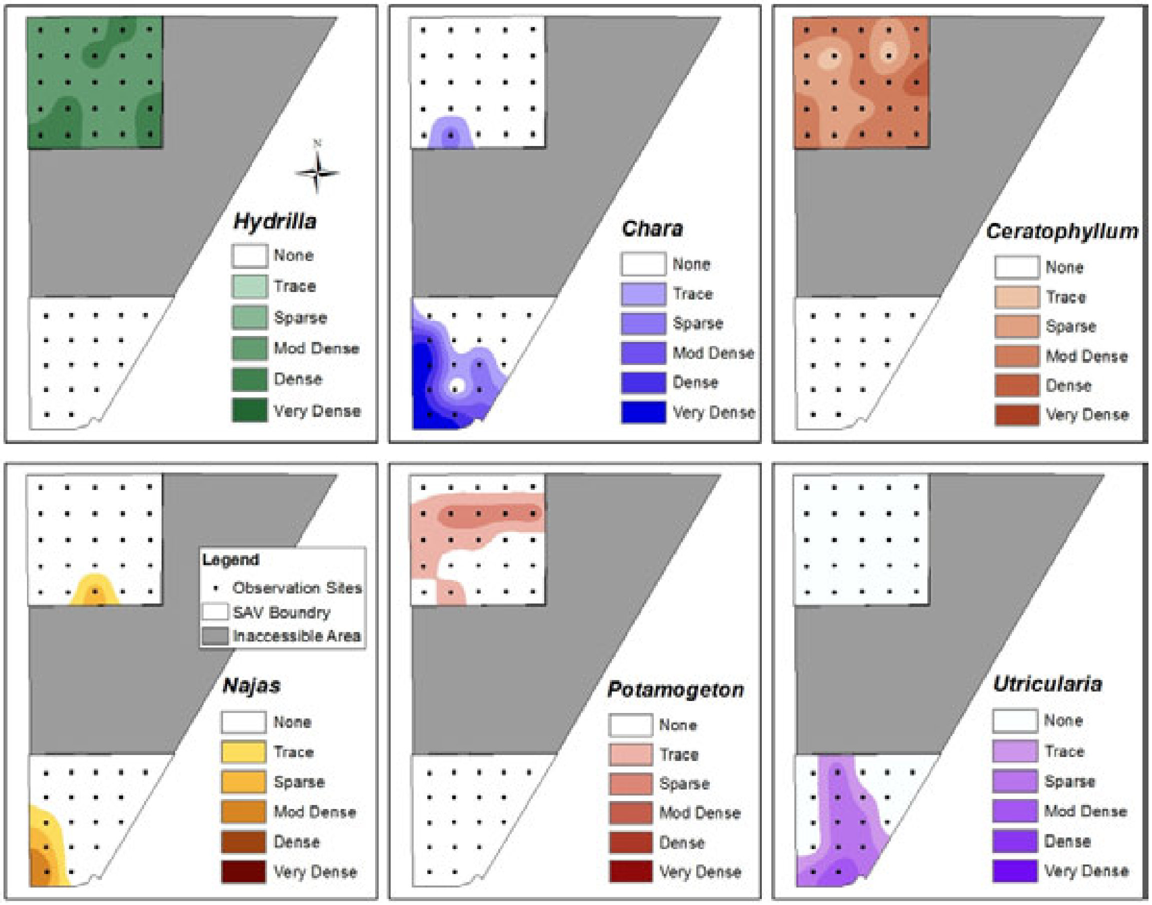


Figure 5-22. Vegetation survey results depicting the spatial distribution and relative density of hydrilla (*Hydrilla verticillata*), musk grass (*Chara* sp.), hornwort (*Ceratophyllum demersum*), southern naiad (*Najas guadalupensis*), pond weed (*Potamogeton* sp.), and hornwort (*Ceratophyllum demersum*) in STA-2 Cell 2 on July 8 and 12, 2011.

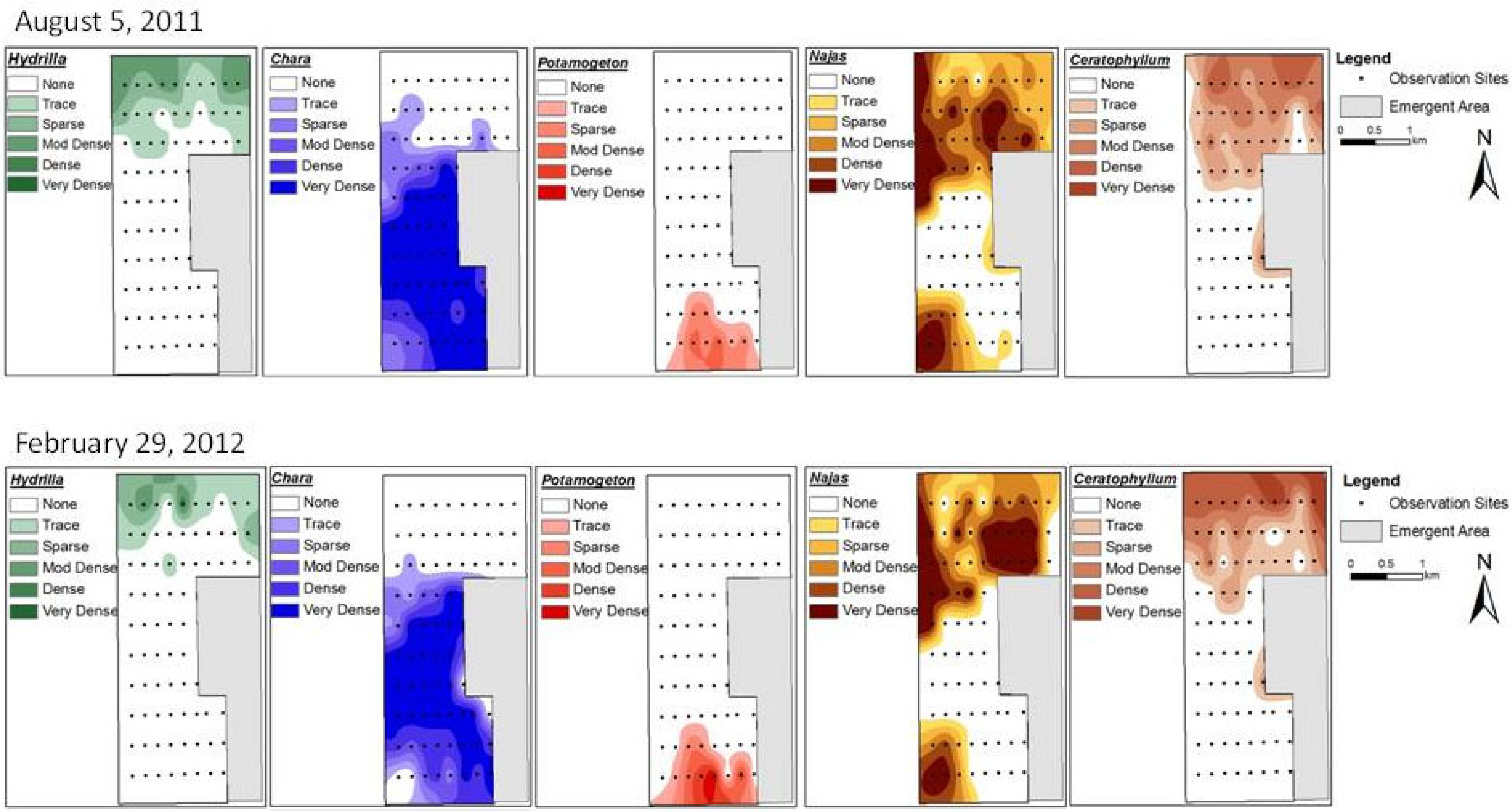


Figure 5-23. Vegetation survey results depicting the spatial coverage of *Hydrilla*, *Chara, Najas, Potamogeton,* and *Ceratophyllum* in STA-2 Cell 3 on August 5, 2011, and February 29, 2012.

STA-3/4

Stormwater Treatment Area 3/4 (STA-3/4) is located northeast of the Holey Land Wildlife Management Area and north of Water Conservation Area 3A (WCA-3A) (**Figure 5-1**). It provides a total treatment area of 16,535 acres to treat stormwater runoff originating within the S-2/7, S-3/8, S-236, and C-139 basins and Lake Okeechobee (SFWMD, 2007). During dry months, supplemental water is also delivered from Lake Okeechobee to maintain hydration on priority cells. STA-3/4 is comprised of three flow-ways: the Eastern Flow-way (Cells 1A and 1B), Central Flow-way (Cells 2A and 2B), and Western Flow-way (Cells 3A and 3B) (**Figure 5-24**; Appendix 5-1). A 445-acre section of Cell 2B is the site of the STA-3/4 PSTA Project, aimed at testing and evaluating PSTA technology.

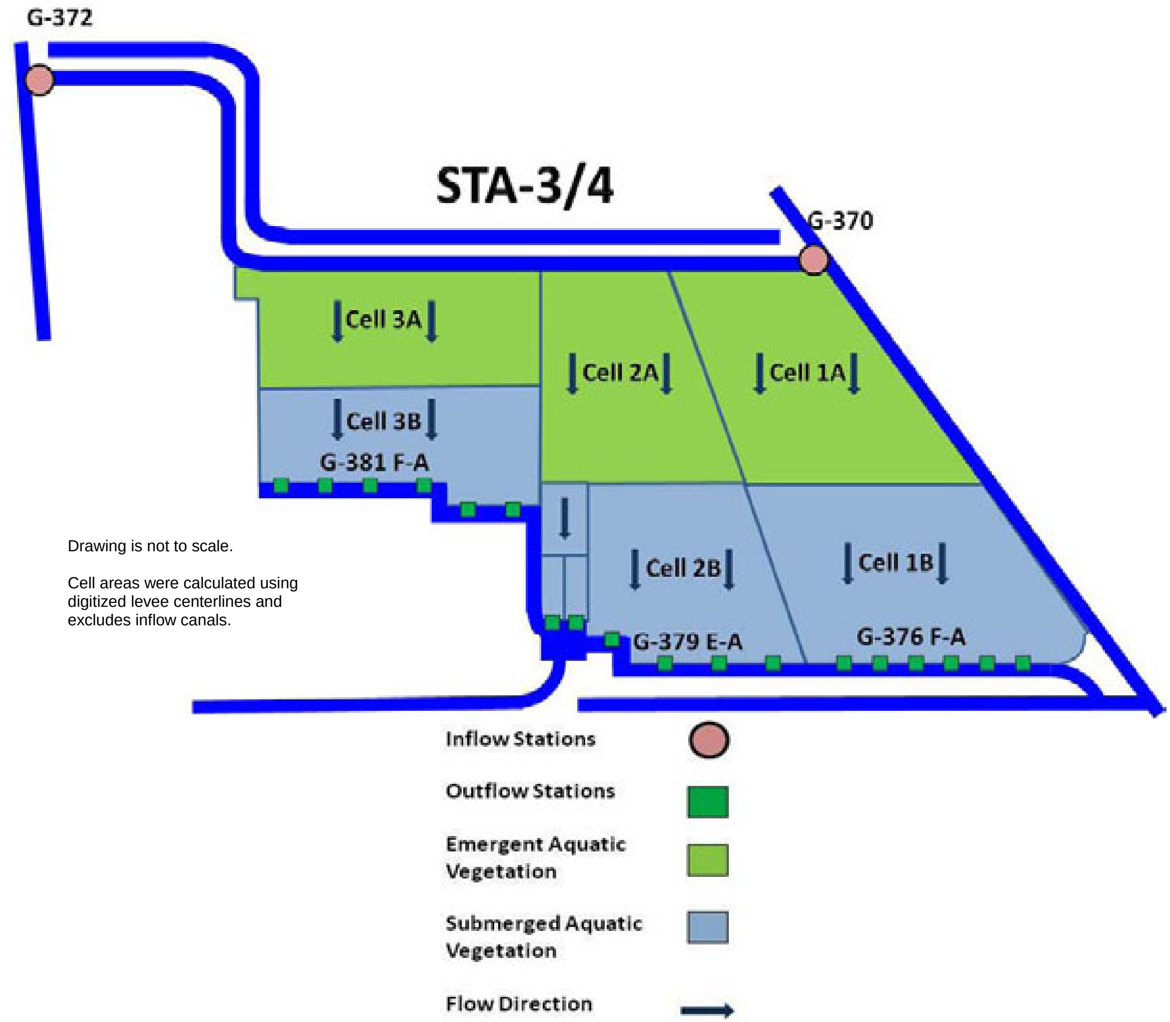
Since operations started in October 2003, STA-3/4 has treated approximately 3.7 million ac-ft of runoff water, retaining over 440 mt of TP, and reducing TP concentration from 114 to 18 ppb (**Table 5-1**; **Figure 5-2**). Similar to the other STAs, STA-3/4 has been impacted by extreme weather events (regional drought and storm events) and high hydraulic loadings during the wet season. The WY2011 drought season resulted in dryout in all cells in STA-3/4 in June 2011. The impacts and other effects of the dry condition are discussed in the *Drought Impacts* section.

Another issue for this STA is relatively high water depths for extended periods in the EAV cells during and following storm events. As a consequence of persistent deep water conditions in Cells 1A and 2A, cattail communities have been negatively impacted, particularly in the northern portion of the cells. A detailed discussion of operational adjustments made in this STA in July–August 2011 is included under the *Facility Status and Operational Issues* section. Also, a report on preliminary evaluation of the effects of Cell 1A drawdown in WY2011 and WY2012 is included in the *Applied Scientific Studies* section of this chapter.

STA PERFORMANCE

Considering the dryout that occurred in the entire STA in the early part of the water year and the subsequent high flows in the later part of June through early July 2011, STA-3/4 had good performance in WY2012. This STA treated almost 270,000 ac-ft of runoff water, retained approximately 30 mt of TP, and reduced TP concentration from 109 ppb (inflow FWM) to 19 ppb (outflow FWM) (**Table 5-1**; **Figure 5-2**). These values are comparable to the POR inflow and outflow values for this STA. The WY2012 outflow concentration is 2 ppb higher than what was reported in WY2011 and is likely a result of the TP spike after dryout and subsequent rehydration, the disturbance in the soil substrate resulting from high flows following the dryout period, and the loss of vegetation. The calculated HLR and PLR are 1.36 cm/d and 0.54 $g/m^2/yr$, respectively. The impacts of dryout and subsequent rehydration, which involved high hydraulic loading and disruption of the underlying peat substrate, resulted in TP spikes from late June to July 2011. Consequently, the 12-month average increased significantly between WY2011 and through the end of WY2012 (**Figure 5-25**).

Of the three flow-ways, the Western Flow-way treated the highest volume of inflow (123,600 ac-ft) (**Table 5-9**). The HLR and PLR observed in WY2012 for each of the flow-ways were comparable to WY2011. While the Western Flow-way had the highest HLR of the three, the resulting outflow TP concentration (15 ppb FWM) is much lower than outflow TP concentrations in either the Eastern or the Central flow-ways (20 and 21 ppb FWM, respectively). This trend is consistent to the values observed in WY2011. In terms of TP load reduction, the flow-ways had consistently less reduction in WY2012 than in WY2011, primarily due to the impacts of SAV loss during the dryout period and also from internal loading upon rehydration.



Cell	Cell Area (acres)
1A	3,052
1B	3,504
2A	2,533
2B	2,888 (includes PSTA Project cells)
3A	2,444
3B	2,114
Total	16,535

Figure 5-24. Simplified schematic of STA-3/4 showing major inflow and outflow structures, flow directions, and dominant/target vegetation types. (Note: A more detailed schematic is included in Appendix 5-1.)

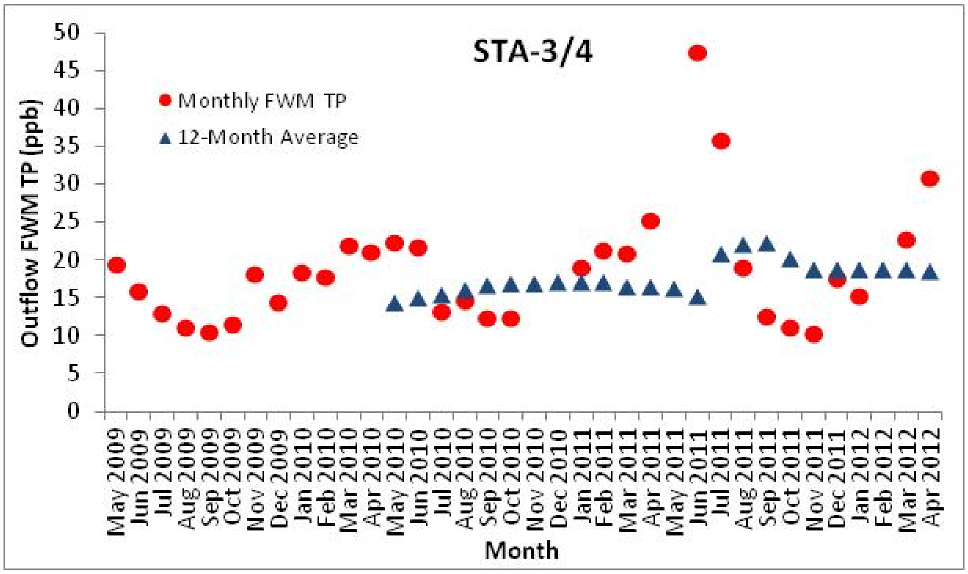


Figure 5-25. Monthly flow-weighted mean TP concentration and preceding 12-month average TP concentration in STA-3/4.

Table 5-9. Comparison of flow-way performance in STA-3/4 between WY2011 and WY2012.

Flow-way/ Water Year	Area (acres)	PLR (g/m^2/yr)	HLR (cm/day)	Inflow Volume (ac-ft)	Inflow FWM TP (ppb)	Outflow FWM TP (ppb)	TP Retained (mt)	TP Retained (%)
Eastern Flow-way	6527							
WY2011		0.4	1.2	93,579	84	16	7.7	79
WY2012		0.2	1.0	80,369	60	20	3.8	62
Central Flow-way	5436							
WY2011		0.3	1.5	97,230	52	21	3.9	61
WY2012		0.3	1.4	93,373	49	21	3.2	55
Western Flow-way	4580							
WY2011		0.4	2.1	112,832	51	14	5.2	72
WY2012		0.3	2.3	123,600	35	15	3.1	57

FACILITY STATUS AND OPERATIONAL ISSUES

Water level drawdown in Cell 1A, which was initiated in the later part of WY2011 to encourage cattail reestablishment, continued in WY2012. The Eastern Flow-way was online with restrictions due to vegetation enhancement activities in Cell 1A from May 1–August 23, 2011 (**Table 5-2**). The Western and Central flow-ways were fully operational during most of the water year; however flow and stage restrictions were implemented from July 5 to August 23, 2011, to allow for vegetation reestablishment following an extended dryout period where much of the SAV was lost in all the SAV cells.

Drought Impacts

Following the driest period of record for South Florida during the period from October 2010 to June 2011 and late start of the wet season, water levels in STA-3/4 cells receded gradually and by June 2011, all cells dried out despite providing supplemental water from Lake Okeechobee

(**Figures 5-26** and **5-27**). Consequently, SAV was lost in all cells. At the onset of the wet season in late June, water stages rose rapidly in STA-3/4, causing the previously desiccated soil layer to rise to the top of the water column, an increase in turbidity, and spikes in outflow TP concentration (78 ppb during the first week after rehydration). Deep water conditions threatened the recovery of cattail, particularly the new growth in the EAV cells, and inhibited the recovery of SAV. To minimize impacts to vegetation and applying the provisions under the Everglades Forever Act Specific Condition 23, a 28-day partial diversion of runoff through G-371 and G-373 occurred July 2–July 29, 2011. Approximately 55,000 ac-ft was diverted, equating to approximately 5.9 metric tons of TP. During the diversion period, EAV and SAV was allowed to acclimate to increasing depths and by August 30, when field observations indicate that vegetation has began to recover, STA operations were returned to normal.

While complete dryout is not desired for the STAs, primarily due to negative impacts on SAV vegetation and the resulting TP spike upon rehydration, field surveys indicate positive benefits in terms of cattail regrowth. Thick establishment of cattail seedlings were observed throughout Cells 1A and 2A upon cell rehydration. A more detailed discussion on the benefits of dry conditions on cattail reestablishment is included in the *Applied Scientific Studies* of this chapter. Contingency drought strategies and weekly monitoring of water stages were implemented to avoid recurrence of dryout that was experienced in the beginning of WY2012. Target stages were raised by 6 inches and approximately 17,860 ac-ft of supplemental water was delivered from Lake Okeechobee during WY2012.

Impacts of Migratory Bird Nesting

Due to the receding water level in STA-3/4 during the early part of WY2012, a large number of black-necked stilt nests (142 nests) was observed via a levee survey from May to June 2011 (Appendix 5-4). Most of these nests (95 nests) were found in the PSTA, specifically at the upper and lower SAV cells. There were also nests found in the Eastern Flow-way, Cell 2B, and Cell 3B during this period. Due to lack of flows to the STA during this survey period, there was little to no impact on STA operation. By the start of the wet season in early July, nesting season was over. No nests were observed in April 2012 in STA-3/4.

STA-3/4 Periphyton Stormwater Treatment Area

The PSTA project in STA-3/4 was constructed to investigate the performance of a periphyton-dominated treatment system. The project comprises 400 acres of STA-3/4 within Cell 2B that is divided into one 200-acre upper SAV cell and two adjacent parallel downstream 100-acre cells (lower SAV and PSTA cells). All cells have been managed to promote an SAV community and associated periphyton assemblage. In WY2012, the PSTA cell annual inflow FWM TP concentration was 17 ppb while the annual outflow FWM TP concentration was 12 ppb, which was within the 8–12 ppb range achieved over its period of operation. Further details concerning the STA-3/4 PSTA project are included in the *Applied Scientific Studies* section of this chapter.

MAINTENANCE AND ENHANCEMENTS

As mentioned previously, the water level in Cell 1A was drawn down in an effort to revitalize the cattail stand by providing conditions conducive for vegetative expansion, enable planting of bulrush, and for colonization of new seedlings. The drawdown occurred between March 1 and June 1, 2011, using two temporary pumps. Due to a regional drought, the water level in this cell and the rest of STA-3/4 receded naturally, and the temporary pumps were removed by May 2011. During the drawdown and in April 2012, bulrush was also planted in some of the open areas. A more detailed evaluation of the success of drawdown on cattail reestablishment is included in the *Applied Scientific Studies* section of this chapter.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

Based on an annual imagery flight, coverage of EAV and SAV+open area was estimated for each STA. Imagery for CY2011 (conducted in May 2011) is presented in this chapter; a comparison with the previous year (conducted in April 2010) is also included (**Table 5-10**; Appendix 5-5). The biggest changes in vegetation coverage were in Cells 1A and 1B. Cell 1A, which was intentionally drawn down for vegetation rehabilitation purposes, had a 13 percent increase in EAV coverage at the time of 2011 aerial imagery (May 2011). Field observations during this period and six months later confirm large areas with new cattail growth and successful germination of cattail seeds particularly in areas that were previously devoid of vegetation (**Figure 5-28**).

Ground Survey for Submerged Aquatic Vegetation

SAV surveys in Cells 1B, 2B, and 3B were performed immediately following the reflooding of the cell to assess the impacts of dryout and begin monitoring SAV reestablishment. Results were compared with pre-dryout information. As a large portion of Cell 1B was inaccessible by airboat due to low water levels and very dense cattail stands, the surveys could not be performed in those areas (**Figure 5-29**). In September 2010, the dominant SAV species in this cell were primarily *Chara* and *Najas*. Following the drydown (July 7, 2011), these SAV species were still present but at much lower densities. During the two subsequent surveys, an increase in both *Chara* and *Najas* were observed. In August 2010, *Chara* dominated Cell 3B with just a small amount of *Najas* observed (**Figure 5-30**). Upon rehydration, following the dryout period (7/7/11), a reduction in the density of *Chara* was observed; however, during the two subsequent surveys, *Chara* appeared to be quickly reestablishing to pre-drydown densities within this cell.

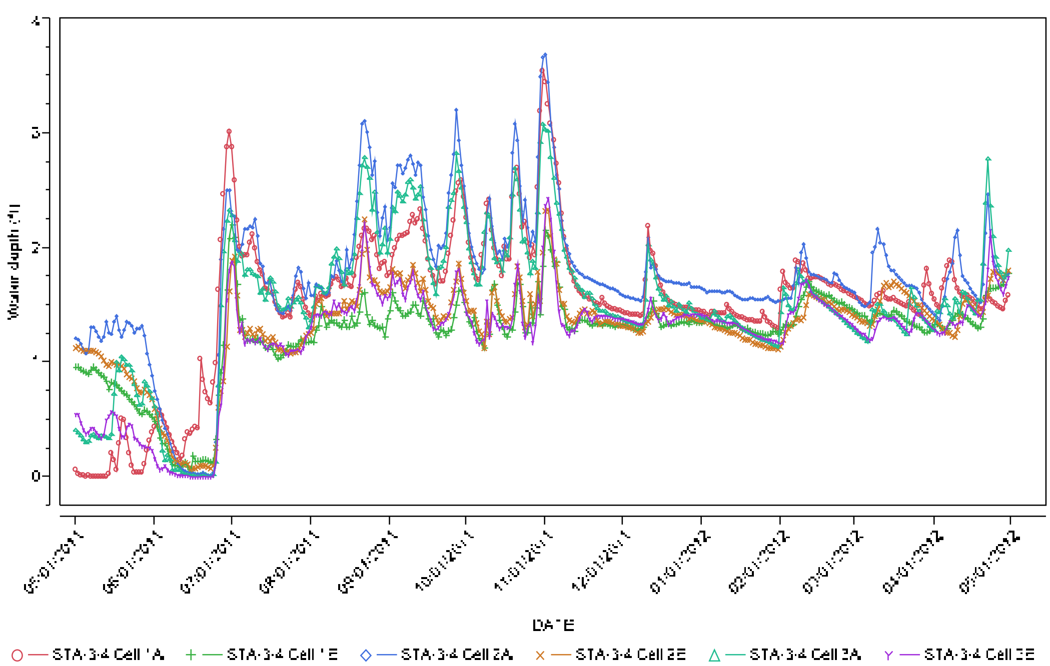


Figure 5-26. Daily average water depths by cell in STA-3/4 during WY2012.

Figure 5-27. Dried out cells in STA-3/4 as a result of a regional drought, high evapotranspiration rates, seepage losses, and delayed wet season; aerial photos taken by SFWMD on June 16, 2012.

Table 5-10. Summary of vegetation coverage in STA-3/4, based on May 2011 aerial imagery. Numbers shown are expressed as percentage of total cell area.

	Cover Category		
Area	% EAV	% SAV+ Open Area	% Change in EAV Cover from 2010 to 2011
Cell 1A	79	21	13
Cell 1B	48	52	-11
Cell 2A	80	20	3
Cell 2B	25	75	-1
Cell 3A	95	5	0
Cell 3B	32	68	-2

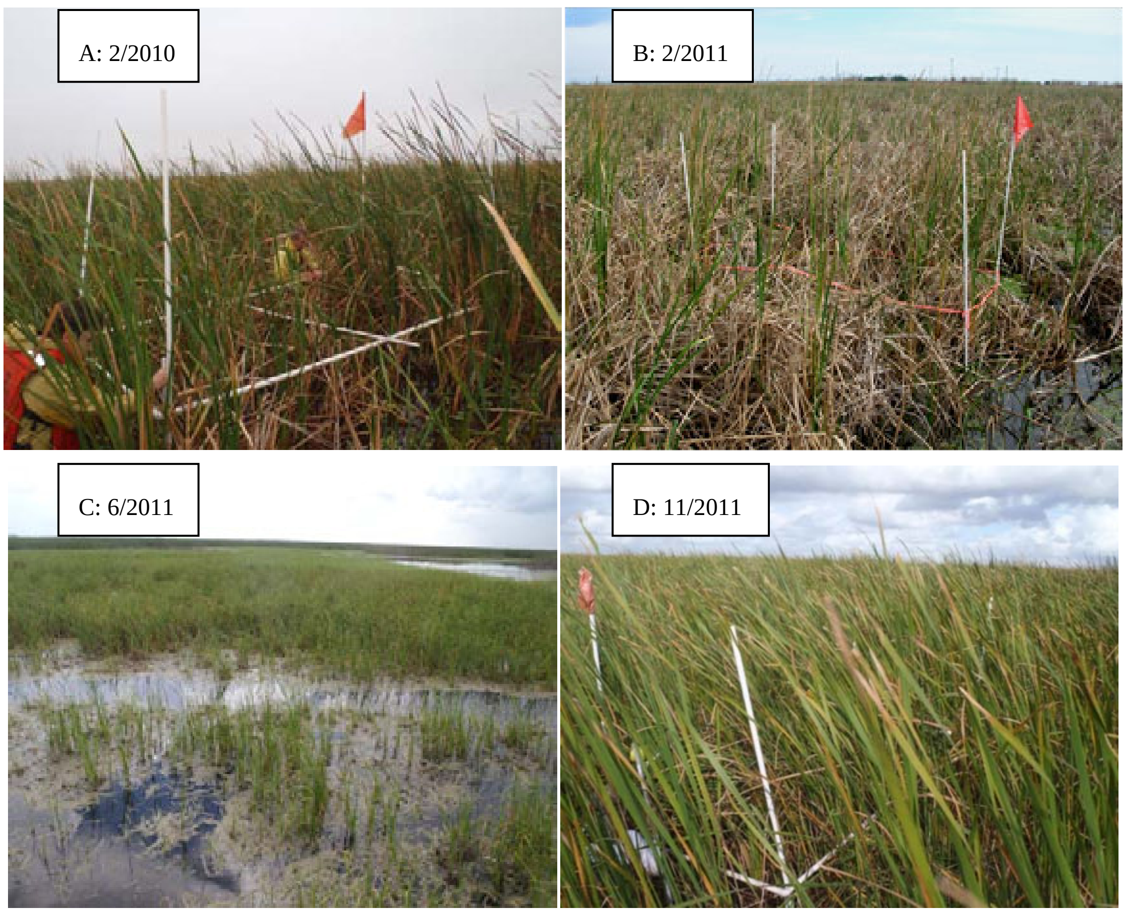


Figure 5-28. Cattail vegetation in STA-3/4 Cell 1A in February 2010 (A), February 2011 (B, pre-2011 drawdown), June 2011 (C, post-drawdown), and November 2011 (D, six months after rehydration) (photos by the SFWMD).

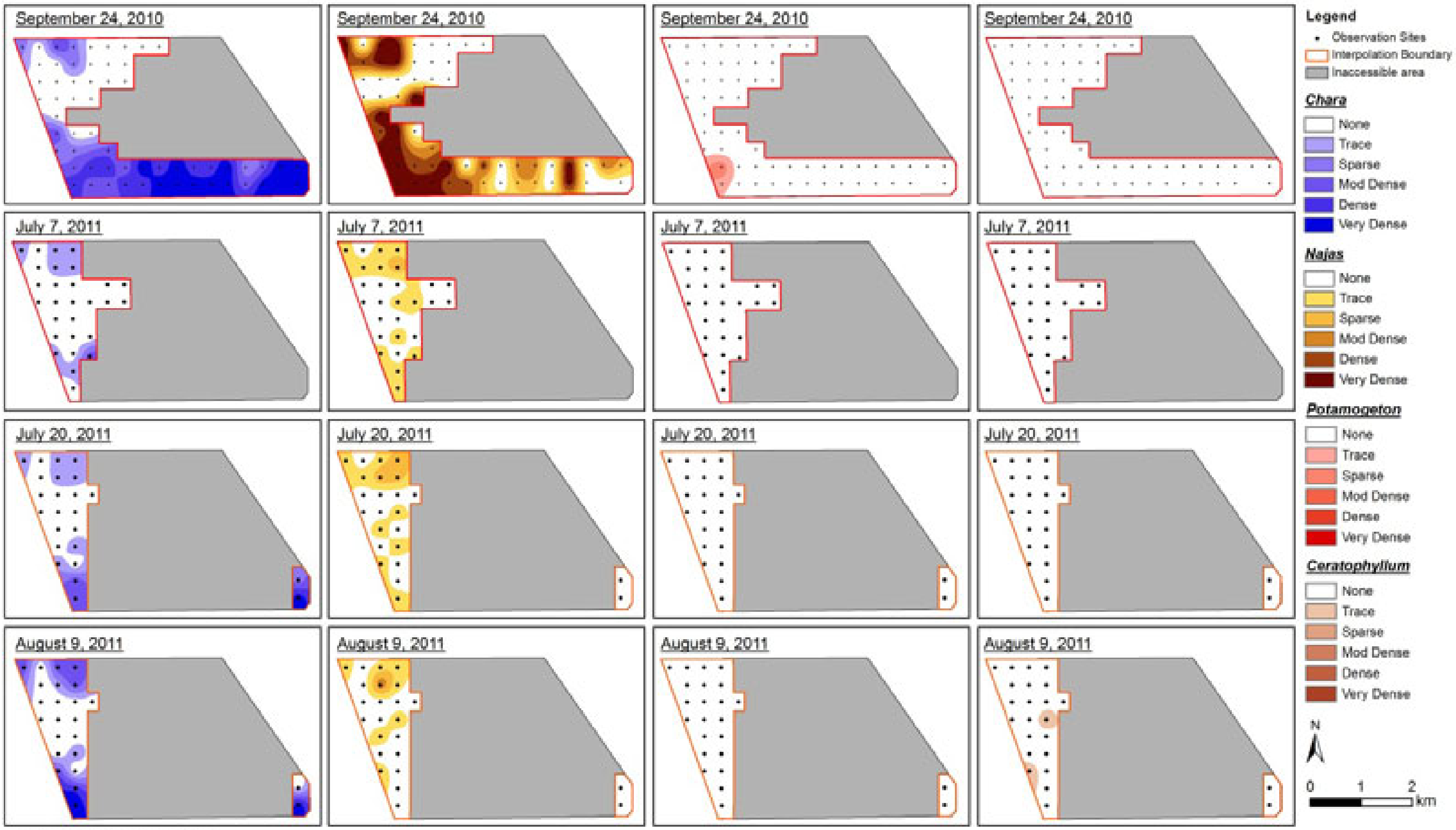


Figure 5-29. Vegetation survey results depicting the spatial distribution and relative density of *Chara, Najas, Potamogeton*, and *Ceratophyllum* in STA-3/4 Cell 1B on September 24, 2010, and July 7, July 20, and August 9, 2011.

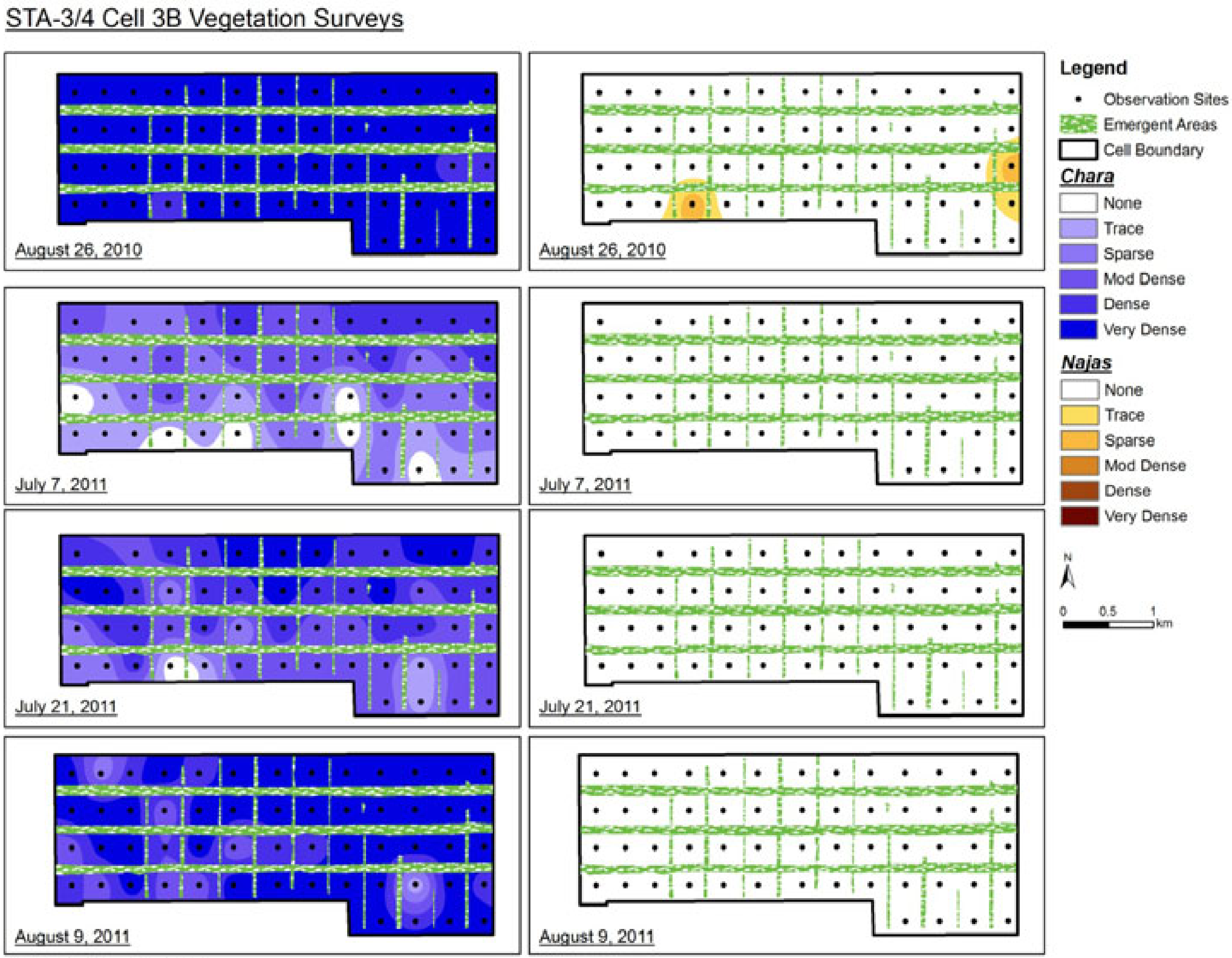


Figure 5-30. Vegetation survey results depicting the spatial coverage and relative density of *Chara* and *Najas* in STA-3/4 Cell 3B on August 26, 2010, and July 7, July 21, and August 9, 2011.

STA-5/6

The original STA-5, which began operation in WY2000, consisted of the Northern (Cells 1A and 1B; now referred to as Flow-way 1) and Central (Cells 2A and 2B; now referred to as Flow-way 2) flow-ways, totaling 4,110 acres of effective treatment area. In 2006, a third flow-way (Cells 3A and 3B; Flow-way 3) was added, with approximately 1,985 acres of treatment area (Gary Goforth, Inc., 2008). The lack of sufficient inflows due to the regional drought has delayed vegetation grow-in and flow-through in Flow-way 3.

The original STA-6 consisted of 870 acres of effective treatment area (Cells 3 and 5; Flow-ways 7 and 8, respectively) and began operation in 1997. STA-6 was expanded by 1,387 acres in 2006 with the addition of Section 2 (now referred to as Cell 6-2 and Flow-way 6), yielding a total of approximately 2,257 acres of effective treatment area for STA-6.

The former STA-5 and STA-6 are now referred to as STA-5/6, following the completion of Compartment C construction in mid-2012 (**Figure 5-31**). However, the Compartment C build-out will not be operational until operations permits for this expanded area are issued by the Florida Department of Environmental Protection (FDEP) and the new flow-ways have passed the permit start-up performance criteria. Future reporting will refer to these two STAs as one system. For reference, the former and new flow-way nomenclatures are as follows:

- Flow-way 1 (formerly STA-5 Northern Flow-way: Cells 1A and 1B)
- Flow-way 2 (formerly STA-5 Central Flow-way: Cells 2A and 2B)
- Flow-way 3 (formerly STA-5 Southern Flow-way: Cells 3A and 3B)
- Flow-way 4 (new Compartment C Flow-way: Cells 4A and 4B)
- Flow-way 5 (new Compartment C Flow-way: Cells 5A and 5B)
- Flow-way 6 (includes new Compartment C Cell 4 and former STA-6 Section 2, which is now known as Cell 6-2)
- Flow-way 7 (formerly STA-6 Cell 5)
- Flow-way 8 (formerly STA-6 Cell 3)

Since October 1999 (WY2000), STA-5 has treated over approximately 1.2 million ac-ft of water and retained approximately 212 mt of TP. STA-6 has treated 687,681 ac-ft of water and retained approximately 66 mt of TP. The POR inflow FWM TP for STA-5 (225 ppb) is the highest among all STAs and more than twice as much as the POR inflow TP FWM concentration in STA-6 (100 ppb). The POR outflow concentration in STA-5 is 93 ppb, also the highest among all STAs, while STA-6 has produced a POR outflow FWM TP concentration of 34 ppb (**Table 5-1**).

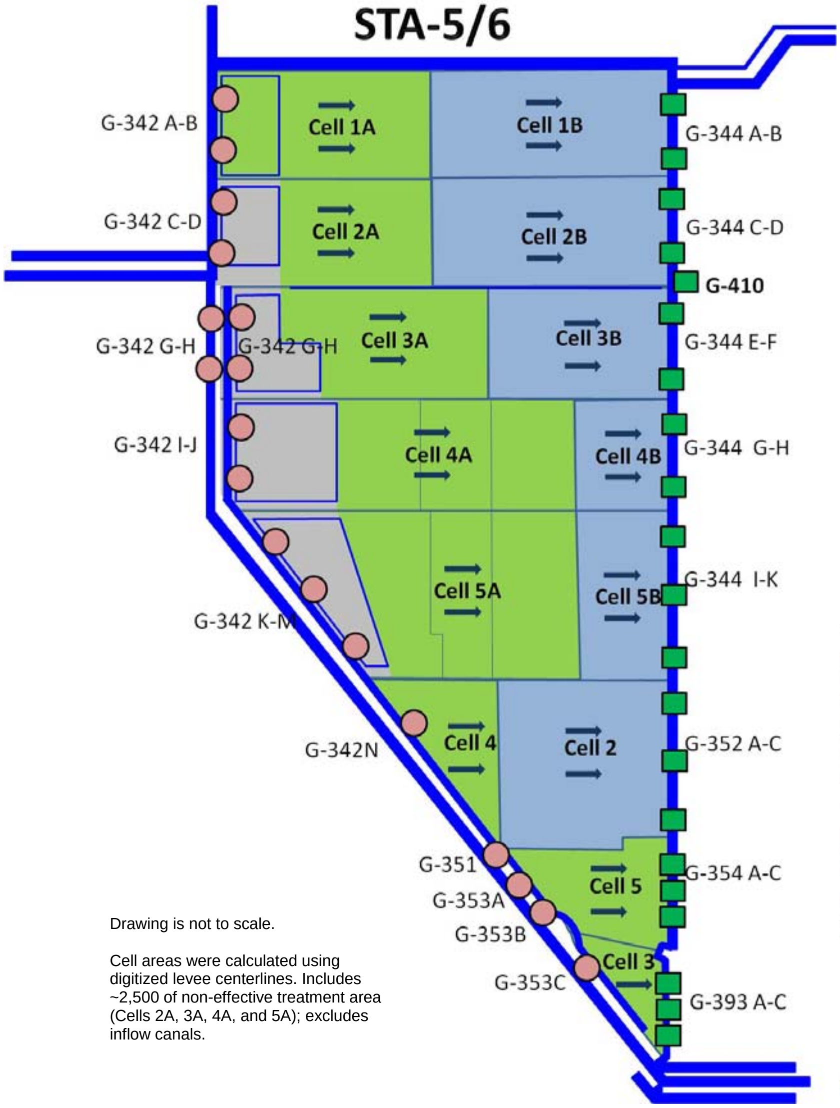
Over its period of operation, STA-5/6 has been impacted by high inflow concentrations and extreme weather events (regional drought and storm events). Almost every year during the dry season, dryout occurs in the EAV cells of these STAs. High TP flux follows rehydration of these cells, usually resulting in temporary spikes in outflow TP concentration. In WY2012, drought contingency strategies, including delivery of supplemental water from Lake Okeechobee, prevented or minimized the impacts of drought in Flow-ways 1 and 2 SAV cells. A discussion of recent enhancements in STA-5/6 is in the *Maintenance and Enhancement* section.

STA PERFORMANCE

In WY2012, STA-5 and STA-6 treated 47,508 and 17,055 ac-ft and retained approximately 7.5 (82 percent of inflow load) and approximately 1.8 mt (68 percent of inflow load) TP, respectively (**Table 5-1**). These STAs, particularly STA-5, continued to receive higher inflow concentrations than the other STAs; inflow TP annual FWM concentration was 156 ppb and 125 for STA-5 and STA-6, respectively. The 12-month average for STA-5 shows a significantly improving trend in outflow TP concentration (**Figure 5-32**); outflow concentration in WY2012 was 32 ppb, which has been the lowest achieved over its period of operation. This can be attributed to the combined effects of effective operation, recent enhancements (including Cell 1A rehabilitation, enhancement of vegetation strips in the SAV cells, and improved vegetation establishment), and reduced HLR and PLR. As mentioned earlier, the ability to maintain hydration in the SAV cells of Flow-ways 1 and 2 (Cells 1B and 2B) during dry months and delaying discharge upon rehydration help control outflow TP levels. The modification of the former non-effective treatment area in Flow-way 1 is also likely contributing to the performance observed in that flow-way.

In STA-6, the 12-month average plot shows an increase in WY2012, primarily due to a TP spike of more than 300 ppb that occurred upon resumption of flow in this STA in July 2011 (**Figure 5-33**). Due to the high amount of P flux upon resumption of flow, the resulting outflow concentration from STA-6 in WY2012 was 75 ppb. The STA has received little to no flow from October 2011 through the end of WY2012. Consequently, the 12-month average slowly decreased toward the end of the water year.

Flow-ways 1 and 2 yielded lower outflow TP concentration in WY2012 than in WY2011, and these values are also much lower than WY2012 outflow concentrations in STA-6 Cells 3 and 5 (**Table 5-11**). This indicates a positive trend in the performance of STA-5 Flow-ways 1 and 2, likely a result of lower loading rates and improved conditions in these areas. The PLR for STA-5 Flow-ways 1 and 2 and STA-6 Cells 3 and 5 were comparable (0.6–0.7 $g/m^2/yr$), and the HLRs were comparable among Flow-way 1 and STA-6 Cells 3 and 5 (1.5–1.8 cm/d), while STA-5 Flow-way 2 had a lower HLR (1.0 cm/d).



Cell	Cell Area (acres)
5-1A	1,211
5-1B	1,239
5-2A	1,214
5-2B	1,250
5-3A	1,517
5-3B	938
5-4A	2,034
5-4B	478
5-5A	2,515
5-5B	718
6-4	550
6-2	1,389
6-5	639
6-3	252
Total	15,944

Figure 5-31. Simplified schematic of STA-5/6 showing major inflow and outflow structures, flow directions, and dominant/target vegetation types. (Note: A more detailed schematic is included in Appendix 5-1.)

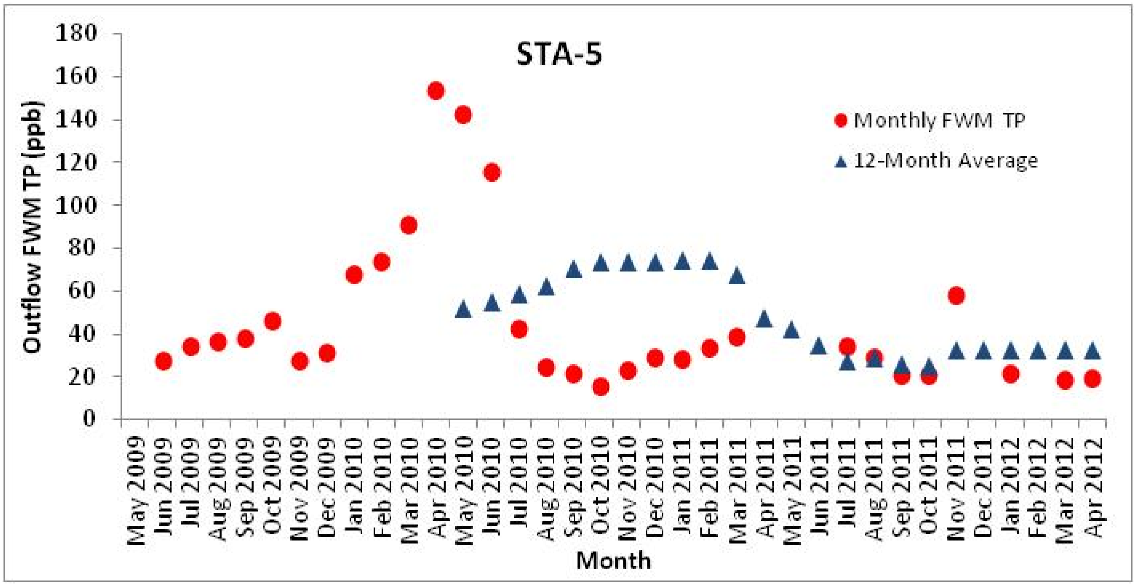


Figure 5-32. Monthly flow-weighted mean TP concentrations and preceding 12-month average TP concentrations in STA-5.

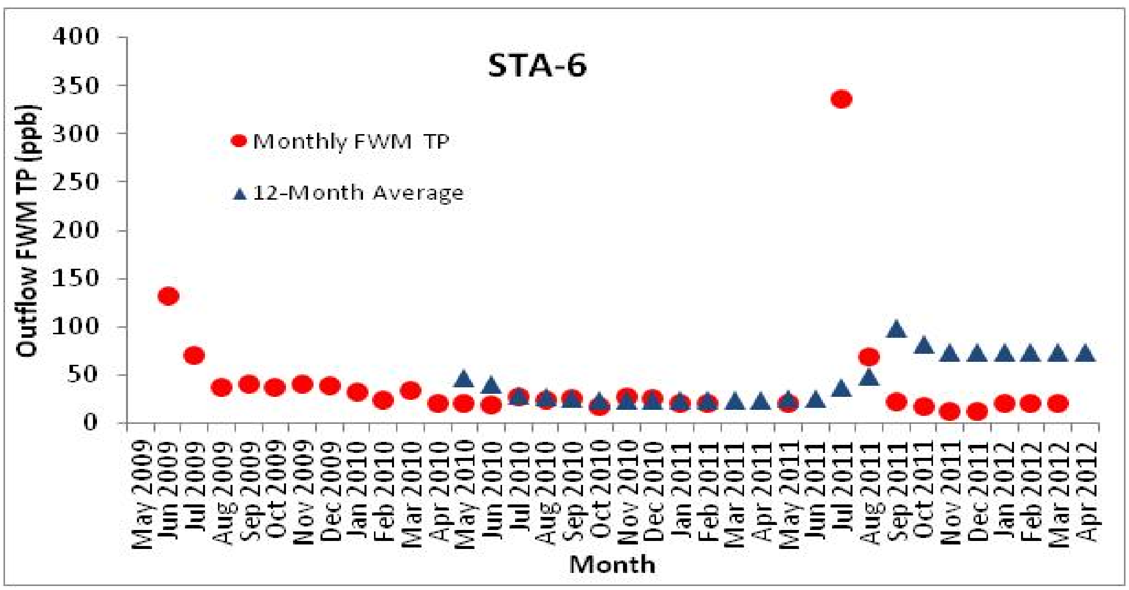


Figure 5-33. Monthly flow-weighted mean TP concentrations and preceding 12-month average TP concentrations in STA-6.

Table 5-11. Comparison of flow-way performance in STA-5/6 between WY2011 and WY2012.

Flow-way/ Water Year	Area (acres)	PLR ($g/m^2/yr$)	HLR (cm/day)	Inflow Volume (ac-ft)	Inflow FWM TP (ppb)	Outflow FWM TP (ppb)	TP Retained (mt)	TP Retained (%)
Flow-way 1	2055							
WY2011		0.4	1.4	33,423	84	41	2.6	75
WY2012		0.6	1.5	36,393	106	36	3.8	79
Flow-way 2	2055							
WY2011		0.2	0.4	9,379	149	54	1.4	81
WY2012		0.6	1.0	24,515	165	28	4.3	86
Flow-way 7	625							
WY2011		0.5	1.3	9,941	97	17	1.0	81
WY2012		0.7	1.6	11,650	129	85	1.2	63
Flow-way 8	245							
WY2011		0.6	1.9	5,629	93	16	0.5	82
WY2012		0.7	1.8	5,251	112	53	0.6	80

PERMIT-RELATED PERFORMANCE ISSUES AND ACTION PLANS

In WY2012, STA-6 is the only STA that did not meet the interim effluent limit specified in the Everglades Forever Act (EFA) permit. Due to the regional drought and lack of an efficient way to bring supplemental water to STA-6, the operational cells in this STA (i.e., Cells 3 and 5) dried out during the drought period of October 2010 to July 2011, and again from December 2011 to the end of WY2012. Consequently, extremely high TP values (greater than 300 ppb at initiation of flow) were observed upon resumption of flow in July 2012, as a result of P flux from the oxidized soil. The 12-month moving average TP concentration shows that the trend was slowly decreasing toward the end of the water year; however, TP spikes are anticipated again upon rehydration. Interim measures includes a gradual hydration of the cell, with no flow-through (no discharge), until there are indications of stabilization of TP levels within the cell. Once Compartment C is operational, it is anticipated that flow can be distributed more evenly among the eight flow-ways that now comprise the STA-5/6 flow path. The added capacity may help prevent discharging from a flow-way immediately after rehydration.

FACILITY STATUS AND OPERATIONAL ISSUES

All flow-ways in STA-5 were operational in WY2012 (**Table 5-2**). Cells 1A, 2A, 3A, and 3B dried out beginning in April 2012 and remained dry for the remainder of the water year as a result of drought (**Figure 5-36**). The North and Central flow-ways were fully operational during WY2012, despite the fact that some of the cells dried out during the dry season. Beginning on May 18, 2010, the south flow-way was offline because flow into the G-342E and G-342F structures stopped due to Compartment C construction. Cells 1A, 2A, and 3B dried out in December 2011 and remained dry for the remainder of the water year due to dry conditions in the basin. Restricted flow through the new G-520 and G-521 structures allowed some flow into Cell 3A in October 2011. Water was added to Cell 2B in June 2011 for SAV hydration. This hydration was facilitated using the existing G-350B structure and the newly constructed culvert, G-510, located at the southeast corner of Cell 2B.

In STA-6, Cells 3 and 5 were operational in WY2012 (**Table 5-2**); however both cells dried out during the dry season as a result of basin conditions (**Figure 5-34**). Section 2 has been offline since WY2010 for Compartment C construction. Construction began on April 11, 2012, to remove the redundant levee upstream of STA-6 Cell 5 (**Figure 5-35**). The fill from this removal will be used in Cell 5B of STA 5 for the environmentally sensitive area and for a new boat ramp on the L-3 canal. Because Cell 6-2 was offline the entire water year and STA-6 Cell 5 was offline for redundant levee removal, the adjusted effective treatment area acreage was reduced to reflect the acreage that was operational (**Table 5-1**).

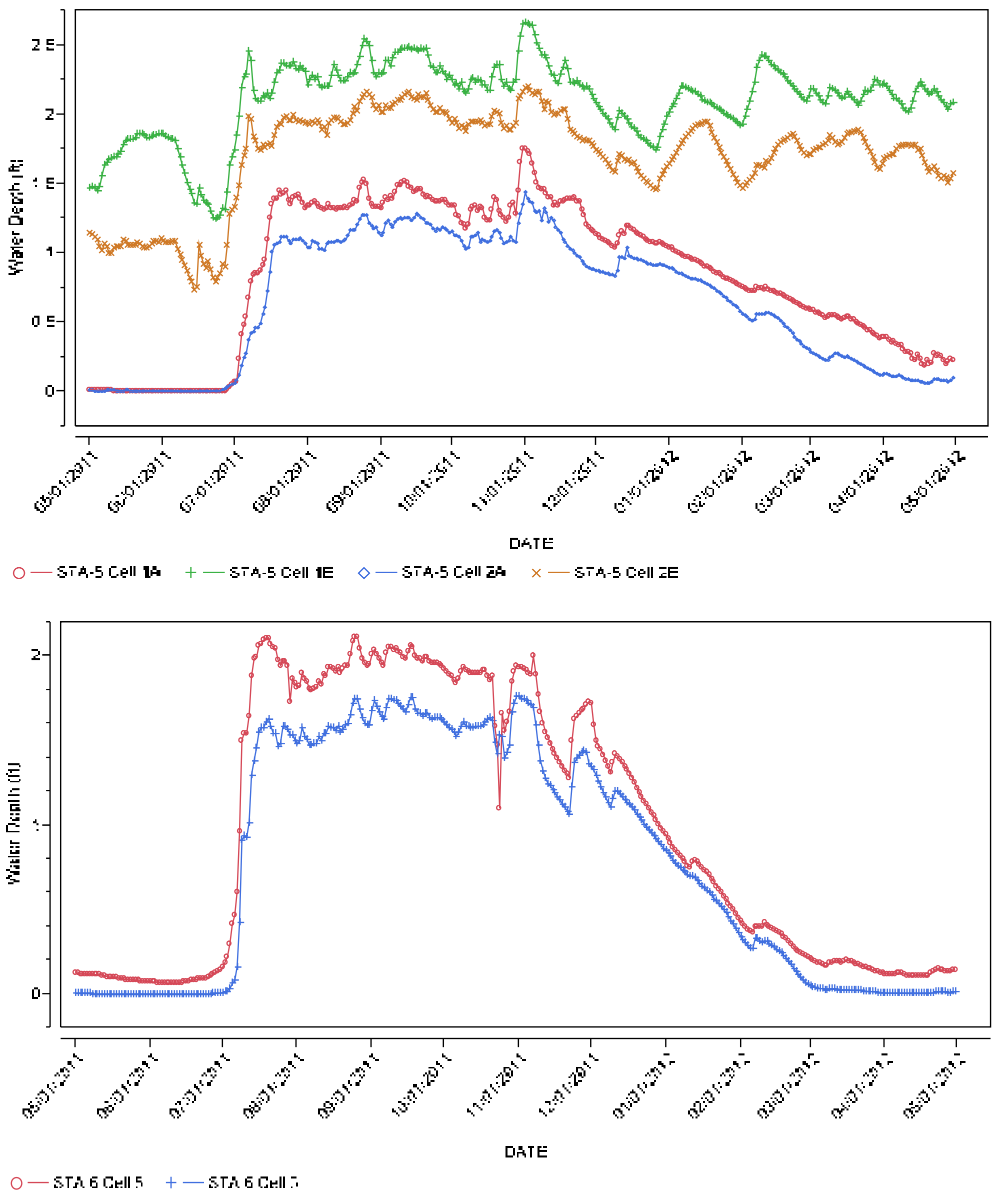


Figure 5-34. Daily average water depths in Cells 1A, 1B, 2A, and 2B of STA-5 (top), and Cells 3 and 5 of STA-6 (bottom) during WY2012.

Figure 5-35. A portion of a redundant levee in STA-6 between the G-601 and G-602 structures (top photo); approximately 2,800 linear feet of levee was removed (bottom photo) (photos by the SFWMD).

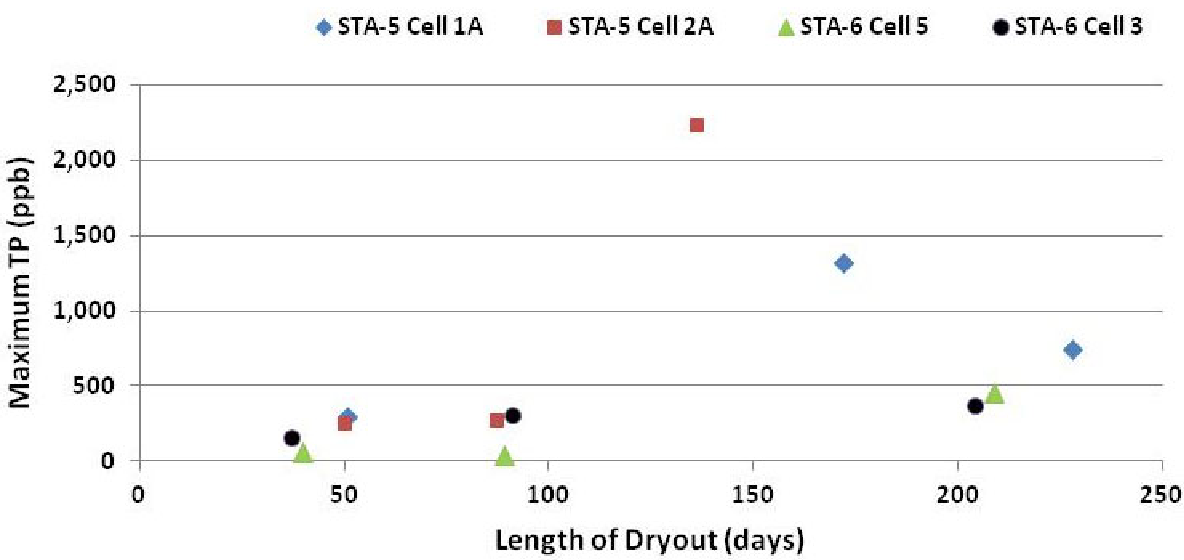


Figure 5-36. Relationship between the length of dryout (water level below ground elevation) and total phosphorus spikes after resumption of flow in STA-5 and STA-6 (period of record).

Drought Impacts

The EAV cells of STA-5 (Cells 1A, 2A, and 3A) and Cell 3B dried out during the WY2012 drought period (**Figure 5-34**). Approximately 9,827 ac-ft of supplemental water was delivered to STA-5 SAV cells through G-507, G-350B, and G-349B. These two cells were held at the drought contingency stages (6 inches above the normal target stage) during the 2012 dry season. As a result, Cells 1B and 2B remained hydrated during the WY2012 drought season. Cells 3A and 3B have been dry for most of the time since it became operational in 2008; as a result, SAV establishment in Cell 3B has not been successful.

STA-6 was dry from the beginning of May 2011 through July 5, 2011, and went online during the week of July 11, 2011 (**Figure 5-34**). The STA began drying out again during the week of January 23, 2012, and Cells 3 and 5 and Cell 6-2 reached dryout conditions of March 26, 2012. The effects of dryout-rehydration cycles in STA-6 have been discussed in the 2010 SFER – Volume I, Chapter 5 (Pietro et al., 2010).

An evaluation of the POR dryout period effects on STA-5/6 show that TP concentration spikes in STA-5, resulting from rehydration post-dryout period, was positively correlated with the duration of dryout while in STA-6, the duration of dryout did not show any correlation with resulting TP spike (**Figure 5-36**). This is likely due to the differences in soil TP and organic matter content between these two STAs. Further analysis is under way to determine the effects of water depth, hydropattern, soil characteristics, and lag time between rehydration and discharge on TP spikes following period of dryout.

Impacts of Migratory Bird and Snail Kite Nesting

Migratory bird nesting did not affect STA-5 or STA-6 in WY2012. In May 2011, a small number of nests were in Cells 1A, 2B, and 3A (Appendix 5-4), but STA-5 and STA-6 operations were not impacted due to the lack of flows during the nesting season. Ground nesting was also observed in the Compartment C construction area in May and July 2011 surveys; nests were marked accordingly and construction personnel avoided the nest areas until the eggs hatched. Nests observed in April 2012 were in non-operational cells (Cells 5A and 5B, and Cell 6-2), so there was no impact to STA operations.

There was one unconfirmed snail kite nest in STA-5 Cell 2B, based on a report from the Hendry County Audubon Society (Appendix 5-4). As a precaution, the cell’s target stage was maintained at 13.0 feet, and activities were withheld within a 500 m distance from the potential nest site until May 10, 2012. Fledglings were observed within the area on April 17, 2012.

Compartment C Build-out

The Compartment C Build-out Project is located in Hendry County between existing STA-5 and STA-6 (**Figure 5-1**). The EFA permit for construction of the Compartment C Build-out was issued on January 12, 2009; construction activities started in April 2009, and pump station construction began in September 2009. The project was flow-capable as of December 2010 and achieved final completion on September 18, 2011. Construction of the G-508 inflow pump station is scheduled to be complete by September 2012 (**Figure 5-37**). Operation of the Compartment C Build-out Project depends on the acquisition of state and federal discharge permits.

Startup activities in Compartment C began in August 2011 when approximately 1,100 acres of primarily Brazilian pepper (*Schinus terebinthifolius*) in the non-effective treatment areas along the western side of the new cells were aerially treated with herbicide. Subsequently, extensive measures were undertaken to prepare the new cells in Compartment C to support the desired wetland vegetation cover to establish the mechanisms for water quality treatment. In October 2011, an aerial herbicide application was used to treat extant trees and shrubs, which covered approximately 1,700 acres of Cells 4A and 4B and STA-6 Cell 4. This included primrose willow, an invasive exotic shrub that forms dense thickets that can rapidly spread and outcompete herbaceous wetland vegetation, and stands of the native coastal plain willow, which appear to have established in depressions in the former agricultural fields and have expanded since these lands have been laid fallow and not subjected to previous levels of active drainage activity. Both coastal plain willow and primrose willow have little or no understory cover, and as a result do not have the litter-based filtration and phosphorus uptake mechanisms that provide water quality treatment in emergent cells. They also preclude growth of SAV and associated periphyton. In addition to the herbicide treatments, ground crews cut the larger shrubs and trees. In Cells 4B and 5B, vegetation control was done through airboat-based herbicide treatments of approximately 500 acres of para grass (*Urochloa mutica*), West Indian marsh grass (*Hymenachne amplexicaulis*), and wild taro (*Colocasia esculenta*) between December 2011 and April 2012. Additional vegetation startup measures are planned for WY2013, including herbicide treatments of tree and shrub cover in Cells 5A and 5B of STA-5, and SAV inoculation in the new SAV-designated treatment cells.

Figure 5-37. Construction of the G-508 pump station in Compartment C, December 2011 (photo by the SFWMD).

Environmentally Sensitive Areas in Compartment C

The District continues to work with the Seminole Tribe of Florida, the Miccosukee Tribe of Indians of Florida, USACE, and Florida's State Historic Preservation Office toward completion of the permanent protective measures on the environmentally sensitive cultural resource areas in Flow-way 5. The permanent protective measures under construction will ensure that the areas within Compartment C boundaries will be preserved and protected from permanent inundation. Soil material from degradation of a redundant levee in STA-6 was brought to the area for berm construction. This construction effort is planned to be completed by October 2012. It is anticipated that rainfall and limited stormwater inflows (depending on water availability) will help in recruitement of wetland vegetation within Flow-way 5 during the latter part of the WY2012 wet season. Flow-way 5 will not be placed into normal operation until the permanent protective measures have been implemented. Once in place, the District will monitor and evaluate operations in a concerted effort to maintain preservation and protection of these areas.

MAINTENANCE AND ENHANCEMENTS

Routine vegetation management included control of FAV in inflow distribution canals and in outflow collection canals to provide an even distribution of flow across each cell, and to ensure the efficiency of discharge structures. Within the cells, water lettuce and other floating plants such as water hyacinth and frog's bit were routinely treated to promote growth of submerged beds of aquatic vegetation in SAV cells. A summary of herbicide use in the STAs is included in Volume III, Appendix 3-1, Attachment E. Vegetation control activities related to Compartment C cells are discussed under the *Compartment C Build-out* section of this chapter.

In STA-5 Cell 1B, deep gaps in existing vegetation strips along the southernmost region of the cell were plugged with earthen material in June 2011, and giant bulrush was planted over the newly filled gaps in July 2011 (**Figure 5-38**). This is anticipated to remedy observed short-circuiting and help improve treatment performance in this region of the cell.

In October 2011, approximately 400 acres of cattail in the eastern half of STA-5 Cell 3B were aerially treated with herbicide in an effort to begin an incremental conversion of this area to SAV. Cell 3B is intended to function with SAV being the dominant plant type, but due to hydrologic and hydraulic limitations, this cell has not received the consistent inundation needed to establish and sustain SAV species, and is presently covered with an emergent cattail marsh. The installation of the new G508 pump station is expected to alleviate this hydrologic constraint. Incremental conversion has proven successful in other areas (e.g., STA-3/4 Cell 1B and STA-2 Cell 2) since treatment capability of the cell is retained within the EAV region while the converted area is stabilizing.

Another significant enhancement in STA-5 was the improvement in elevation of the former high pad area just west of Cell 1A, formerly referred to as a non-effective treatment area due to its high elevation. This area was scraped in WY2010 to obtain fill material for a slough area in Cell 1A. As a result, the ground elevation of the high pad area was lowered by approximately 1 foot and consequently has allowed more flow and more desired wetland vegetation establishment since the modification. Field observations on September 7, 2011, also indicate water levels ranging from 7.4 to 39 inches and good coverage of mixed wetland species, including EAV (e.g., *Sagittaria*, *Pontederia*, *Typha*), SAV, and periphyton. If this area can stay hydrated, along with the remainder of the flow-way, then coverage of desired wetland vegetation species is likely to improve and expand.

Figure 5-38. To alleviate hydraulic short circuiting in the southern region of Cell 1B in STA-5, deep gaps in existing vegetation strips (left photo) were plugged with earthen fill and planted with giant bulrush (right photo) during June–July 2011 (photos by the SFWMD).

VEGETATION SURVEYS

Based on an annual imagery flight, areal vegetative coverage of EAV and SAV+open area is estimated for each STA. Imagery for CY2011 (conducted in May 2011) is presented in this chapter; a comparison with the previous year (conducted in April 2010) is also included (**Table 5-12**; Appendix 5-5). For STA-5, the most significant gains in EAV coverage were observed in Cell 1A and 2B, with 24 and 11 percent gain between CY2011 and CY2012, likely as a result of the dry conditions. The highest decrease in EAV coverage was in Cell 3A (-11 percent between CY2010 and CY2011). In STA-6, both Cells 3 and 5 gained EAV coverage, also due to dry conditions. STA-6 Cell 2, which is targeted to be an SAV cell, had a 20 percent gain in EAV coverage as the cell was dry for Compartment C construction.

Also, based on ground surveys of SAV in STA-5 Cells 1B and 2B on November 2, 2011, hydrilla remains the dominant SAV within both cells. Hornwort was also present in patchy beds throughout the cells, while southern naiad was observed primarily in the northeastern region of Cell 1B (**Figure 5-39)**.

Table 5-12. Summary of vegetation coverage in STA-5/6 based on May 2011 aerial imagery. Numbers shown are expressed as percentage of total cell area.

Area		Cover Category		
		% EAV	% SAV+ Open Area	% change in EAV Cover from 2010 to 2011
STA-5	Cell 1A	88	12	24
	Cell 1B	21	79	8
	Cell 2A	91	9	5
	Cell 2B	30	70	11
	Cell 3A	72	28	-11
	Cell 3B	91	9	-3
STA-6	Cell 2	80	20	20
	Cell 3	86	14	3
	Cell 5	97	3	4

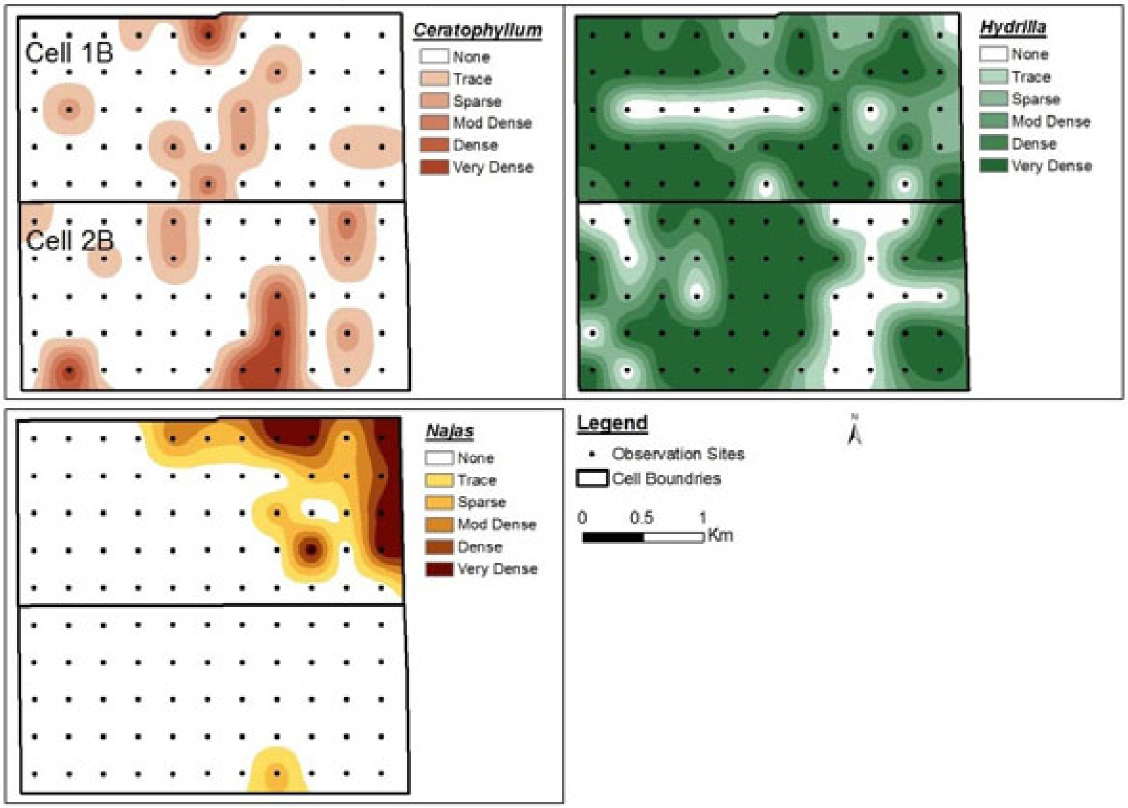


Figure 5-39. Vegetation survey results depicting the spatial coverage of *Ceratophyllum*, *Hydrilla,* and *Najas* in STA-5 Cells 1B and 2B on November 2, 2011.

APPLIED SCIENTIFIC STUDIES

Scientific research associated with the STAs is conducted help explain their complexity, better recognize the many challenges related to their operation, and to meet the demand to achieve and sustain low TP outflow concentrations. These activities include studies that range in duration from short- to long-term and from mesocosm scale to field-scale, as well as analysis of existing data to enhance the knowledge of the complex treatment systems, the factors affecting performance, and the various TP removal mechanisms. The mesocosm and field-scale studies are conducted to address key issues including (1) understanding and documenting the condition of the STA during the water year reporting period, (2) evaluating proposed and completed enhancements, (3) evaluating impacts of extreme weather condition, (4) investigating failing or poor performance, and (5) finding ways to further improve performance. **Table 5-13** summarizes these studies grouped into two categories according to their primary purpose: monitoring and documenting STA condition, and evaluating ongoing or potential management strategies or technologies. The objectives of some of these studies are discussed earlier in this chapter. Some studies are directly linked to ongoing field implementation of management strategies (e.g., STA-3/4 Cell 1A drawdown evaluation), and some are directly linked to permit requirements such as the research and STA optimization activities described in the Long-Term Plan (e.g., vegetation surveys).

In WY2012, no new research projects were started due to funding limitations, although studies initiated in previous years continued. An extensive multivariate analysis of historical data is also under way, with the primary goal of understanding the factors that control TP removal in the STAs. Preliminary data screening and verification of assumptions for various statistical options have been conducted, including principal component analysis and multi-regression. This effort is continuing and results are expected to be reported in the 2014 SFER as the analyses are completed. As indicated in **Table 5-13**, the discussion of findings for many studies are included in this section, while some STA-specific findings are incorporated in the *Vegetation Surveys* or *Maintenance and Enhancements* sections under the individual STA sections of this chapter.

Table 5-13. Summary of applied scientific studies in the STAs during WY2012.

Study	Description and Objective	Finding and Status (as of April 30, 2012)
Purpose: *Evaluate different management strategies to improve treatment performance of the STAs*		
STA-3/4 PSTA Project	This project, which began in WY2007, is a field implementation of PSTA technology aimed at further lowering outflow TP concentrations in STA discharges. The outflow concentrations to date have been promising, but further evaluation of the data will aid in a better understanding of the P removal mechanisms of PSTA technology and allow a more accurate assessment of its performance.	The STA-3/4 PSTA project structures and operations were modified in WY2012 to improve flow data accuracy. A more in-depth scientific evaluation also began in WY2012. Further information on the ongoing scientific investigation is included in this section.
STA-1W Phosphorus Mesocosm	This is a three-year study to investigate whether several species of native aquatic macrophytes (sawgrass, water lily, spikerush, and water lily + spikerush) can be used to enhance the treatment performance (TP removal) of the STAs. The TP removal capability of these species is being compared to that of cattail and SAV, plant communities that currently dominate the STAs. The study is being conducted at the STA-1W South Research Site.	This is the second year for the mesocosm study, the first year being a grow-in period, and a period of adjustment of controls and instrumentation. Initial findings are presented in this section. Data collection is continuing in WY2013.
Potential Water Quality Benefits and Constraints of "Front-end" FAV communities in the STAs	This test cell-scale study, initiated in 2008, and mesocosm-scale study, initiated in 2010, are being performed to document the TP removal effectiveness of floating aquatic vegetation (FAV) as a front-end vegetation for the STAs, as well as to evaluate the influence of herbicide applications to FAV on water quality. Duplicate test cells were maintained with the following vegetation: cattail, cattail + FAV mix, and FAV.	Biweekly water quality sampling for soluble reactive phosphorus (SRP), TP, total soluble P, and pH was conducted at the test cell inflow and outflow until April 2011. Sampling for pH and TP at S-5A facility mesocosms was initiated in February 2011. Data collection continues and findings are planned to be reported in future SFERs.
Purpose: *Document STA condition, success of STA enhancements, impact of extreme events, and trends in treatment performance and other issues of critical importance to the STAs*		
STA Vegetation Monitoring: Aerial Imagery	Aerial photographs (using high-contrast infrared film) of the STAs are taken annually during the summer to document vegetation coverage (emergent vegetation versus SAV+open water areas) in accordance with the STA operating permits. Specific areas of interest in the STAs are mapped in more detail on an as-needed basis. Aerial photographs, together with ground-truthing data, have been used to evaluate vegetation density on a relative basis in selected areas. Vegetation maps and GIS interpretation efforts are associated with this project, and findings are reported annually in the SFER.	Results of the 2011imagery are presented in this chapter (STA Conditions, under each STA subheading). The 2012 imagery is being processed and will be presented in the future. Further analysis of the vegetation density index for selected areas in the STA is under way and results will be presented in a future SFER.

Study	**Description and Objective**	**Finding and Status (as of April 30, 2012)**
STA Vegetation Monitoring: Ground Surveys	Ground surveys are conducted to assess SAV species coverage and relative abundance. Surveys are also conducted as part of extreme event assessments. Spatial species distributions are mapped and reported annually in the SFER and as needed for performance-related evaluations.	Results for STA-1E are presented in the chapter. Additional SAV maps are expected to be presented in future SFERs.
STA-3/4 Cell 1A Drawdown Evaluation	Evaluate baseline and post-drawdown condition of vegetation in STA-3/4 Cell 1A, which has been negatively impacted by extended periods of deep water (e.g., greater than 2ft). Results were compared with data from the adjacent cell (Cell 2A), which was not drawn down. Monitoring includes site surveys and vegetation analysis. Results from this study will help in determining if water-level drawdown can be incorporated as a routine management strategy to maintain healthy emergent vegetation in the STAs.	Results to date are discussed in this section. Additional measurements and surveys, including evaluation of biomass and tissue nutrient concentrations, is planned to be done in WY2013.
STA Water Quality Internal Transects Evaluation	Evaluate phosphorus removal from the water column along transects of selected flow-ways in STA-1E, STA-1W, STA-2 and STA-5. Data are being used to monitor P cycling within STA flow-ways under various operational and environmental conditions. Over time, these data may provide insight about key processes such as internal P transformations and spatial relationships between vegetation type/health and P retention or sediment P release.	Data from STA-5 transects are presented in this section. Previous results have also been utilized to help characterize particulate P (PP) transformations in STA-2 Cell 3 (Dierberg and DeBusk, 2008) and as evidence of background TP concentrations in SAV-dominated wetlands constructed on previously farmed muck soils (Juston and DeBusk, 2011).
STA-2 Cell 2 Partial SAV Conversion Evaluation	Emergent vegetation in the southern portion of STA-2 Cell 2 was treated with herbicide in April 2009 to allow for conversion of this area to SAV. Several different efforts are linked to this project, including SAV surveys, sampling along water quality transects and water level monitoring.	An update on the SAV establishment in the initial vegetation conversion area is presented in this chapter under each STA's *Maintenance and Enhancements* section.
Impacts and Benefits of Dryout on Cattail Communities	This mesocosm-scale study, which was concluded in WY2009, originally aimed at determining early signs of cattail stress due to dryout conditions because during periods of low rainfall, there are many emergent vegetation cells in the STAs that are prone to dryout. During the course of the study, it appeared that short periods of dryout may be beneficial to cattail health by allowing new growth to occur. Final evaluation of the study includes determining both the impacts and benefits of dryout conditions on cattail growth and survival.	An initial discussion of study results is included in this section.

Study	Description and Objective	Finding and Status (as of April 30, 2012)
Investigation of Factors Influencing SAV Performance and Sustainability in STAs	A better understanding is needed of the factors (e.g., water chemistry, soil chemistry, soil physical characteristics, herbivory) and their interactions that influence SAV species distribution, persistence, and colonization/recovery in STAs. This investigation includes (1) SAV distribution and speciation as a function of water depth; (2) an investigation on the potential impacts of bird herbivory on SAV communities; (3) a mesocosm study to determine the effects of mixed EAV and SAV communities on water quality and stability of sediment P; and, (4) a large sediment core evaluation study to assess impacts of sediment treatments (dry down, floc removal, etc.) on SAV recruitment and water column turbidity.	SAV surveys were conducted on potential bird herbivory study sites. Exclosures were installed at STA-1E Cell 4S and STA-1W Cell 5B in January 2011. Initial findings indicate that birds were actively feeding in and around the plot areas and that SAV beds exhibited damage caused by grazing. The density of hydrilla and naiad in the exclosures increased relative to the biomass density in the open plots whereas musk grass exhibited a decline in density in the enclosed plots. Data analysis for this effort continued in WY2012; results are expected to be presented in future SFERs.
Characterization of Hydraulic Resistance of Emergent Macrophytes in STA-2 Cell 2	Many of the emergent macrophyte-dominated STA cells now contain dense vegetation stands, consisting of both living and dead plant material. Under high flow events, hydraulic resistance by the dense vegetation could be contributing to the high water depths in the front-end of many STA flow-ways. For this effort, water stage monitoring devices were deployed throughout an EAV cell in 2008 to help characterize internal stage changes as a function of flow rate and vegetation community type and condition.	A synopsis of the results from this study is presented in this section. Journal publication on this topic is also in review process.

STA-3/4 PERIPHYTON-BASED STORMWATER TREATMENT AREA PROJECT

Tracey Piccone, Hongying Zhao, ShiLi Miao, Kevin Grace[1],
Tom DeBusk[1] and Delia Ivanoff

The STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Project is a 400-acre project built in 2005 to study and implement field-scale PSTA treatment (**Figure 5-40**). Peat was scraped from the 100-acre PSTA cell to the caprock to remove a potential source of TP. Emergent vegetation strips were planted perpendicular to flow to improve the PSTA cell's hydraulic efficiency. The STA-3/4 PSTA Project has been in operation since WY2008 and its performance and operational parameters have been reported in previous SFERs.

Over the first four water years (WY2008–WY2011) of operation, the PSTA cell achieved an average annual FWM TP concentration of about 10 ppb. However, over this period, there were various issues with the hydraulic data associated with the PSTA Project. First, there were significant issues with the accuracy of the flow data at all the project's water control structures. Second, the amount of seepage entering the PSTA cell from the surrounding water bodies (i.e., the surrounding PSTA Project cells, STA-3/4 treatment cell, and discharge canal) was not known but was assumed to be quite large as evidenced by higher outflow than inflow volumes. Third, the quality of the seepage water was not known, making it difficult to calculate the TP budget for the PSTA cell. Finally, of the four water years of operation, there was only one year (WY2010) that the PSTA cell was operated year-round, whereas the PSTA cell was operated less than half a year for the other three years. As a result of these various hydrologic and hydraulic issues, interpreting the PSTA cell's strong performance over the first four water years is problematic.

Therefore, in WY2012, various efforts were initiated to improve understanding of the PSTA cell's performance, including structural, monitoring, and operational changes, as well as improvements to data evaluation and research efforts. These efforts will be implemented over the next three water years (WY2013–WY2015) and are planned to be reported in this and future SFERs as information and results become available.

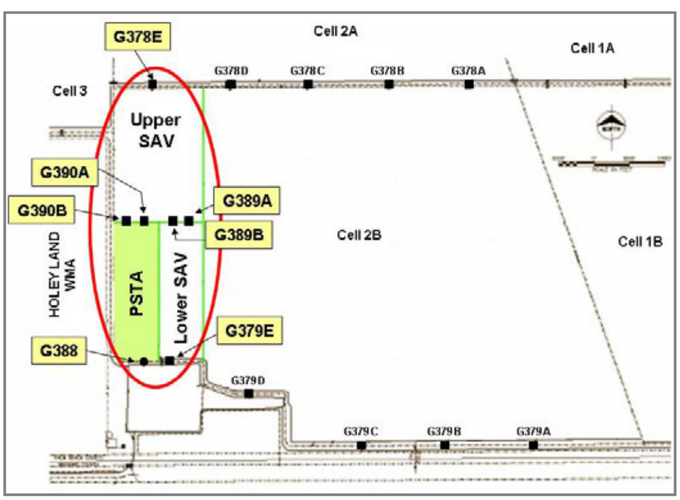


Figure 5-40. Location of upper and lower SAV cells, the PSTA cell, and related water control structures.

Structural, Monitoring and Operational Improvements

To improve the hydraulic data associated with the PSTA Project and thereby improve understanding of the PSTA cell's performance, various structural, monitoring, and operational improvements were initiated in WY2012. In August 2011, the pump speed of Pump #2 in the G-388 PSTA cell outflow pump station was changed from 350 revolutions per minute (rpm) to 224 rpm to reduce the pump on/off frequency. The flow rating equation for Pump #2 was subsequently updated to reflect the decrease in speed and capacity. In October 2011, the PSTA cell inflow culvert G-390B was modified to improve flow measurements (**Figure 5-41**). The inflow cross-sectional area was reduced by inserting a 36-inch diameter aluminum pipe inside the existing 6-foot by 6-foot concrete box culvert thereby allowing for a higher flow velocity that can be measured with better accuracy. A new rating equation was developed for G-390B after the structure modification was completed.

Vegetation strip modifications in the PSTA cell were also implemented in late WY2012 through early WY2013 to improve the cell's conveyance capacity. Herbicide was applied to 6 of the 12 vegetation strips and degradation of the treated vegetation was implemented. Efforts are planned to install a headwater sensor at the G-378E culvert to improve inflow estimates for the upper SAV cell and a tail water sensor at the G-379E culvert to improve outflow estimates for the lower SAV cell and thereby improve the water and TP budgets associated with the project components. Groundwater levels and water quality data are being collected at the existing monitoring wells located in the PSTA cell levees. The well monitoring information will be used to improve seepage estimates and thereby improve the water budget and TP removal performance evaluations for the PSTA cell.

Figure 5-41. Modifications at G-390B (left photo) to improve flow data collection. A 36-inch diameter aluminum pipe was inserted inside the existing 6-foot by 6-foot concrete box culvert (right photo) (photos by the SFWMD).

Performance Results

As part of ongoing efforts to better understand the PSTA cell's performance, five-year POR (WY2008–WY2012) results are summarized in **Table 5-14**. These data reflect some revisions compared to previous years' SFER reporting of the PSTA cell's performance. Similar to previous reporting, the performance calculations shown in this table take into account the operational period for the PSTA cell, which is defined as the number of days that one or both of the PSTA cell inflow structures (G-390A and G-390B) were open. Days with no inflow to the PSTA cell as a result of bird nesting, due to structure maintenance, or to preserve water during drought conditions are excluded from the operational period, and days with no inflow due to normal hydrological conditions are included. From WY2008–WY2012, the operational periods are defined as follows:

- WY2008: July 5–December 12, 2007, n = 161 days
- WY2009: July 9–December 23, 2008, n = 168 days
- WY2010: May 25, 2009–April 30, 2010, n = 341 days
- WY2011: May 1–June 1, 2010; August 3–December 7, 2010, n = 159 days
- WY2012: July 19, 2011–April 5, 2012, n = 262 days

Compared to previous SFERs, this year's summary includes improved flow data for structures G-390A and G-390B for May 1, 2007–December 31, 2010, based on the water balance analysis conducted by District staff. The summary also utilizes different approaches to calculating the surface water hydraulic loading rate (HLR), the phosphorus loading rate (PLR), the nominal hydraulic residence time (HRT), and the TP settling rate (k). Literature terminology in wetland hydrology is somewhat ambiguous concerning hydrologic variables (Kadlec and Wallace, 2009). The definitions used in this report are specified below.

$$\mathrm{HLR} = \frac{\mathrm{Q_d}}{A} \times 30.48 \quad (1)$$

$$\mathrm{HRT} = \frac{\mathrm{V}}{\mathrm{Q}} \quad (2)$$

$$\mathrm{k} = \frac{\frac{(\mathrm{V_{in}}+\mathrm{V_{out}})\times \mathrm{N}}{2}}{\mathrm{A}} \times \left(\left(\frac{\mathrm{C_{in}}-\mathrm{C^*}}{\mathrm{C_{out}}-\mathrm{C^*}}\right)^{\frac{1}{\mathrm{N}}} - 1\right)/3.28 \quad (3)$$

where:

HLR is the hydraulic loading rate in cm/day
HRT is the nominal hydraulic residence time in days
k is the TP settling rate in m/yr
Q_d = V/n, Q_d is the daily flow rate in ac-ft/day during the operational period, n
V is the average daily volume (ac-ft) in the PSTA cell during the operational period
Q is the average of the inflow and outflow rates in ac-ft/day during the operational period
V_{in} is the total inflow volume (ac-ft/yr) to the PSTA cell during the operational period
V_{out} is the total outflow volume (ac-ft/yr) from the PSTA cell during the operational period
A is the PSTA cell effective treatment area in acres
N is the number of continuously stirred tanks in series, N = 6 (DB Environmental, Inc., 2009)
C* is the background TP concentration, C* = 4 ppb; 4 ppb of C* was a typical value applied in normal STA design
C_{in} is the inflow flow weighted mean concentration in ppb
C_{out} is the outflow flow weighted mean concentration in ppb

Overall, changes to the PSTA cell's inflow data did not have a major impact on the annual inflow FWM TP concentrations, which ranged from 14 to 27 ppb. No major changes were made to the PSTA cell's outflow data, and results continue to show that the PSTA cell consistently yielded annual outflow FWM TP concentrations of 12 ppb or less. In WY2012, the HLR and PLR of 14 cm/day and 0.39 g/m^2/yr, respectively, are almost twice as much as WY2011. In contrast to previous reporting, the data presented in **Table 5-14** on POR surface-water areal phosphorus loading rates are not adjusted to represent an assumption that the flow-way was online for the entire water year. Utilizing this year's changes to the POR data, the PSTA cell's phosphorus settling rate for WY2012 is 12.5 m/yr and is within the same range as that observed in previous water years.

Table 5-14. Summary of annual operational and performance parameters in the STA-3/4 PSTA cell from WY2008–WY2012.

Water Year	Surface-Water HLR (cm/d)	Nominal HRT (d)	Total Surface Water Inflow (ac-ft)	Total Surface Water Outflow (ac-ft)	Surface Inflow FWM TP (ppb)	Surface Outflow FWM TP (ppb)	Surface Water Areal TP Loading (g/m^2/yr)	Operation Period (days)	TP Settling Rate (k) (m/yr)
WY2008	5.5	4.3	2,919	5,201	27	12	0.24	161	14.2
WY2009	6.2	4.2	3,309	6,105	14	8	0.14	168	13.8
WY2010	13.2	4.5	7,022	10,078	20	10	0.42	341	27.4
WY2011	6.0	4.9	3,198	3,933	18	11	0.17	159	7.3
WY2012	14.0	3.3	7,463	9,610	17	12	0.39	262	12.5

HLR: Hydraulic Loading Rate; HRT: Hydraulic Residence Time;
FWM: Flow-weighted Mean; TP: Total Phosphorus

PSTA Project Research Plan

A PSTA Project Research Plan is being implemented to provide a more accurate assessment of the PSTA technology performance, to determine design and operational factors that contribute to that performance, and to develop replication options. Specifically, the research plan focuses on the following questions:

- What are the important design elements and biogeochemical characteristics that enable the PSTA cell to achieve ultra-low outflow TP levels?
- What are the key operational ranges that enable the PSTA cell to achieve ultra-low outflow TP levels?
- What management practices are required to sustain the PSTA cell's good performance?

The current strategy is to implement the PSTA Research Plan over the next three water years (WY2013–WY2015) and to produce a document summarizing the results of the research plan that can be used to design future PSTA cells with the lowest construction and operational costs.

Sub-study: Influence of Soil and Enzyme Activities on Outflow Phosphorus Concentration

Examination of outflow phosphorus speciation in the PSTA cell suggests that ultra-low outflow TP levels are achieved through slight reductions in both particulate phosphorus (PP) and dissolved organic phosphorus (DOP), beyond what appears achievable in SAV communities on previously farmed lands. Reductions in these constituents may be due to activity of phosphatase enzymes produced by microbial communities, the presence of a relatively inert (with respect to P release) underlying substrate, such as provided by the limerock base, or a combination of these.

Methods

During late 2011 and early 2012, detailed characterizations of water quality and soils in the STA-3/4 PSTA cell were initiated. Sampling was also performed in the outflow region of adjacent cells (2B and 3B) in STA-3/4 that support healthy SAV communities and yield 14–16 ppb outflow TP levels. Water samples were collected along transects within the PSTA cell, at varying distances from the inflow levee, under different flow regimes. Samples from the water column, floating periphyton, and the benthic floc layer were assayed to determine the activity of phosphatase enzymes, which may be important to the breakdown of DOP molecules. Sediment accretion depth was measured spatially within the cell, and sediments will be analyzed for TP, total nitrogen (TN), total carbon (TC), total organic carbon (TOC), and calcium (Ca) contents at a subset of those stations.

A series of soil core studies also were conducted to examine differences in sediment P flux and enzyme activity between the PSTA cell and muck-based treatment cells in STA-3/4. Intact 15 cm diameter cores were retrieved from the PSTA cell, Cell 2B, and Cell 3B. The core sediment depth was approximately 10 cm, with a water column depth of 30 cm. Cores were incubated outdoors, under a shade structure, with water exchanges performed biweekly. Water column TP removal and phosphatase enzyme activity was characterized routinely during the incubations.

Results and Discussion

On December 8, 2011, surface water in the PSTA cell was sampled along internal transects to evaluate the spatial variability of P species and other important constituents. The average inflow rate on the day of sampling was 6 cubic feet per second (cfs) and the mean outflow was 15 cfs, suggesting a range in HRT of 4 to 11 days. The results of the internal survey indicated highest TP concentrations along the A transect (in the first compartment, between the inflow and the first vegetation strip), and decreasing TP concentrations with distance through the cell (**Figure 5-42**). Mean surface water TP concentrations were below 10 ppb along the E, G, I, K. and M transects, and at the outflow structure G-388. A reduction of PP between inflow and the mid-point of the cell (G-transect) was apparently responsible for the decrease in TP levels. DOP was the dominant P species exported from the cell.

During mid-January, a sediment depth survey revealed a mean floc (entire accrued layer above either bedrock or remnant peat layer) depth of 9.2 cm, with a range of 3.5–19 cm (**Figure 5-43**). No clear inflow-to-outflow gradient in floc depths was observed: the greatest depth of accrued material was observed adjacent to the cell inflow levee, and also along the western levee.

Sediment core incubations (**Figure 5-44**) demonstrated that outflow region sediments from STA-3-4 Cell 2B exhibited a higher release of TP and DOP as compared to the PSTA cell or Cell 3B outflow region sediments (**Figure 5-45**). Water column phosphatase enzyme activity was highest in the PSTA-sediment treatments (**Figure 5-45**). Additional studies are under way to clarify the relative stability of P forms in the muck and accrued sediments of the PSTA and SAV cells, and to better define the substrates (surficial soils, periphyton, etc) responsible for greatest levels of phosphatase enzyme activity in the PSTA cell. Future efforts also will include algal growth studies to examine periphytic biofilm development in the PSTA and adjacent muck-based SAV treatment cells. The standing crop, nutrient content, growth rates, and taxonomic composition of the periphytic biofilms on artificial substrates (glass slides) will be used to examine whether the taxonomy and chemistry of PSTA periphyton differs from that in muck-based cells.

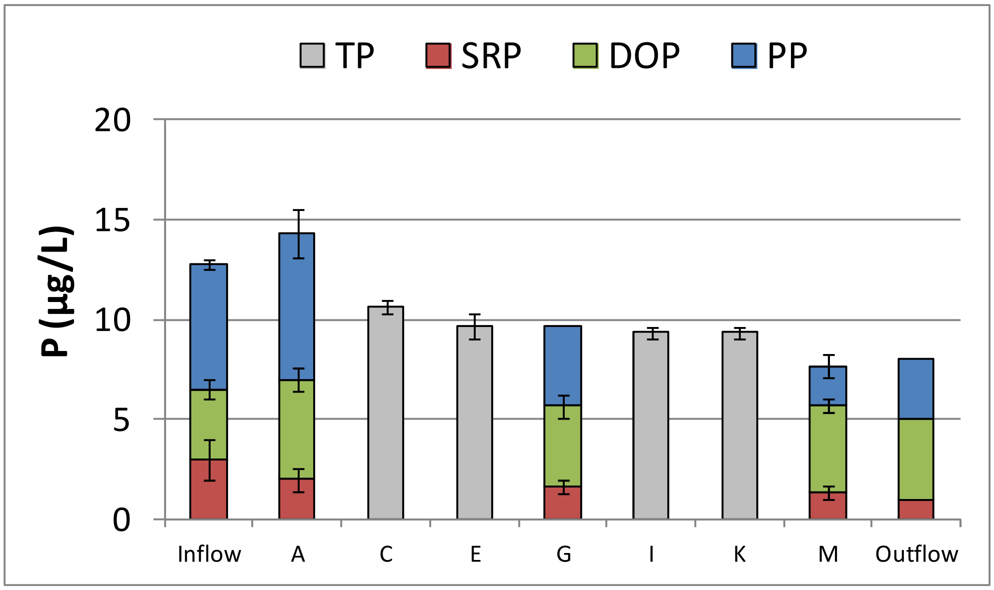


Figure 5-42. PSTA cell water column TP and phosphorus species (SRP: soluble reactive phosphorus; DOP: dissolved organic phosphorus; PP: particulate phosphorus) concentrations during December 2011. Data is depicted for each sampling location at the inflow, outflow, and along three internal transects (A, C, E, G, I, K and M). Error bars denote ± standard error (SE) around the mean of three stations along each internal transect, or two stations at the inflow levee. Outflow values were derived from a single grab sample at the G-388 outflow structure.

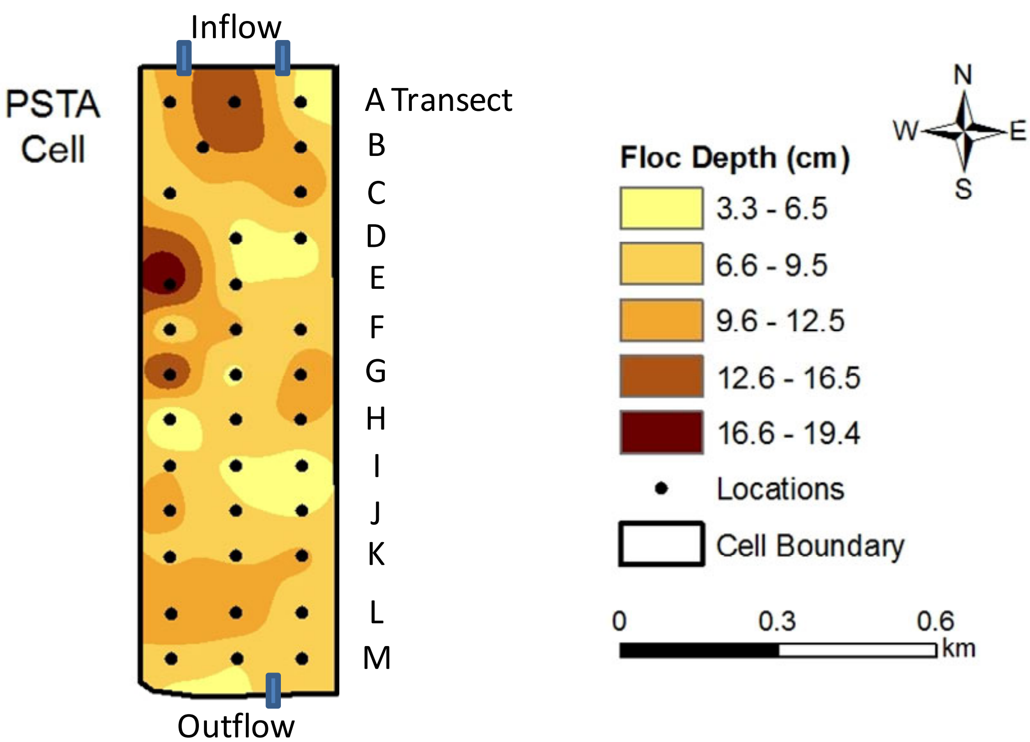


Figure 5-43. Spatial interpolation of floc depth measured at 39 locations within the PSTA cell in STA-3/4 in January 2012.

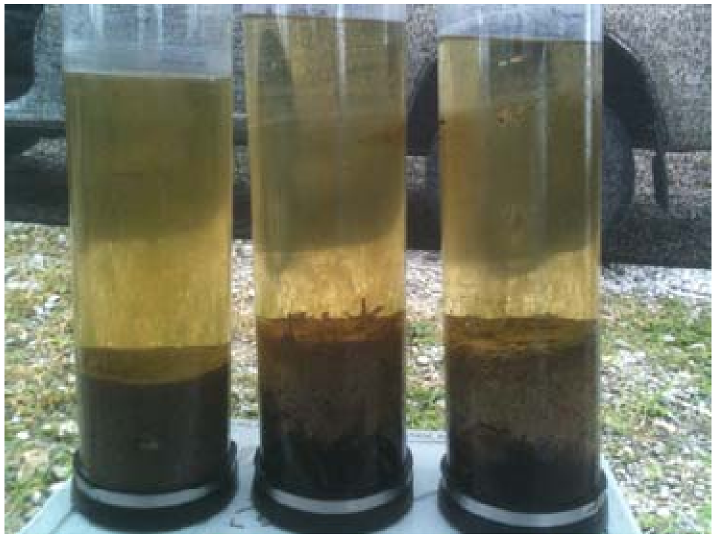


Figure 5-44. Intact sediment cores were used to examine differences in sediment P flux and enzyme activity between the PSTA cell and muck-based treatment cells in STA-3/4. Depicted are cores from the PSTA cell (left), and the adjacent SAV-dominated Cells 2B (middle) and 3B (right) (photo by the SFWMD).

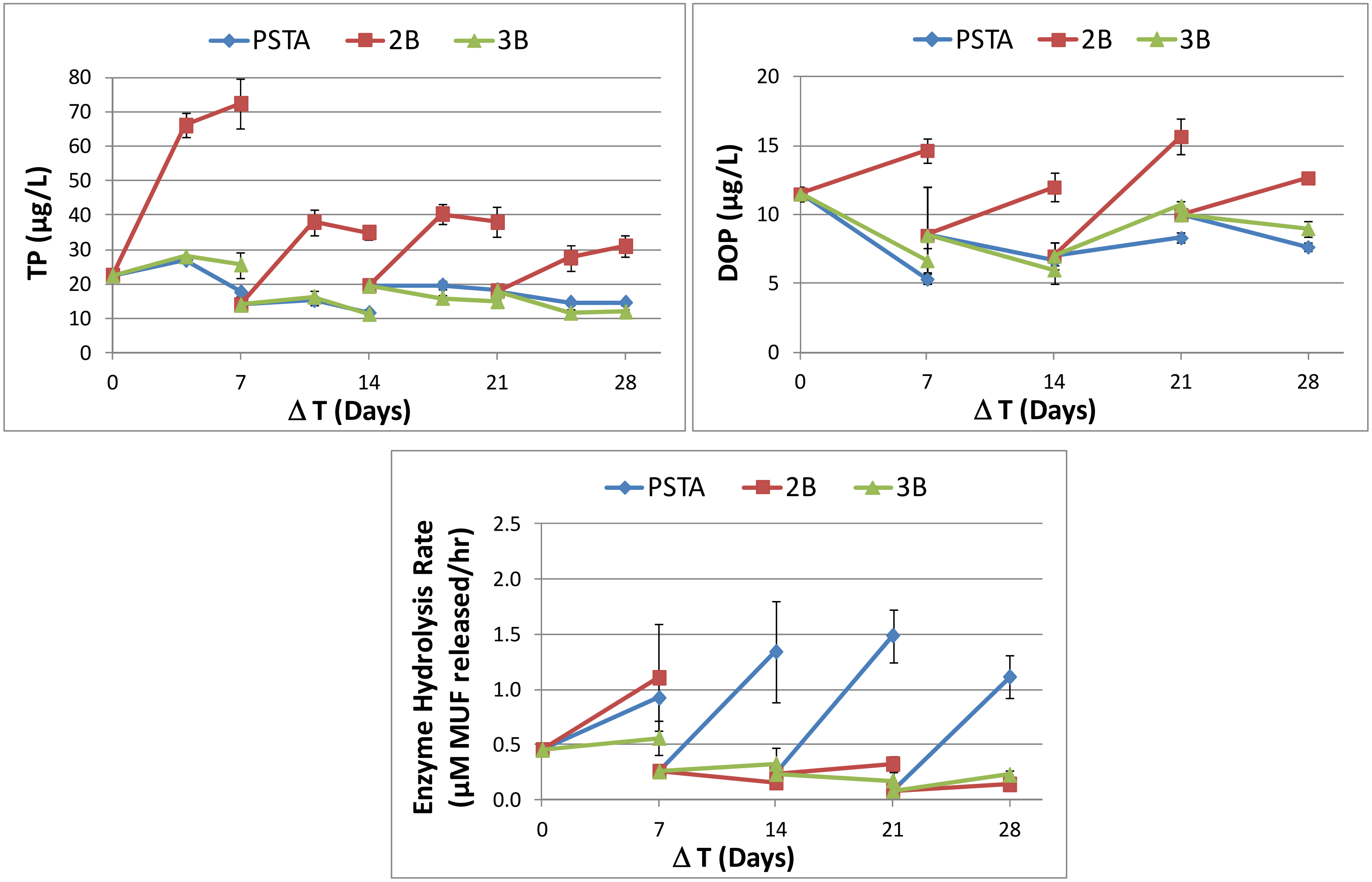


Figure 5-45. TP concentration (top left), DOP concentration (top right), and alkaline phosphatase (monoesterase) (bottom) activity in the overlying water column from the outflow region of the PSTA cell and STA-3/4 Cells 2B and 3B during outdoor core incubation with no vegetation present. The water column was refreshed with PSTA cell inflow water every 7 days.

STA-1W PHOSPHORUS MESOCOSM STUDY

ShiLi Miao, Chung Nguyen[4],
William Mitsch[4] and Li Zhang[5]

Although the STAs have substantially reduced TP loading to the Everglades over the past decade, the District has a pressing need to find additional strategies to further lower the outflow TP concentration of the STAs. The historical Everglades as well as the current reference areas of the WCAs are oligotrophic and dominated by sawgrass ridge and water lily (*Nymphaea odorata*) sloughs. The survival mechanisms of these native vegetation types, particularly for P uptake, utilizing, storage, and retention may provide vital information for further P removal and new management strategies to enhance the treatment performance of the STAs. The District initiated a three-year (2010–2013) proof-of-concept mesocosm study in collaboration with the Ohio State University.

Objectives

The key objectives of the study are to assess nutrient removal efficacy of six vegetation types under a very low TP concentration and examine major mechanisms in water, soil and plants underlying TP removal function. The study was designed to use effluent water from STA-1W as the inflow source for the mesocosms. It is hypothesized that historical native vegetation treatments, including sawgrass and water lily, may reduce water-column TP concentrations to levels below that of the cattail and SAV treatments.

Methods

The study was established at the STA-1W Research Site in late April 2010 using a randomized block design with six vegetation types: (1) sawgrass, (2) water lily monoculture, (3) water lily and spikerush mixture, (4) cattail, (5) SAV (southern naiad and musk grass), and (6) a control with no vegetation (soil only, but changed to control-SAV treatment about three months later) (**Figure 5-46**). Each vegetation type is replicated three times, resulting in 18 mesocosms. Each mesocosm is a 6 m × 1 m × 1 m fiberglass tank filled with 40 cm of soil previously obtained from STA-1W. All plant materials were obtained from STA-1W. The plants were transplanted into the mesocosms with different densities based on the vegetation treatment. After transplanting, the water depth in each mesocosm was gradually raised to 40 cm. The inflow water to the mesocosms is pumped from a nearby STA-1W outflow canal. About four months after transplanting (by late August 2010), when vegetation in the mesocosms became established, the HLR in all mesocosms has been maintained at approximately 2.6 cm/d and retention time at about 13–15 days. Briefly, each of the mesocosms received an inflow pulse twice a day (3 a.m. and 3 p.m.) with about 20 gallons each time. Baseline soil and nutrient content were determined at the time of planting. Measurements of water, soil, and plants were started in late August 2010. Water quality has been monitored biweekly at the main inflow and at the outflow chamber located at the end of each mesocosm. Water quality parameters measured include TP, dissolved organic carbon (DOC), total dissolved Kjeldahl nitrogen (TDKN), and dissolved calcium (Ca^{2+}). All measurements will be completed by December 2012.

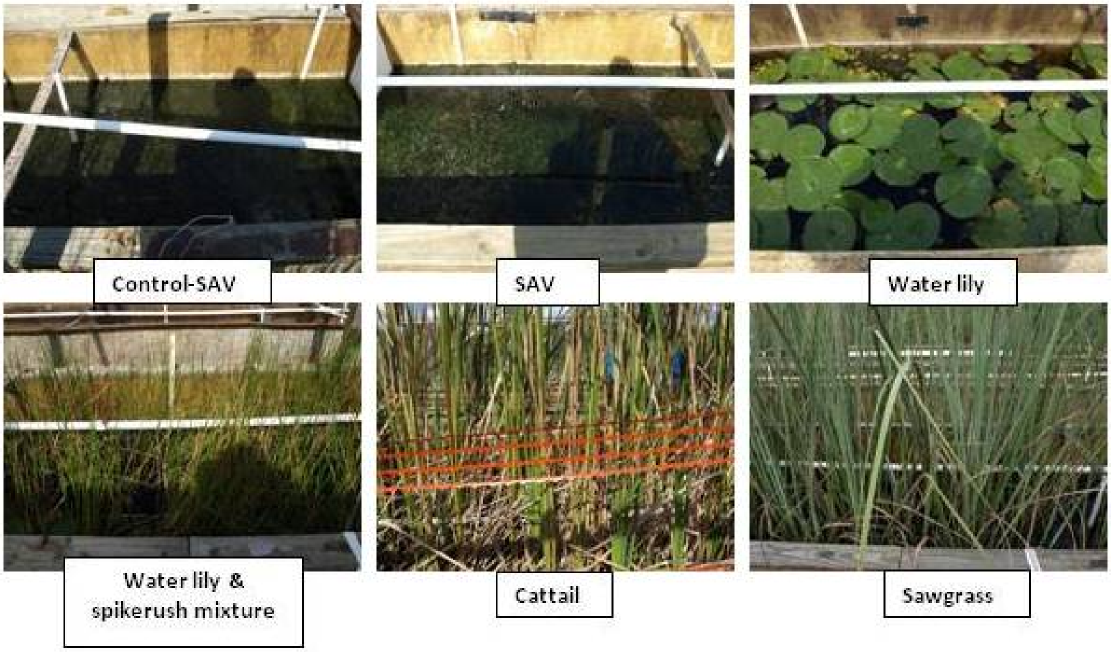


Figure 5-46. Six vegetation types being tested for the STA-1W phosphorus mesocosm study to determine the efficacy of the different species in removing low level P (photos by the SFWMD).

Results and Discussion

Surface water TP (both inflow and outflow) is the primary parameter measured to assess P removal efficacy among the six vegetation treatments. Average inflow TP concentrations were 24.1±6.1 ppb during late August 2010 and May 2012 (a period of 20 months). The outflow TP concentrations can be divided into two major periods, although they varied with the vegetation treatments (**Figure 5-47**). About four months after the initiation of the study, all treatments exhibited markedly higher outflow TP relevant to the inflow, up to three to four times as high. This suggested that soil flux might be affecting the outflow TP concentration during that period regardless of vegetation treatment. This trend observed was similar to what has been observed in some newly established constructed wetlands, where outflow concentrations have exceeded inflow concentrations during start-up and stabilization period. The magnitude of soil P flux in the mesocosms was particularly influenced by the very low TP concentrations for this study. The soil used for the mesocosms was previously enriched STA soil, which contain labile P.

Afterwards, the outflow TP concentrations of all the vegetation treatment mesocosms (except for the water lily and spikerush mixture) showed a gradual decrease, but remained higher than the inflow TP. By February 2012, approximately 19 months from start-up, the outflow TP concentrations were similar to the inflow for five of the six treatments. This trend lasted until May 2012. However, the outflow TP concentrations of the water lily and spikerush mixture were exceptional in terms of magnitude and duration of the P spike. Starting around December 2010, the outflow TP concentration of this treatment increased to approximately 300 ppb in March 2011, then gradually decreased, but remains higher than inflow almost two years after the study. The extremely high outflow TP concentration and an extended period of such high outflow TP is likely associated with the quick growth and decomposition rates of spikerush.

Results indicate that the seasonal variation in inflow concentration DOC, TDKN, and Ca is not comparable with the observed variation in inflow TP (**Figure 5-48**). The seasonal patterns of inflow DOC and TDKN concentrations were similar with an apparent decrease between March and June 2011 regardless of the vegetation treatments. However, the differences between the inflow and outflow for the two parameters differed. For DOC the outflow concentrations were, in general, greater than the inflow concentrations during the first 14 months after start-up; then they approached the inflow concentration levels. In contrast, for TDKN the outflow concentrations regardless of the vegetation treatments were, in general, lower than the inflow concentrations, except for the three months between March and June 2011. For Ca, differences between the inflow and outflow concentrations varied greatly with the vegetation treatments (**Figure 5-48**). For the two treatments with SAV (SAV and control-SAV treatments); the outflow Ca concentrations were consistently lower than the inflow concentration. The sawgrass treatment showed an opposite trend; the outflow Ca concentrations were consistently higher at the outflow than at the inflow up to April 2012. Yet, for the other three treatments (water lily, water lily and spikerush mixture, and cattail) the outflow Ca concentrations were similar to the inflow concentrations. Further data collection and analyses are in progress and is planned to continue until WY2013. Results will be presented and discussed as they become available.

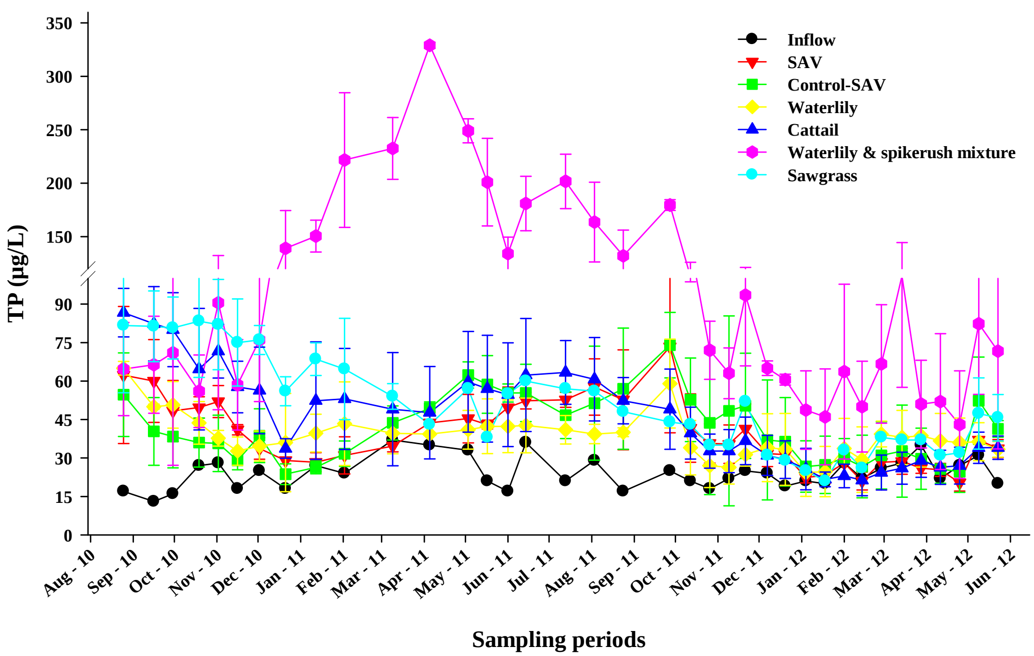


Figure 5-47. Temporal dynamics of surface water TP of inflow and outflow for six vegetation treatments between August 2010 and May 2012.

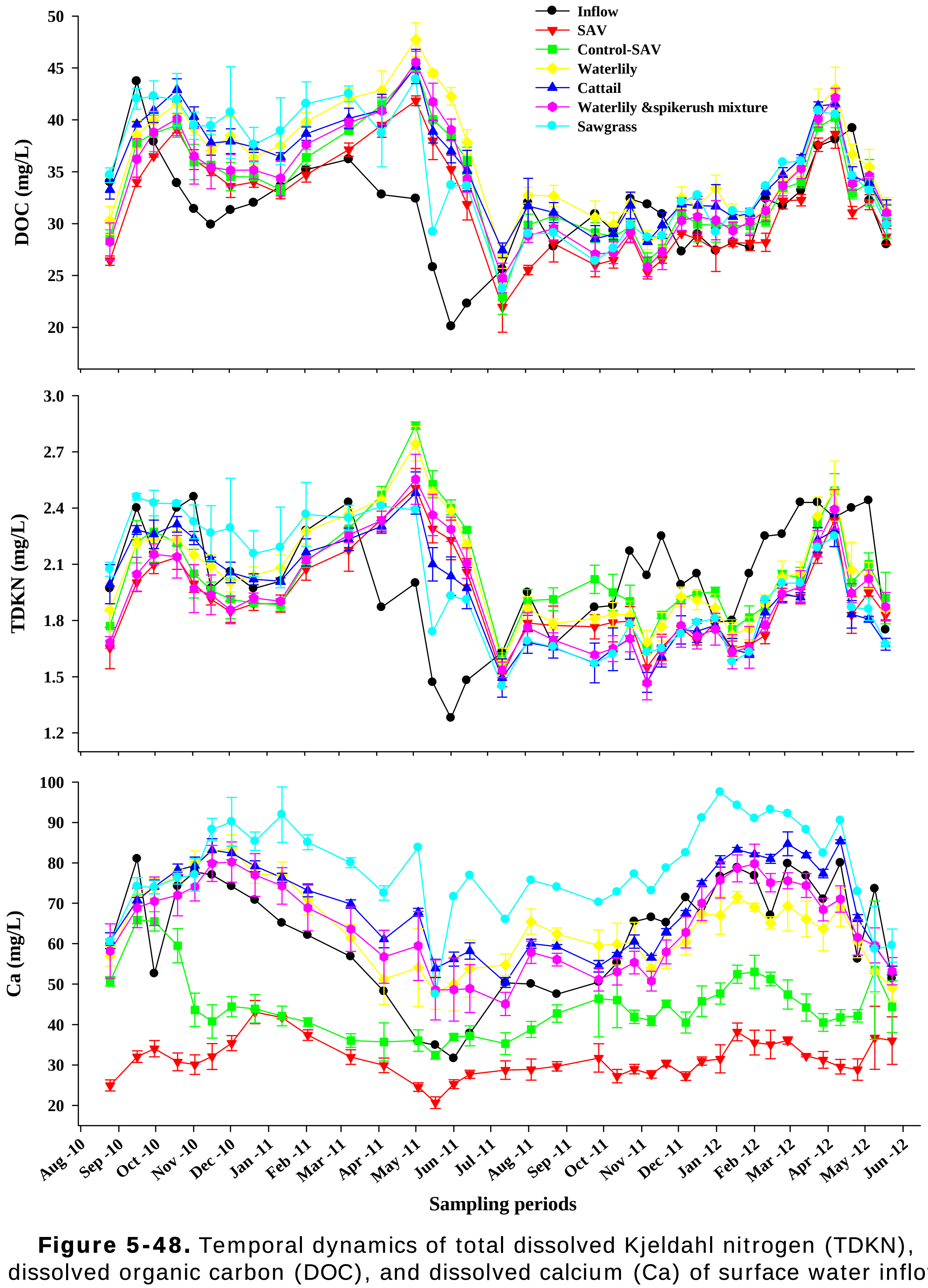


Figure 5-48. Temporal dynamics of total dissolved Kjeldahl nitrogen (TDKN), dissolved organic carbon (DOC), and dissolved calcium (Ca) of surface water inflow and outflow for six vegetation treatments between August 2010 and May 2012.

EFFECT OF WATER-LEVEL DRAWDOWN ON CATTAIL COMMUNITIES IN STA-3/4 CELL 1A

Hongjun Chen

Changes in hydrologic regimes in a marsh can have subtle to drastic effects on the southern cattail (*Typha Domingensis*) (Grace, 1989; Chen et al., 2010). Cattail species can be eliminated under extended periods of deeper water level conditions (Apfelbaum, 1985; Sojda and Solberg, 1993). Shallow water is ideal for broadleaf cattail (*T. latifolia*) germination (Sojda and Solberg, 1993). After broadleaf cattail is established, this species withstands water level fluctuation between 55 and 120 cm for a two-year period, but following two years of deep water condition, about half of the species cannot produce living sprouts and stem densities are 50 percent lower than the previous year (Beule, 1979). Also, extended deepwater conditions can cause the formation of southern cattail floating mats in the STAs (Chen et al., 2010). Apfelbaum (1985) has reported mature broadleaf cattail mortality at water depths of 64 cm. Therefore, maintaining water depths at levels optimal to cattail growth and survival is an important management strategy in the STAs.

Cell 1A of STA-3/4 has been experiencing prolonged periods of deep water conditions since it began operation in 2003 (Pietro et al., 2010). A target water depth has been set at 1.25 feet (38 cm) for EAV treatment cells in the STAs. However, heavy hydraulic loading, particularly during storm events has impacted cattail coverage and density in the northern portion of this cell and the adjoining Cell 2A (Pietro et al., 2010). The water level in this cell was drawn down during the dry season of 2010 and 2011 to encourage new cattail growth and improve overall vegetation condition. The objective of this study was to evaluate if water level drawdown provides significant benefits to cattail communities and make recommendations on whether this practice can be used as a periodic management strategy in the STAs.

Methods

Water-level drawdown events were carried out through the use of temporary pumps in Cell 1A in March 2010 and March 2011, respectively. During the dry season of 2010 and 2011 water levels in this cell were lowered to near ground elevation in an effort to encourage vegetation to regrow. In 2010, early rainfall in the last week of May resulted in a short drawdown period with water depths of less than 6 inches for 17 days. In 2011, the water-level drawdown lasted approximately 110 days (from March 1 to June 23) with water depths of less than 6 inches for more than 100 days. As a result of a regional drought and lack of supplemental water, the cell dried out completely (water level below the ground surface) for 63 days in 2011.

Twenty-four plots were established for vegetation-related monitoring in Cell 1A. For comparison purposes, 10 plots were randomly selected and established in Cell 2A of STA-3/4 to serve as a reference site because of the similarity in vegetation and hydrology between the two treatment cells. Each plot was 2 m by 4 m and marked with PVC pipes. All plants in each plot were counted according to two categories, juvenile (<1.5 m tall) and adult (>1.5 m tall) in February and July 2010, and February, July, and November 2011. Water depth was measured at the four corners of the plots during the vegetation survey.

Results and Discussion

During the 2010 dry season, there was little change in hydrologic conditions caused by the brief drawdown period in Cell 1A (**Figure 5-49**). The water level was lowered to 6 inches for about 17 days (from May 12 to May 28). In 2011, the drawdown started on March 1 and ended on

June 23. During the drawdown period, the cell had a 63-day dry-out (water level below the ground surface). Heavy rainfall events in the basin followed the drawdown period, necessitating the delivery of water into the STA treatment cells and resulting in water depths of 2.4 ft in Cell 1A in a week (June 26 to July 2).

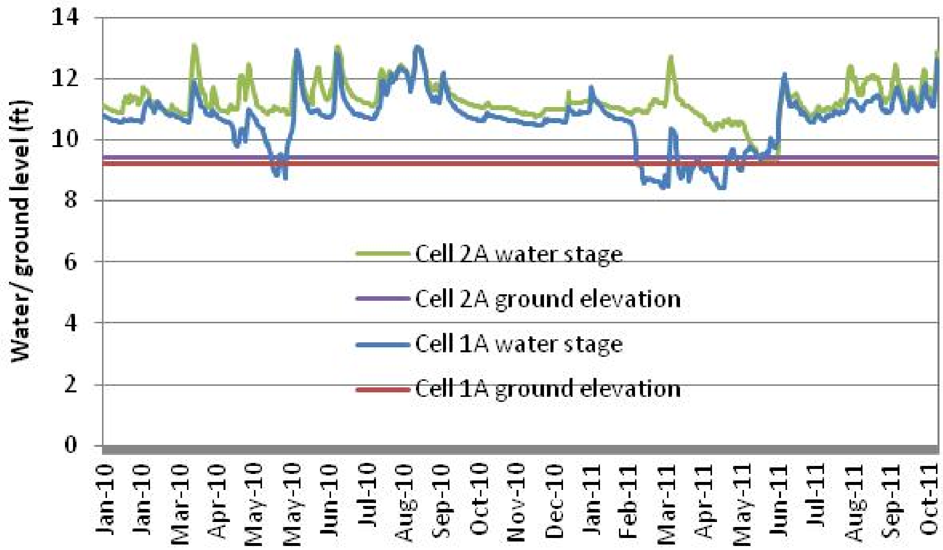


Figure 5-49. Average water stages and ground elevations in STA-3/4 Cells 1A and 2A from January 2010–October 2011.

Due to the short-period drawdown in 2010, the difference in total, adult, and juvenile cattail density between the two treatment cells was not substantial in July 2010 (**Figure 5-50**). In contrast, the difference in total and adult cattail density between the two cells was obvious in July and November 2011, following the second drawdown. However, juvenile cattail density did not reflect changes in hydrologic conditions and was likely not affected by the water-level drawdown but by the season. Also, total cattail density increased in Cell 1A in July and November 2011 compared to the pre-drawdown in February 2010.

Both the field observation (**Figure 5-51**) and quantitative vegetation survey indicated successful recruitment and establishment of cattail seedlings in southern end of Cell 1A following the 2011 drawdown. A short drawdown period, such as the 2010 drawdown event, did not result in significant improvement in cattail establishment.

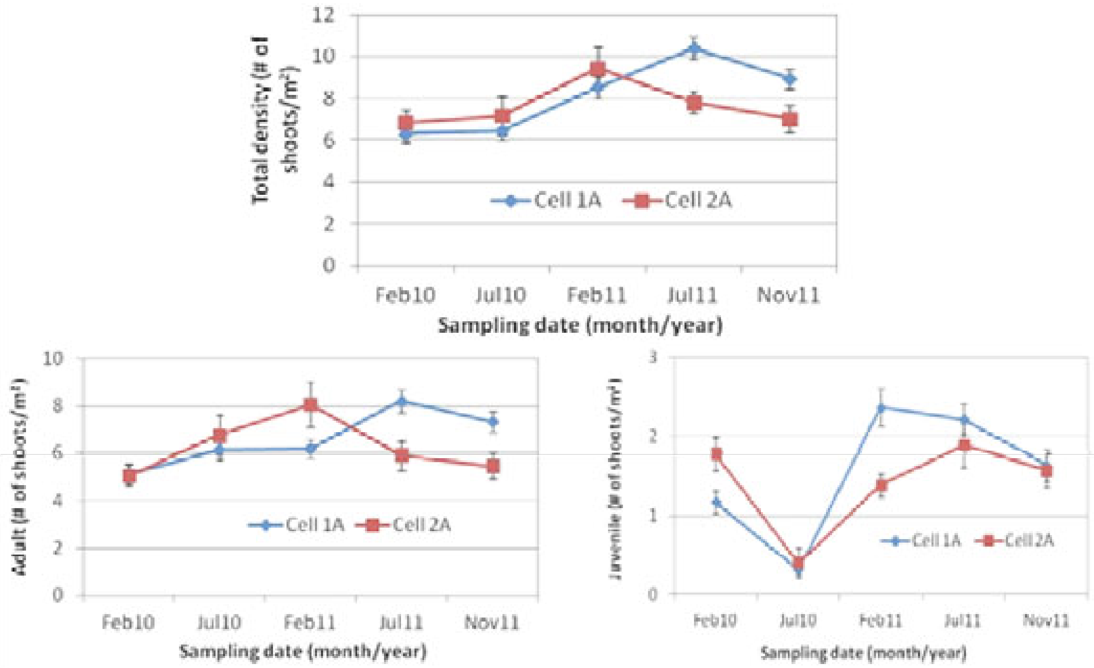


Figure 5-50. Changes in total cattail shoot density, adult cattail density, and juvenile cattail density (mean ± SE) in STA-3/4 Cells 1A and 2A from February 2010–November 2011.

Figure 5-51. Recruitment and establishment of seedlings following water level drawdown in southern Cell 1A of STA-3/4 (upper; July 25, 2011). Pre-drawdown (lower left, February 16, 2010) and post-drawdown (lower right, November 21, 2011) cattail communities in plots of Cell 1A.

COMPARISON OF SOIL CHARACTERISTICS AND PHOSPHORUS STABILITY BETWEEN EMERGENT AND SUBMERGED AQUATIC VEGETATION CELLS OF STA-2

Delia Ivanoff, Manuel Zamorano and Rupesh Bhomia

Phosphorus reduction in the STAs is carried out by the various physical, chemical, and biological processes such as settling, filtration, oxidation-reduction, adsorption, coprecipitation, and plant uptake. These processes primarily take place at the soil-water-plant roots interface, assisted by microbes in the water column and within the soil layer. STAs exhibit variable treatment performance over time and space, as influenced by factors such as antecedent land use, nutrient and hydraulic loading, vegetation composition and condition, soil type, cell topography, cell size and shape, extreme weather conditions, construction activities, and regional operations (Germain and Pietro, 2011). Detailed knowledge of these interrelated factors and linked processes could play a key role in finding ways to optimize and sustain STA performance.

STA-2 Cell 1 became operational in WY2002, Cells 2 and 3 in WY2003, and Cell 4 from WY2009 to WY2010. Three of these cells contain areas that were previously not farmed (Cell 1, most of Cell 2, and a small portion of Cell 3) while the remainder of these three cells and Cell 4 were previously under agricultural production. The antecedent soil in this STA is primarily muck. The dominant plant communities in Cells 1 and 2 are cattail with sparse sawgrass. The northwestern portion of Cell 2 is SAV/open water and in 2009, the southernmost portion of Cell 2 was sprayed to allow for establishment of SAV communities. For the purpose of this study, Cells 1 and 2 are designated as EAV cells and Cells 3 and 4 are SAV cells.

The pattern of P accretion and the nature of P forms found in STA soils have a direct implication on the short-term bioavailability and long-term sequestration of P. Improved understanding of the quality and quantity of P pools in the accreted soil layer of STAs could help with developing management strategies for optimizing P removal performance. As discussed earlier, there are three primary differences between STA-2 cells: antecedent land use, dominant vegetation types, and hydrologic pattern. These are hypothesized to influence the characteristics of the soil that affects P accretion and stability in these cells. The objective of this study was to (1) compare key soil characteristics and spatial patterns in P distribution between EAV and SAV cells, and (2) determine the relative proportion of reactive and stable P pools in floc, recently accreted soil (RAS), and pre-STA soils, as indicators of soil P stability.

Methods

Soil Characteristics

Data analysis and evaluation were performed on floc and soil samples from Cell 2 (EAV) and Cell 3 (SAV) that were collected in 2009 (**Figure 5-52**). Sampling locations followed a systematic grid design at 1,333 ft x 1,333 ft. Intact cores were obtained using a 9.6-cm internal-diameter stainless steel corer, then extruded and sectioned into floc and upper 10-cm soil layers. Floc and soil samples were analyzed for bulk density (BD), ash-free dry weight (AFDW), TP, TN, TC, and total calcium (TCa). Summary statistics were performed for each chemical parameter and values were plotted with means, medians, interquartile ranges, and the 10^{th} and 90^{th} percentiles.

Spatial analysis for TP concentration was also performed on the floc and soil layers using a spline tension interpolation method [ArcGIS version 9, Spatial Analyst, Environmental Systems Research Institute (ESRI), Redlands, CA], to include as many observations in the calculation process as possible. Interpolated maps were created to depict any spatial variability in soil characteristics within each cell.

Soil Phosphorus Stability

A total of 27 intact soil cores were collected from May to June 2011 from STA-2 Cells 1, 2, 3, and 4 along transects parallel to water flow direction (**Figure 5-52**). Soil P pools [inorganic P (Pi), organic P (Po), and residual P] were measured using a sequential chemical fractionation based on the method used by Ivanoff et al. (1998). The procedure involved extraction (1:50 dry sediment-to-solution ratio) with 1 M HCl followed by 0.5M NaOH. The fraction extracted by HCl is comprised of labile inorganic P and also P that is bound to Ca, Mg, Fe, and Al, while the fraction that was extracted by NaOH represents organic P associated with fulvic and humic fractions. Phosphorus remaining in the sediment after sequential extraction, which is considered non-reactive or stable, was measured by ignition method (Andersen, 1976). Extracts from each of these fractions were analyzed for soluble reactive phosphorus (SRP) and TP. Results were compared using Student's t test.

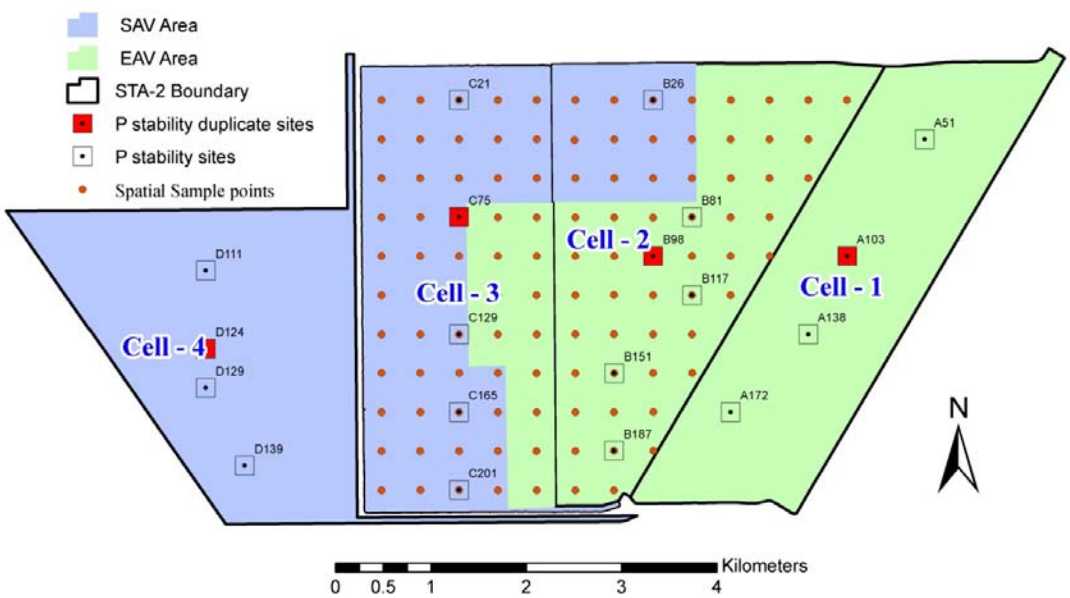


Figure 5-52. Locations of spatial soil sampling in Cell 2 (EAV) and Cell 3 (SAV) for the phosphorus stability study in Cells 1–4 of STA-2.

Results and Discussion

Bulk Density, Ash-Free Dry Weight, Total Nitrogen, Total Carbon and Total Calcium

Floc and upper soil layer BD in the SAV cell were significantly higher than in EAV cell, primarily as a result of the type of residue that has accreted in these two cells (**Figure 5-53**). Based on the BD, AFDW, and TCa results, the SAV cell has been accreting more mineral matter in the floc layer from SAV decomposition while EAV cell has been accreting more organic matter in the floc layer from EAV decomposition. There were no differences in AFDW in the soil layer. As an indicator of organic matter (OM) content, AFDW values reflect the properties of the primary source of soil accretion, for example, areas with larger macrophytes are expected to accrue materials with higher AFDW. In the EAV cell, floc AFDW was significantly higher than in the SAV cell, while the soil layer showed comparable AFDW results for both cells.

TC and TN were significantly higher in EAV cell floc than in SAV cell floc, likely a result of high productivity of the emergent vegetation in Cell 2 compared to SAV in Cell 3. At the soil layer, there was no significant difference in TC concentration while TN was significantly higher in EAV cell soil. TCa accrued in the STAs as a result of precipitation, particle settling, and through biomass turnover. Results show a significantly higher floc TCa concentration in the SAV cell than in the EAV cell (**Figure 5-53**). There was no significant difference on soil layer TCa between the two cells.

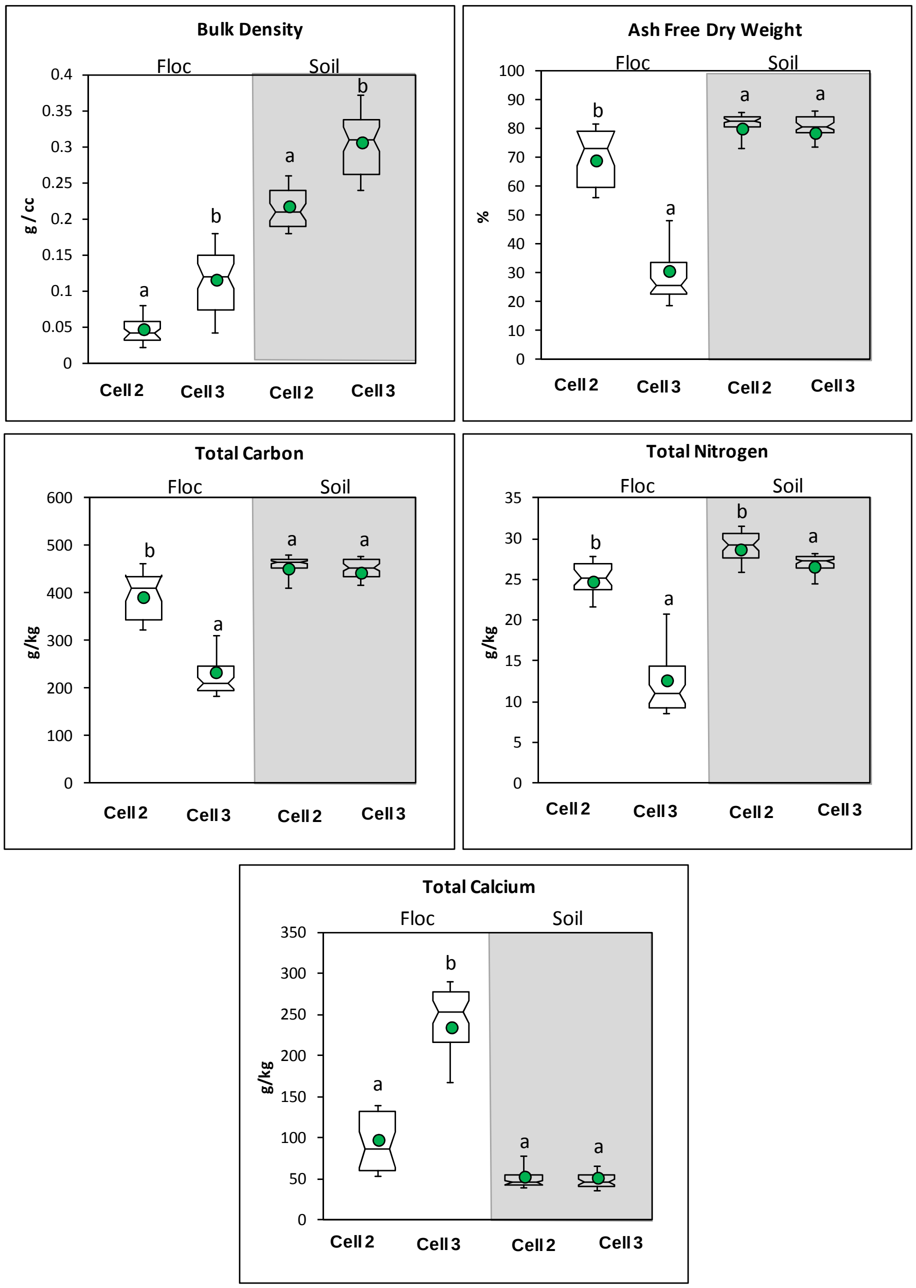


Figure 5-53. Comparison of bulk density, ash-free dry weight, total carbon, total nitrogen, and total calcium between Cell 2 (EAV) and Cell 3 (SAV) floc and upper 10 cm soil layers. The letters (a, b) represent significance of difference in results between Cell 2 and Cell 3 for each of the layers; a difference in letters denotes a significant difference.

Total Phosphorus

In both cells, floc TP concentration was significantly higher than soil TP concentration (**Figure 5-54**). Floc TP concentration in the EAV cell was also much higher than in the SAV cell, at 1,436 ± 423 and 827 ± 298 mg/kg, respectively. There was no significant difference in TP concentration in the underlying soil layer (490 ± 219 and 484 ± 208 mg/kg in the EAV and SAV cells, respectively). Results did not indicate a definitive downstream (inflow to outflow) gradient in floc TP concentration in either cell (**Figure 5-55**). Based on this observation, and the floc depth distribution within these two cells, it is likely that there is some movement of floc material within the cells. Within the upper 10 cm soil layer, results show generally higher concentrations of TP in the upper than the lower region of the EAV cell (**Figure 5-56**). This pattern was not observed in the SAV cell, where there was no distinct downstream gradient for soil TP concentration.

Floc and soil P storage (3.39 ± 2.51 and 10.35 ± 4.1 g/m^2, respectively) within the SAV cell were higher than those found in EAV cell floc and soil (8.97 ± 6.49 and 14.84 ± 7.01 g/m^2, respectively) (**Figure 5-54**). Generally, P storage is higher in the soil layer than in the floc layer. These values are calculated based on bulk density, hence, the higher values of P storage were found in the SAV cell (with predominantly mineral soil) than in the EAV cell. Also higher P storage was found in the consolidated soil than in the floc layers of both cells.

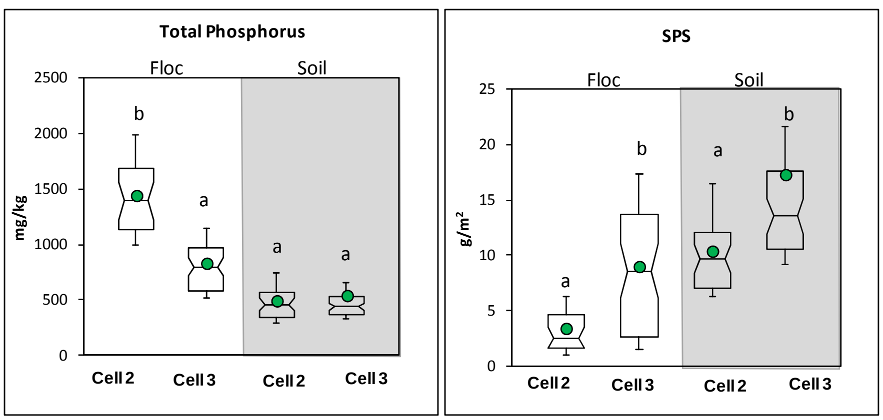


Figure 5-54. Comparison of TP concentration and soil P storage (SPS) between Cell 2 (EAV) and Cell 3 (SAV) floc and upper 10 cm soil layers. The letters (a, b) represent significance of difference in results between Cell 2 and Cell 3 for each layer; a difference in letters denotes a significant difference.

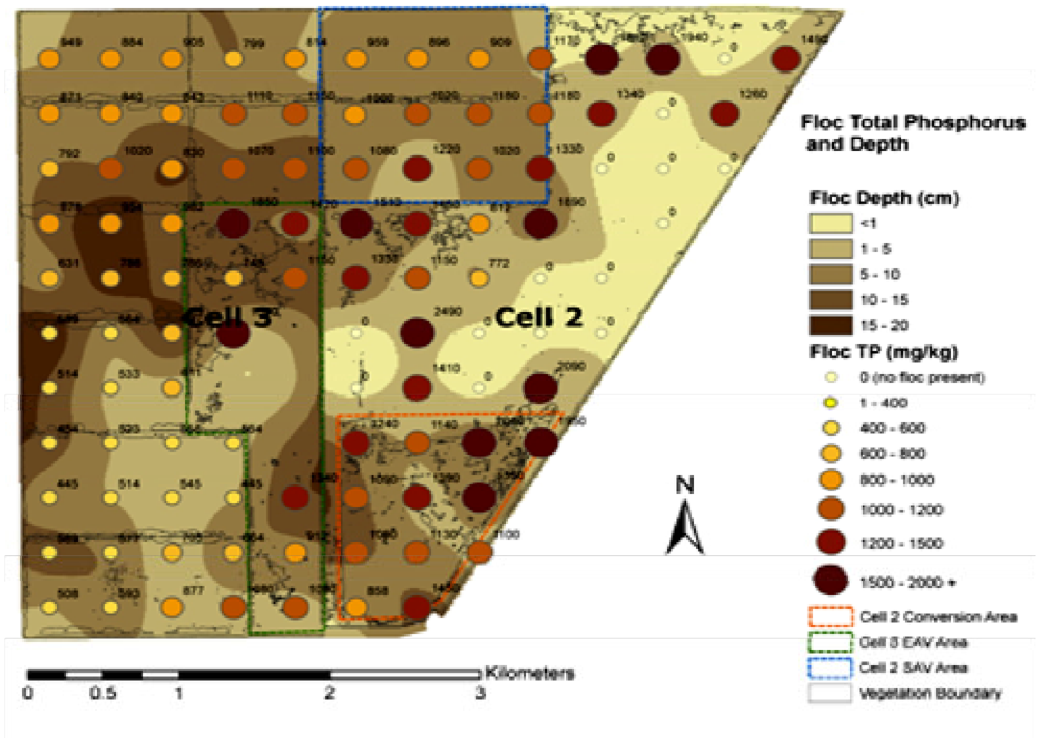


Figure 5-55. Spatial distribution of TP in the floc layer in STA-2 Cells 2 and 3 based on the 2009 soil sampling event.

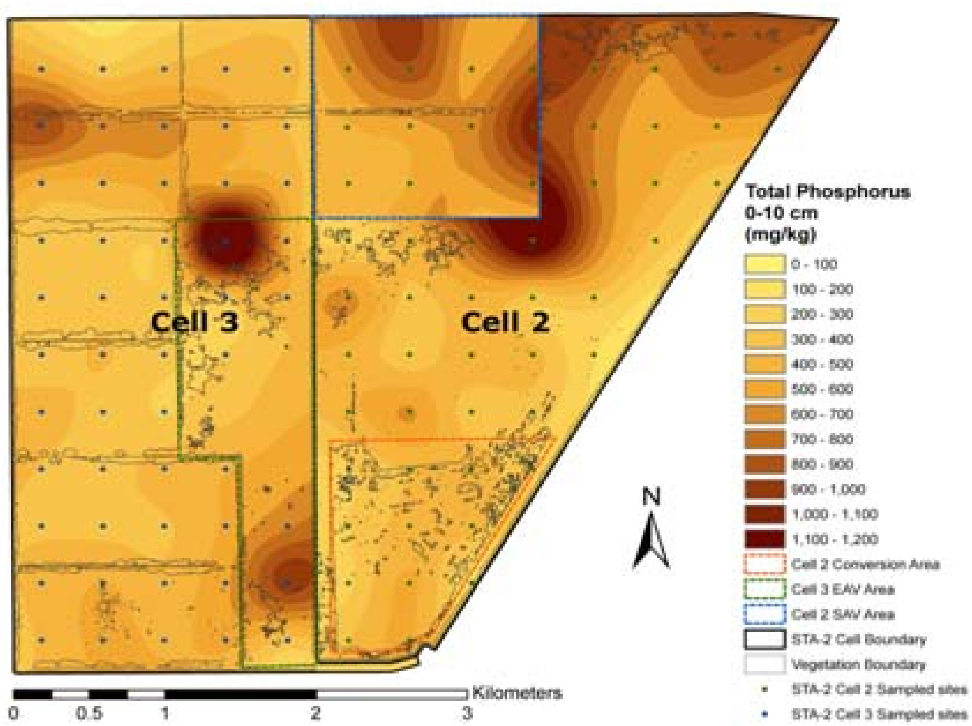


Figure 5-56. Spatial distribution of TP in the upper 10 cm soil layer in STA-2 Cells 2 and 3 based on the 2009 soil sampling event.

Reactive and Stable Phosphorus Pools

Within the floc layer, Po concentration was significantly higher in the EAV cell ($p<0.001$); correspondingly, Pi was higher in the SAV cell floc layer (**Table 5-15**). Within the RAS layer, Pi was also significantly higher in the SAV cells, while in the pre-STA soil layer, Pi, Po and residual TP concentrations were significantly higher in the SAV cells (**Table 5-15**).

The relative size of Pi and Po pools (percentage of soil TP) differs between the EAV (Cells 1 and 2) and the SAV cells (Cells 3 and 4) for the floc, RAS, and pre-STA soil layers (**Figure 5-57**). In all cases, the reactive P pool is much larger than the stable P pool. Within the floc layer, 71 percent of the EAV cell (Cells 1 and 2) soil TP was in reactive form, which was slightly greater than the reactive P pool found in the SAV cells (Cells 3 and 4) (66 percent). In the RAS layer, the proportions of reactive and labile fractions are comparable between the EAV and SAV cells, with 64 and 67 percent of TP, respectively, as reactive and the remaining fraction as stable P. In the EAV cells, the higher percentage of residual (stable) P in the RAS (29 percent of soil TP) than in the floc layer (36 percent of soil TP) indicates potential stabilization of the reactive Po fraction into residual P forms, likely accelerated by the periodic dryout of these cells. This trend was not observed in SAV cells, which have not experienced dryout prior to this study. Within the pre-STA soil layer, the stable P fraction is much higher in the EAV cells (32 percent of soil TP) than in SAV cells (17 percent of soil TP).

The SAV and EAV cells of STA-2 did not differ significantly in relative proportion of reactive and stable P pools (**Figure 5-57**). Reactive P constituted a major pool of TP in floc and RAS sections of EAV cells and SAV cells, respectively. Floc and RAS sections of EAV cells showed higher organic P fractions (48 and 47 percent of TP, respectively) compared to SAV (19 and 34 percent of TP, respectively). Approximately 35 percent of soil TP is in stable forms, whereas 65 percent is potentially available over a range of soil accretion time scales. Floc, RAS, and pre-STA soil showed some difference in P pools, but no significant differences were observed between reactive and non-reactive pools. Accretion of a Ca-rich marl layer in SAV cells suggests Ca-P co-precipitation as a major P removal mechanism. The organic P pool is subject to mineralization in EAV cells particularly during periods of dry out, and therefore could potentially contribute to internal P loading in the STAs.

Table 5-15. Phosphorus fractions [inorganic P (Pi), organic P (Po), and residual P) in floc, recently accreted soil (RAS), and pre-STA soil for EAV and SAV cells of STA-2. Concentration values are means ±SD in mg/kg; values in parenthesis represent the number of samples.

P Fraction	Floc			RAS			Pre-STA		
	EAV	SAV	p-value	EAV	SAV	p-value	EAV	SAV	p-value
Pi	258±115 (14)	359±198 (7)	0.178	65±54 (14)	200±109 (13)	0.001	30±28 (14)	102±72 (13)	0.002
Po	521±189 (14)	145±47 (7)	<0.001	182±53 (14)	209±124 (13)	0.470	104±35 (14)	162±51 (13)	0.002
Residual P	241±70 (14)	220±37 (7)	0.481	147±47 (14)	193±100 (13)	0.141	71±32 (14)	110±39 (13)	0.012

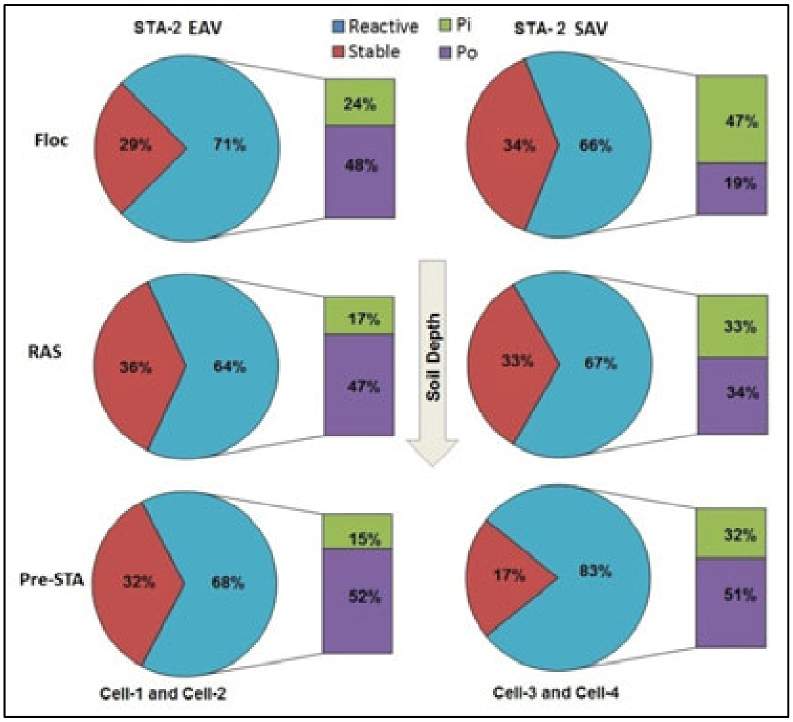


Figure 5-57. Non-reactive and reactive phosphorus pools (percent) in EAV and SAV cells in floc, RAS, and pre-STA soils of STA-2. Reactive fraction is the sum of extractable Pi and Po.

Conclusions and Recommendations

There are differences in the basic characteristics of floc and accrued soil layers of EAV and SAV cells of STA-2. Data confirm that emergent vegetation accrues soils that have higher organic matter content, while SAV results in accrual of mineral soil with high Ca content. Floc, which is the most recently deposited material, has lower BD than the consolidated soil layer. A downstream gradient was evident in the upper 10-cm soil layer in Cell 2, indicating higher P retention in the upper region of the cell. Floc layer TP concentration was significantly higher in the EAV than in the SAV cell, while there were no significant differences in TP concentration in the underlying soil layers between the two cells. Soil P storage shows the opposite trend, the SAV cell floc and soil had significantly higher TP storage than the EAV cell floc and soil layers.

Reactive P pools comprise more than 60 percent of soil TP in STA-2, with a significantly higher fraction in the floc layer, indicating a large pool of P that could be potentially released into the overlying water column. The biogeochemical turnover of P depends on various environmental conditions and processes. For example, highly organic sediment accreted in EAV cells, containing a higher proportion of Po, is subject to oxidation during dryout. When reflooded, mineralized P is released back into the water column, resulting in P spikes. These cells should be managed to stay hydrated when possible, or if an extended dryout occurs, discharge from the affected cells should be delayed until fluxed P can be reabsorbed by the system. Mining of P through plant root uptake from the soil porewater may also be a concern, as vegetation turnover could expedite transport and release of P from the underlying soil column into the overlying water column. Further research is needed to identify means to promote retention of more stable pools of P, and to determine the differences in the form of P (SRP, PP, or organic P) fluxed into the water column between the two cell types.

SPATIAL PATTERNS IN SOIL NUTRIENT RELEASE AND VEGETATION COVER CHANGES IN RESPONSE TO STA DRYOUT

Tom DeBusk[1] and Michelle Kharbanda[1]

STAs periodically experience dryout events as a result of drought conditions or management-related activities. Upon reflooding, P stored in the soils can be remobilized into the water column and released into downstream canals and wetlands. Several factors can potentially affect P release from STA soils. These include, but are not limited to, the degree of prior sediment enrichment, hydrologic pattern (i.e., continuously flooded versus periodic dryout), forms and concentrations of P in soil, minerals, inflow water chemistry, oxidation-reduction potential, vegetation conditions, and management activities. In SAV cells, dryout events can also adversely affect vegetation and may further exacerbate nutrient release, and potentially alter the community characteristics following rehydration.

The Central Flow-way of STA-3/4 experienced a dryout during the 2011 drought. Stage levels were below the mean ground elevation for 23 days (June 3–June 25, 2011). Upon reflooding, elevated outflow TP concentrations were observed for over one month. Researchers compared constituent concentrations in surface waters and porewaters collected within the wetland before and after the dryout event. In addition, SAV cover in the back-end cell of the flow-way was monitored to record the impacts of dryout, as well as the temporal and spatial patterns in SAV reestablishment. These data can provide insight into the impacts of dryout on STA performance (magnitude and duration of P export) and sustainability (recovery and long-term impacts).

Methods

The STA-3/4 Central Flow-way consists of two cells in-series: Cell 2A (EAV) and Cell 2B (SAV) (**Figure 5-58**). SAV cover in Cell 2B was monitored using a semi-qualitative technique in which vegetation species and relative density were visually surveyed. Vegetation monitoring was conducted at 123 stations before (August 12, 2010) and after (July 6, July 20, and August 9, 2011) the dryout-reflood event. Data were analyzed with ESRI's ArcView Spatial Analyst using the spline/tension method.

In December 2009, four monitoring transects, one in the inflow and outflow regions of Cells 2A and 2B, were established (**Figure 5-58**). Porewater and surface water samples were collected at three stations along each transect. Surface water was also collected at one of the five culverts at each of the three levees. Surface waters were analyzed for TP, SRP, ammonia-N, and other constituents. Soil porewaters were collected using a 'sipper' at a depth of 6–10 cm below the surface water/soil interface, and were analyzed for a similar suite of parameters, along with redox potential (Eh). Porewater and surface water sampling was performed on December 3, 2009, under low flow conditions, and again under similar flow conditions on June 30, 2011, following the dryout and subsequent rehydration event.

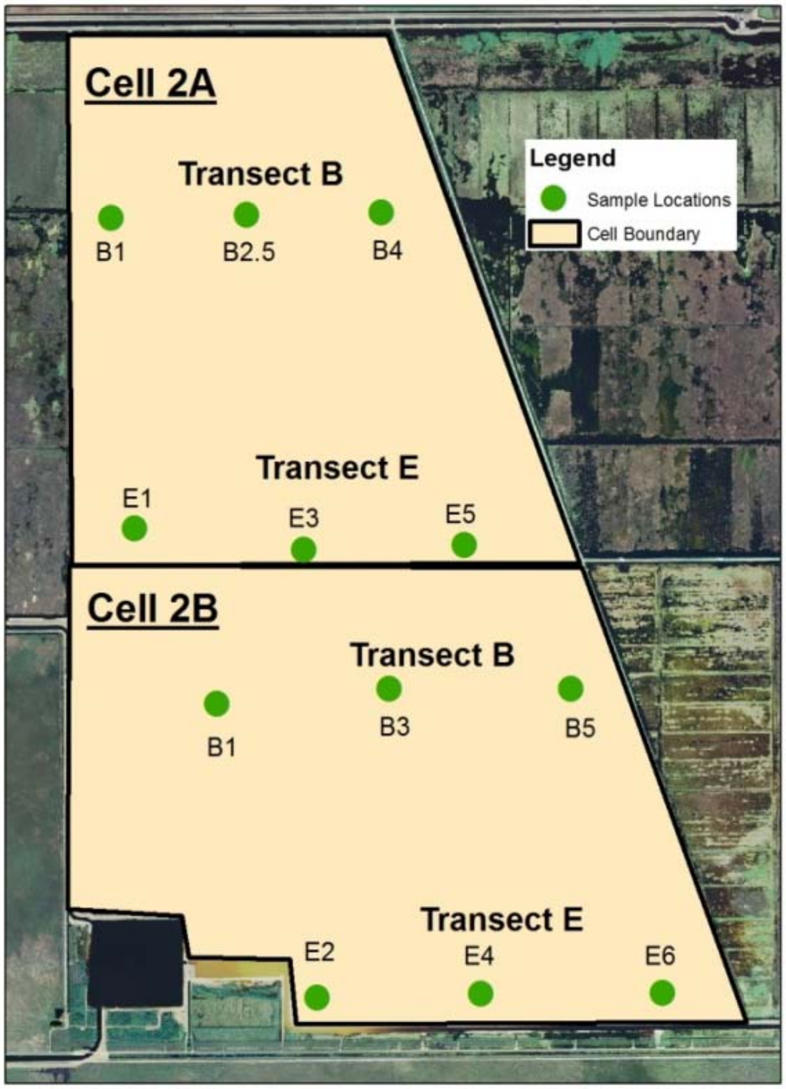


Figure 5-58. Location of internal water quality sampling stations within STA-3/4 Cells 2A and 2B. Transects are identified alphabetically along the north-to-south flow-way. Surface water samples were also collected at one of the five culverts at each levee.

Results and Discussion

Vegetation Effects

The SAV community in Cell 2B was markedly affected by the dryout. During the preceding year, the wetland was dominated by southern naiad and secondarily by musk grass (**Figure 5-59**). Upon reflooding, a sharp decline in cover and density of both species was observed. A rapid expansion of SAV was observed in subsequent surveys during the weeks following reflooding. By August 9, 2011, southern naiad populations remained relatively sparse, whereas musk grass was observed in moderate densities throughout the cell (**Figure 5-59**). Visual assessments of the SAV in early 2012 confirmed that musk grass has remained the dominant SAV species since the dryout event.

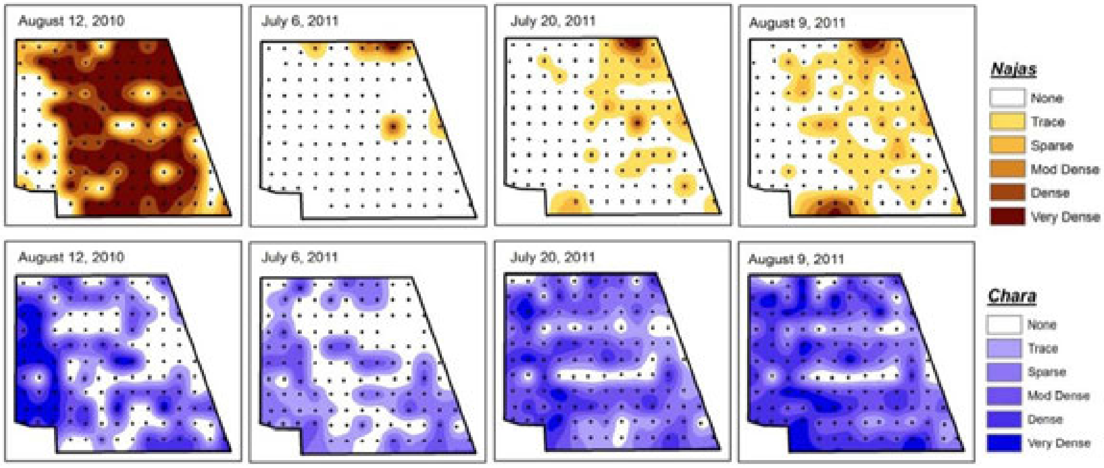


Figure 5-59. Spatial coverage and density of the two dominant SAV species (*Najas* and *Chara*) in late summer 2010 prior to the June 2011 dry down (left panels), and during the two months following wetland rehydration.

Water Quality Effects

Following the 23-day dryout period, reflooding of the STA-3/4 Central Flow-way began on June 26, 2011, and wetland discharges began four days later on June 30. Surface water TP concentrations on June 30, 2011, were extremely high in the outflow region (transect E) of Cell 2B, suggesting TP export (**Figure 5-60**). A broader spatial distribution of high concentrations was observed for ammonia-N, which exhibited elevated levels from Cell 2A, through the entire length of Cell 2B. A prior water quality sampling effort performed on December 3, 2009, under low flow conditions depicted little internal loading of either TP or ammonia-N (**Figure 5-60**). Outflow TP concentrations from Cell 2B declined to below 20 ppb (pre-dryout levels) by August 29, 2011, which appeared to coincide with the successful regeneration of SAV within the wetland (**Figure 5-60**).

Porewater data collected on June 30, 2011, were averaged along each transect to examine SRP, ammonia-N, and Eh gradient profiles. Porewater SRP concentrations varied temporally in a manner similar to ammonia-N, with Cell 2A transect E and Cell 2B transect B exhibiting substantial concentration increases immediately following rehydration (**Figure 5-61**). The similarity in pattern of porewater ammonia-N and SRP, along with the increased Eh at three of the four transects following reflooding (**Figure 5-61**), suggests that organic matter decomposition and oxidation during the dryout may have contributed to the observed nutrient load to the water column.

In conclusion, the STA-3/4 dryout/reflood event resulted in a dramatic change in the SAV community from a system co-dominated by southern naiad and musk grass to one dominated by musk grass. Monitoring will continue in WY2013. Surface water and porewater sampling suggests a broad spatial internal loading of ammonia-N but a more localized internal loading of SRP (primarily at the outflow region of 2B) as a result of dryout and reflooding. Data and observations show that both the massive loss of SAV and soil organic matter decomposition contributed to a spike in internal loading in Cell 2B following a 23-day dryout period.

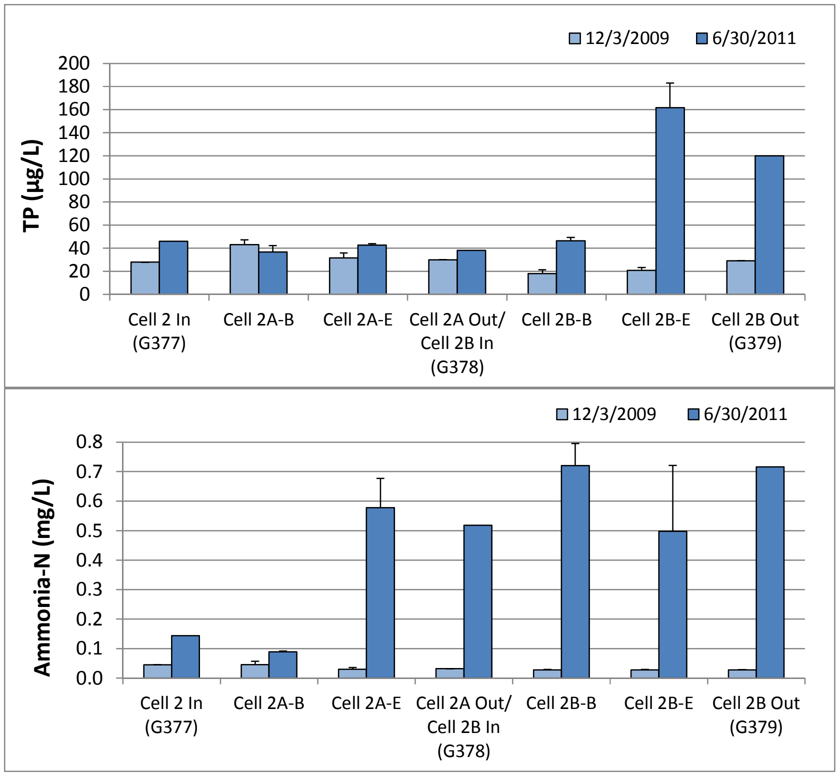


Figure 5-60. Surface water TP (top) and ammonia-N (bottom) concentrations on two sampling dates at the inflow and outflow levees of Cells 2A and 2B, as well as along internal sampling transects.

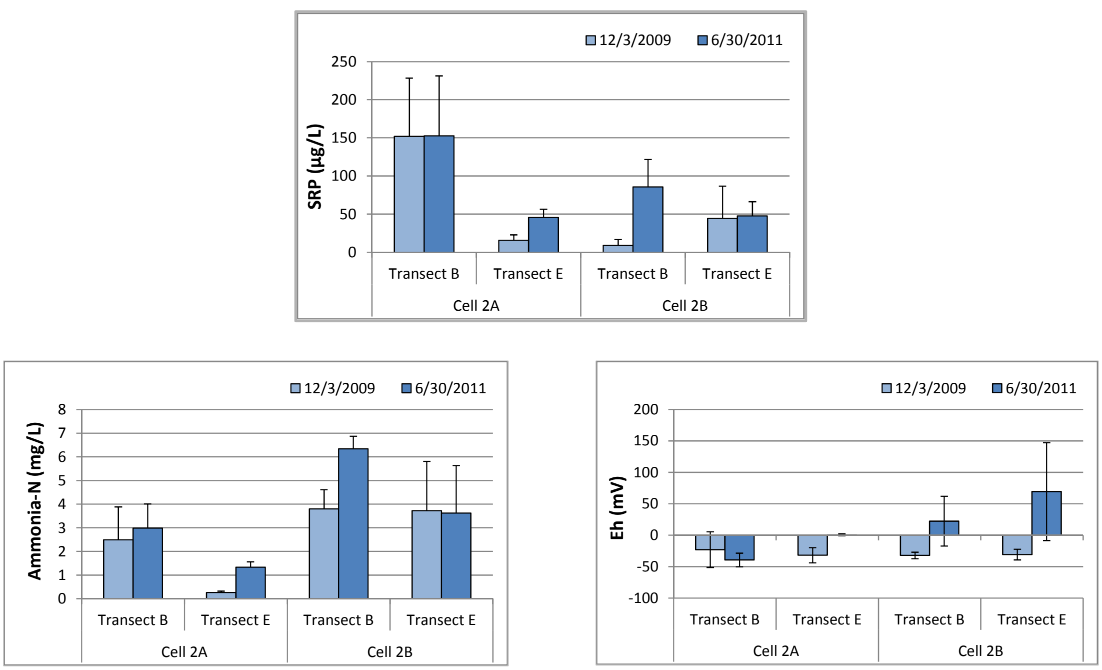


Figure 5-61. Soil porewater SRP (top) and ammonia-N (bottom-left) concentrations, and oxidation-reduction potential (Eh) (bottom-right) on two sampling dates along two internal sampling transects in Cells 2A and 2B.

EVALUATION OF PHOSPHORUS REMOVAL CHARACTERISTICS USING INTERNAL WATER QUALITY TRANSECTS IN STA-5

Tom DeBusk[1] and Michelle Kharbanda[1]

Internal water quality monitoring of P species along STA flow-ways has proven useful for identifying regions of particularly effective or ineffective treatment performance along the inflow-to-outflow gradient. Additionally, when coupled with vegetation surveys, internal transect water quality monitoring enables comparisons of vegetation cover and health with treatment performance. Internal monitoring may also assist with the interpretation of various management activities (e.g., TP loading rate, vegetation management) on STA flow-way TP removal performance and sustainability.

During WY2012, one monitoring event was performed in STA-5 Northern and Central flow-ways (Flow-ways 1 and 2 from the new STA-5/6 scheme). Internal monitoring events also were scheduled to coincide with key operational events (e.g., startup after period of stagnation or dry-down). Collectively, data from numerous internal monitoring events over time for a flow-way or cell facilitate the assessment of key performance factors, such as minimum attainable outflow TP concentration (Juston and DeBusk, 2011).

Methods

For SAV cells, monitoring was performed on multiple internal transects, while for EAV cells, water samples were collected along inflow, mid-region and outflow transects (**Figure 5-62**). Samples are analyzed for TP, total soluble P (TSP), SRP, and selected field parameters (e.g., temperature, pH). Other key constituents (e.g., Ca, DOC) that may influence STA P cycling were analyzed, as deemed appropriate. Data collected along each transect were averaged to produce TP and P species (DOP, SRP, and PP) concentrations profiles.

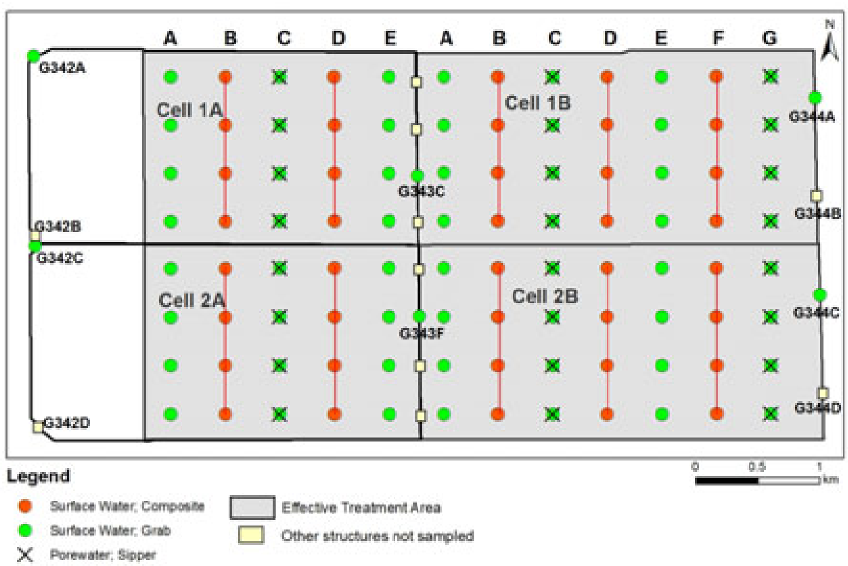


Figure 5-62. Location of internal water quality sampling stations within STA-5 Cells 1A, 1B, 2A, and 2B on August 3, 2011. Transects are identified alphabetically within each cell along the west-to-east flow-way. Grab samples (in green) were analyzed individually, while the samples collected along the red transects were composited in the field prior to analyses.

Results and Discussion

During summer 2011, flows to the EAV cells of the Northern and Central flow-ways began in the first week of July, whereas flow to the SAV cells began on July 17. Due to regional drought conditions, these flow-ways did not receive any water for approximately nine months prior to this time. During the period of no flows, mean stages in Cells 1A and 2A were below mean ground elevation for approximately 200 and 130 days, respectively. SAV Cells 1B and 2B generally remained flooded during this period as a result of delivery of supplemental water directly to these cells from the STA-5 discharge canal. On the day of the internal sampling event (August 3, 2011) and the preceding two-week period, both flow-ways were receiving low to moderate inflows (**Figure 5-63**).

Surface water TP concentrations within Cell 1A fluctuated between 136 and 252 ppb, indicating minimal P removal (inflow and outflow TP was 252 and 240 ppb, respectively) (**Figure 5-64**). These fluctuations were primarily driven by the PP fraction, whereas, SRP concentrations declined from 146 to 60 ppb. Although little P removal occurred within Cell 1A, TP concentrations within the Cell 2A steadily declined from 240 to 17 ppb (**Figure 5-64**).

Surface water P removal exhibited a dramatically different trend along the Central Flow-way. TP concentrations within Cell 2A steadily increased from 147 ppb at the inflow transect to 355 ppb at the outflow transect, indicating substantial internal P loading. The majority of the increase can be attributed to SRP (**Figure 5-64**). Field observations indicate cattail mortality throughout transects A-D, which is a likely source of the internal P loading. Although inflow TP concentrations to Cell 2A were higher than those found at transect A (271 ppb), the inflow sample was collected at G-342C, the culvert that had not received flow since the previous wet season. Surface water TP concentrations within Cell 2B remained high along transects A through F, ranging from 274 to 413 ppb, then declined to 120 ppb at transect G before exiting the flow-way at 206 ppb (**Figure 5-64**). Similar to the observations in the EAV cell, these high concentrations can be attributed to SRP and DOP.

The data depict a uniform reduction in TP with distance from the inflow for Cell 1B (**Figure 5-65**). These data also show that the higher surface water TP concentrations within the Central Flow-way were located in the mid to southern region of Cell 2A and the mid to northern regions of Cell 2B (**Figure 5-65**). Within these same regions of the Central Flow-way, high SRP concentrations were also observed (data not shown).

Dissolved Ca concentrations in Cells 1A (53–58 ppm) and 2A (55–65 ppm) were similar. However, dissolved Ca concentrations in Cell 1B (25–41 ppm) were dramatically lower than in Cell 1A, whereas concentrations in Cell 2B (48–61 ppm) were similar to Cell 2A (**Figure 5-66**).

Collectively, the data indicate different rehydration responses for both flow-ways. While both EAV cells provided little P removal, which would be expected due to the drought-related dry down, the SAV cells differed markedly in initial performance, with Cell 1B exhibiting a pronounced inflow-to-outflow P removal gradient. SAV cover in the two cells was comparable, and the high TP concentration zones depicted in **Figure 5-65** do not represent higher elevation regions that might have been subjected to a more prolonged dry down. The lack of Ca removal in Cell 2B suggests minimal photosynthetic activity by the SAV (effective SAV P removal often occurs in concert with Ca removal), so turbid water conditions may have been responsible for the reduced P removal observed upon post-dryout rehydration. Other potential reasons for these short-term flow-way performance differences are still under investigation.

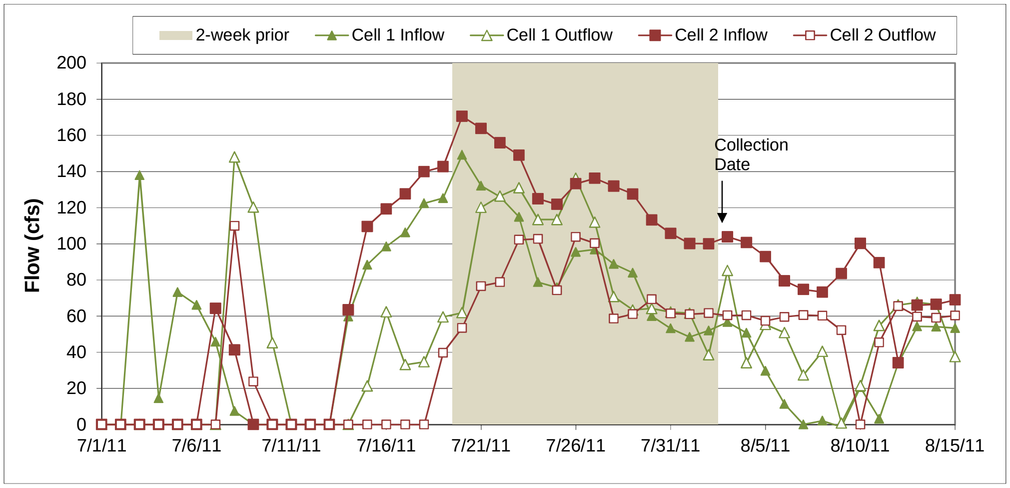


Figure 5-63. Time series of flow into and out of STA-5 Northern (Cell 1) and Central (Cell 2) flow-ways during July 1–August 15, 2011.

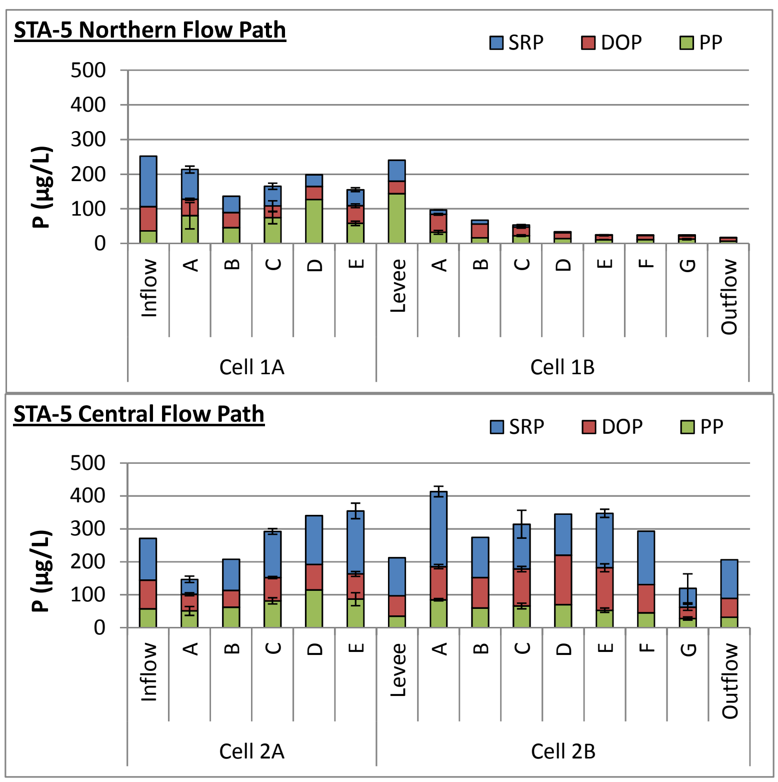


Figure 5-64. Mean surface water phosphorus concentration profiles along the inflow-outflow transects for the Northern and Central flow-ways in STA-5 on August 3, 2011. Error bars represent the ±1 SE of grab stations collected along each transect (n=4). Cell 2A inflow sample was collected at culvert G-342C that had not received flow nine months prior to this sampling event.

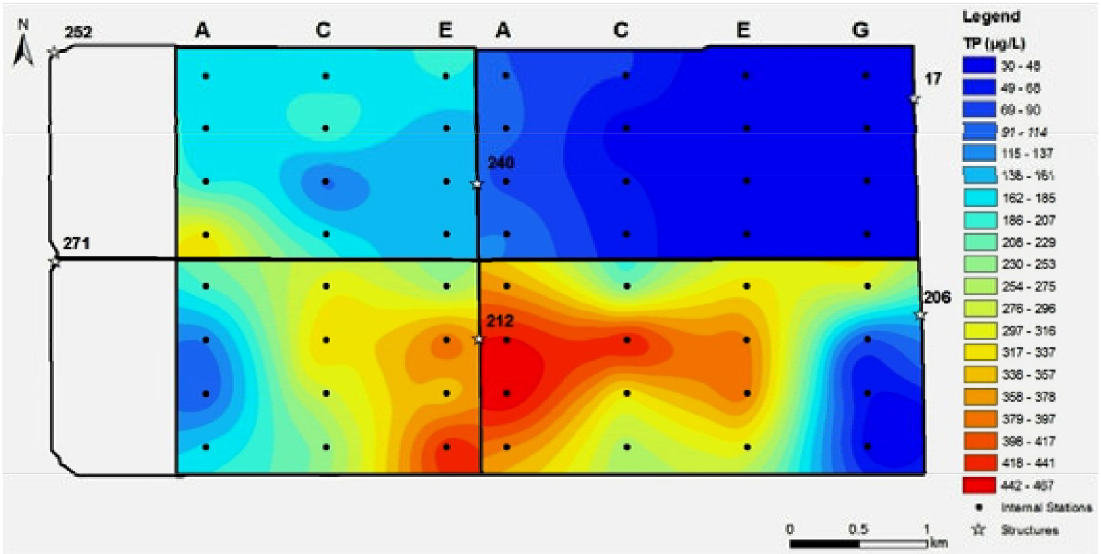


Figure 5-65. Spatial interpolations of surface water TP concentration data collected along the inflow/outflow transects in the Northern and Central flow-ways of STA-5 on August 3, 2011. Note that the TP concentrations from the inflow, mid and outflow structures were not included in the spatial interpolations.

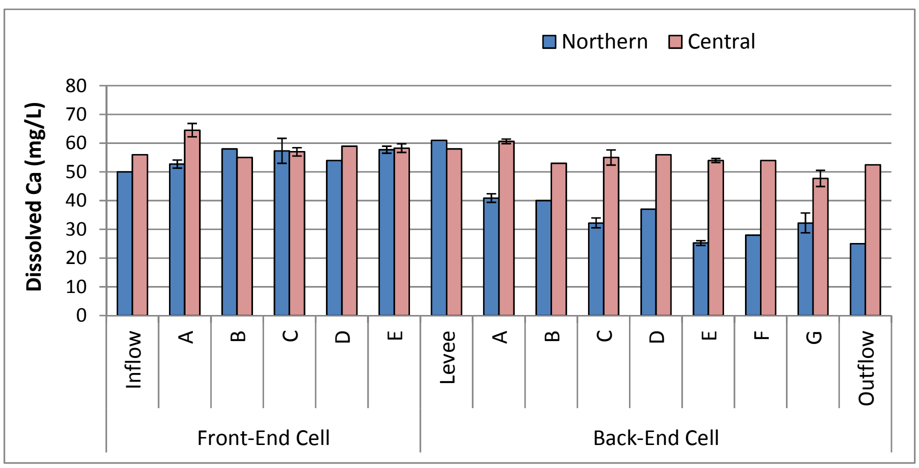


Figure 5-66. Mean surface water dissolved calcium concentration along inflow-outflow gradient for the Northern and Central flow-ways in STA-5 on August 3, 2011. Error bars represent ±1 standard error of grab stations collected along each transect (n=4).

EFFECTS OF EMERGENT VEGETATION ON FLOW DYNAMICS IN STA-2 CELL 2

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Kevin A. Grace[1] and Stacey Galloway[1]

After years of operation, many STA cells now contain dense vegetation stands consisting of both living and dead plant material. Under high flow events, it is hypothesized that the hydraulic resistance created by the dense vegetation contributes to the high water depths observed in the front end of the STA flow-ways. For this effort, water stage monitoring devices were deployed throughout STA-2 Cell 2, which provided data to develop a physically based, spatially distributed dynamic flow model for this wetland. Several model scenarios addressed the following management questions:

- How does stage vary internally within Cell 2, especially under peak inflows?
- What is the spatial extent and duration of water depths greater than 4 ft (1.22 m) for designated peak inflows? Do these trends change in relation to burning/herbicide scenarios (reduced hydraulic resistance by vegetation)?
- Can these estimates be used to evaluate the benefits of vegetation management approaches to minimize hydraulic resistance, such as burning/herbicide?

A synopsis of findings is provided below and more details can be found in a related manuscript (Paudel et al., 2012).

Methods

A physically based, spatially distributed hydrodynamic model of STA-2 Cell 2 was developed based on the framework of the Hydrologic Simulation Engine (HSE) of the Regional Simulation Model (Lal et al., 2005; SFWMD, 2005), which simulates the coupled movement and distribution of overland and groundwater flow. In addition, HSE also simulates hydraulic structures, canal networks, well pumping, levee seepage, and other operational rules and conditions that are common features in the STAs.

The cell was represented by a two-dimensional, variable size finite-element mesh of 1,135 unstructured triangular elements and 632 nodes generated in Groundwater Modeling System v5.1 (Brigham Young University, 2004) (**Figure 5-67**). The triangular mesh elements were approximately 150 m on a side, or about 1 hectare in area, with smaller elements used to define inflow and outflow structures and perimeter canal features. The mesh density was refined along the eastern levee and narrow ditches/channels to better capture local hydrologic effects, and at the inflow/outflow zones to better represent the locations of flow control structures. This mesh resolution was selected to trade-off computation time of each simulation with a reasonable representation of spatial data inputs (topography and vegetation) and outputs (water levels).

Daily average inflow rates and stages at inflow and outflow structures along with daily cumulative rainfall and evapotranspiration (ET) depths were additional inputs to the model. Cell 2 receives inflows through seven gated culverts (G-331A–G, **Figure 5-67**). Water flows southward through the treatment cell into the discharge canal and through a gated outflow spillway (G-332). Topographic data was available from 2010 (**Figure 5-68**, panel a). The model was calibrated to internal stage data recorded at 15-minute intervals from September 23, 2008, through July 31, 2011, by pressure transducers at eight monitoring locations within the cell (**Figure 5-67**).

Vegetation maps were developed from aerial photographs collected on February 11, 2005. Three major vegetation types cover 89 percent of the Cell 2 treatment area (**Figure 5-68**, panel b). These include 53 percent cattail, 19 percent open water with or without SAV, and 17 percent sawgrass. The ET depths were based on lysimeters installed in cattail, open water/algae system, and mixed marsh and predictions from meteorological conditions (Abtew et al., 1995; Abtew, 1996).

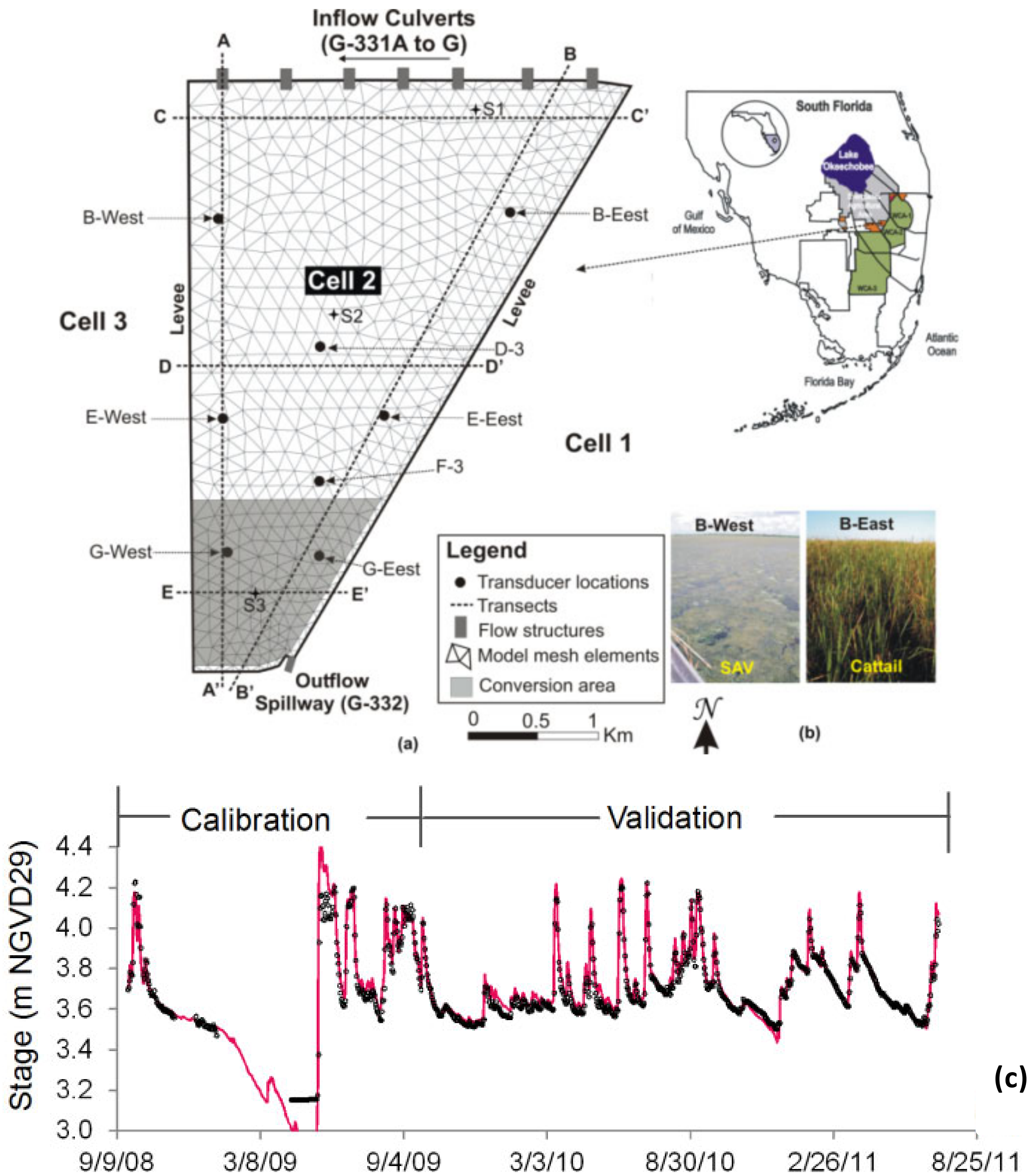

Figure 5-67. Study area in STA-2 Cell 2 location and plan with inflow and outflow hydraulic structures, sampling locations, transects, and computational model mesh (a); photos of vegetation at two sites (b); and daily observed (circles) and simulated (red lines) stage at an internal location (B-East) during the model calibration and validation periods (c).

In April 2009, vegetation in the southern 400 acres of Cell 2 (Conversion Area) was treated with herbicide to convert from EAV to SAV (**Figure 5-67**, panel a). In addition to potential TP removal benefits, conversion of outflow region vegetation to SAV may relieve enough hydraulic resistance to decrease the extent and duration of deep water levels within the cell. To examine the question mentioned above in concurrence with the vegetation conversion, the model was used to compare the outcome of this management action with management alternatives. The primary factor that varied across model scenarios was the spatial extent of the vegetation conversion.

The emergent macrophyte-dominated areas were divided into three zones: Z1, Z2, and Z3 (**Figure 5-68**, panel c). Changes in hydrodynamic variables (i.e., water depth and water level) were evaluated along both longitudinal (AA' and BB') and transverse (CC', DD', and EE') transects (**Figure 5-67**, panel a). The UNB scenario ("unburned") simulated the existing or pre-burn condition. Scenarios BZ1, BZ1-2, and BZ1-3 simulated the effects of "burning" vegetation in zone 1, zones 1 and 2, or zones 1, 2 and 3, respectively. Thus, the scenarios ranged from the existing conditions to complete thinning of all areas supporting emergent vegetation. These scenarios were expected to demonstrate the potential benefits to reducing the flow resistance within the STA-2 Cell 2 as a result of thinning emergent macrophytes via burning or herbicide application. Sixteen peak flow events identified from the time-series inflow data were evaluated because these pulse inflows are generally responsible for deep water conditions in the treatment cell. The wetland area and duration of water depths greater 4 ft immediately after each peak were determined.

Results and Discussion

The 16 peak flow rates ranged from 11.2 to 37.9 cubic meters per second (m^3/s) with a median of 28.9 m^3/s. A gradual stage gradient was observed from north to south (inflow-inflow to outflow-outflow structures) along the flow direction (**Figure 5-69**, panels a and b). However, a sharp change in stage gradient was observed approximately 1.8 and 3.5 km from the inflow-inflow culverts along transect AA' and BB', respectively. After these distances, stage gradients were consistently sharp and stabilized at the bottom end of the cell.

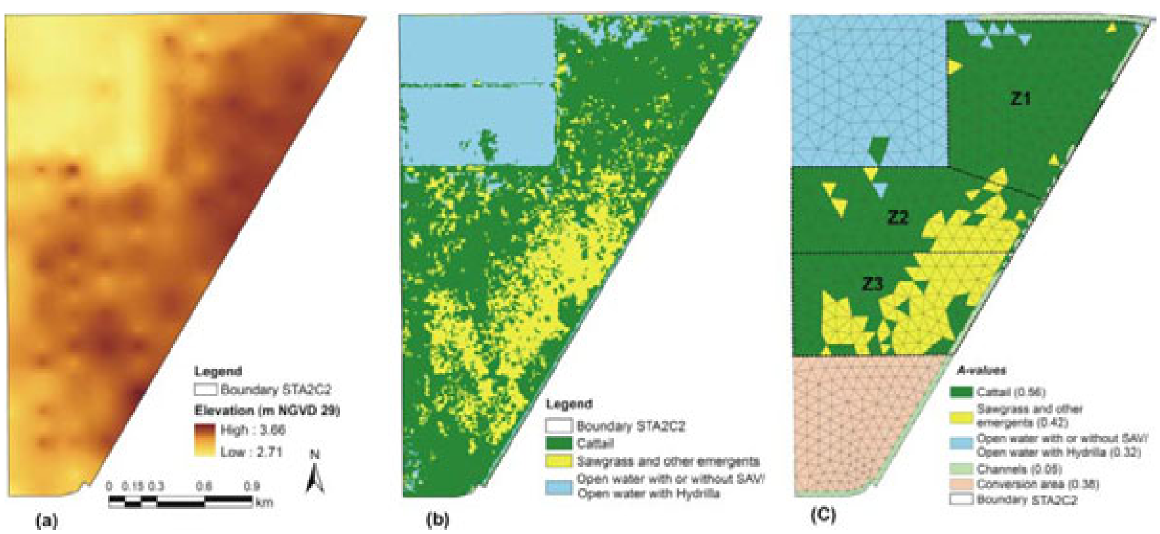

Figure 5-68. Spatial maps of STA-2 Cell 2 (a) bathymetry, (b) major vegetation classes, and (c) flow resistance coefficients used in the model and model scenario zones.

The relationships between daily inflow rates and stage showed a strong regression (r^2 = 0.70) between changes in daily inflow rate and stages near the inflow structures; however, the relationship at the outflow region was relatively weak (r^2 = 0.06; outflow site). In contrast, changes in daily outflow discharges were not correlated to changes in stages at the outflow region (r^2 = 0.06; outflow site), suggesting that outflow operations have less control over the changes in stages. The range of calibrated hydraulic resistance factors (0.56 for cattail and -0.05 for open water/channel) were consistent with the range of Manning's 'n' reported for corresponding mean water depths and similar vegetation class by previous investigators in the STAs (Sutron Corporation, 2007; Min and Wise, 2010).

Most areas within the EAV region remained below the 4 ft water depth even after a large flow pulse (**Figure 5-70**). A maximum 2 percent of the total Cell 2 area was reduced below the 4 ft level by BZ1-3, while above that threshold under existing conditions. Deep water conditions were sustained for long periods when a peak inflow was followed by consecutive flow pulses. For example, depths greater than 4 ft were sustained for 24 days after a peak inflow in May 2009, even in scenario BZ1-3 where all emergent vegetation was thinned, because the peak flow was followed by additional inflow pulses. Therefore, managing both magnitude and timing of peak inflows if possible might be necessary to achieve the desired water depths.

Vegetation thinning operations simulated in this study produced limited reduction in water depths that are probably of little ecological significance. All cattail burning scenarios reduced stages by increasing the discharge capacity of the treatment cell; however, the amount of reduction was much less than expected. Even the scenario with the largest burning area (BZ1-3) resulted in a maximum reduction in stage of about 12 cm at the inflow region and less than 1 cm at the outflow region (**Figure 5-69,** panels c, d, and e). It should be noted that the 22 percent increase in mean velocity after cattail burning may have been too small a change to translate into large stage differences between burned and unburned scenarios.

Collectively, findings suggest that vegetation thinning (i.e., reduced hydraulic resistance from vegetation) may not be effective in minimizing deep water conditions in Cell 2. Potentially damaging periods of sustained high depths were controlled more by reducing inflows to Cell 2 than by vegetative hydraulic resistance. The model presented is flexible and provides a powerful tool to predict spatially and temporally variable responses to structural and operational modifications. With the growing interest in managing emergent macrophytes in the STAs, these results have important implications for developing and testing new strategies to maintain desired water depths and avoid negative ecological consequences or loss of treatment efficacy. However, the generality of these conclusions to other STAs and treatment cells should be investigated.

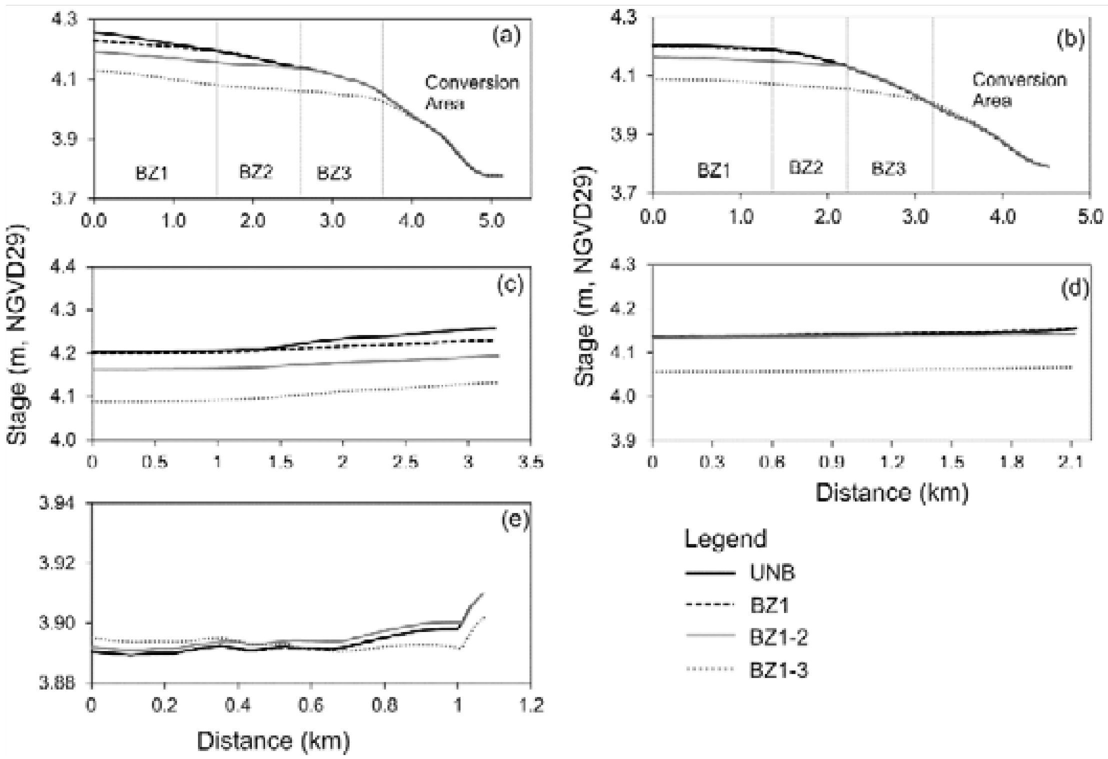

Figure 5-69. Simulated stage profile after a flow pulse in July 2010, along transects: (a) BB', (b) AA', (c) CC', (d) DD', and (e) EE'.

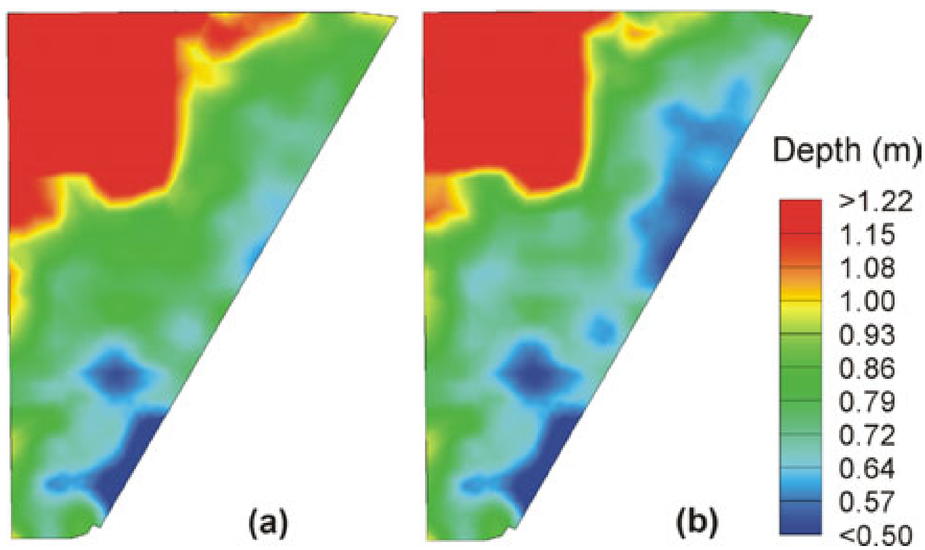

Figure 5-70. Model output of simulated water depths in the emergent vegetation zone after the cell's largest inflow pulse (July 2010), under existing conditions or after vegetation thinning (reduced hydraulic resistance to increase overland flow velocities by 22 percent). Water depths in the northwest corner were more than1.15 m under both scenarios, a result of previous agricultural production; vegetation in that area is typically SAV-dominated.

RECREATIONAL OPPORTUNITIES AND ACTIVITIES

RECREATIONAL FACILITIES

Various public access and recreational opportunities are available in STA-1E, STA-1W, and STA-3/4, including trailheads, boardwalks, and viewing platforms to provide opportunities for scenic and wildlife viewing. Catch and release fishing is allowed from the banks inside the levees at STA-1E. Fishing is allowed by boat or from the bank in the perimeter canals of STA-1W and STA-3/4. A public dual-lane boat ramp offers access to 27 miles of perimeter canals in STA-3/4. STA-1E, STA-1W, and STA-3/4 public facilities are open to the public on Fridays, Saturdays, Sundays, and Mondays. In STA-5, a 100-yard wheelchair-accessible boardwalk/bird blind allows disabled visitors to bird watch and hunt. A trailhead will also be established in this area for public foot access in WY2013.

BIRD WATCHING PROGRAM

The public access sites in the STAs offer substantial bird watching opportunities. Organized bird watching tours are led by the Hendry-Glades Audubon Society on STA-5. The diversity and abundance of birds has made STA-5 and other STAs favorite bird watching destinations (**Figure 5-71**). In WY2012, approximately 900 bird enthusiasts participated in STA-5 birding tours and bird counts, including the annual North American, Christmas, and backyard bird counts in STA-5 and STA-1W. Similar organized bird watching tours at STA-1E began in January 2012 in cooperation with the Audubon Society of the Everglades.

Figure 5-71. Visitors at an STA-1E bird watching event coordinated by the Audubon Society of the Everglades, January 2012 (photo by the SFWMD).

HUNTING

The STA hunting program, which includes alligator and waterfowl hunts, is managed by the Florida Fish and Wildlife Conservation Commission (FWC) in close coordination with the District. Hunting is limited to weekend days to prevent interference with ongoing STA management or monitoring activities. The effective oversight, high quality of hunts, and the limited opportunity results in strict compliance with the set hunting and facility use rules. One of these rules forbids the use of motorized boats during hunting in the STAs; only non-motorized vessels (kayaks or canoes) are permitted.

From mid-August to November 1, 2011, alligator hunting took place in STA-1W, STA-2, STA-3/4, and STA-5. A total of 550 permits were issued and 427 alligators were harvested. An event for youth, deigned to promote conservation among future hunters, was also conducted in STA-2 in August 2011. Waterfowl hunting occurred in STA-1W, STA2, STA-3/4, and STA-5 from mid-November 2011 to February 2012. The waterfowl hunting season includes migratory birds and the bag limits are determined by the FWC. In WY2012, hunting permits were granted to 10,761 hunters and the total bagged count was 40,659 birds.

IMPLEMENTATION OF THE LONG-TERM PLAN FOR ACHIEVING WATER QUALITY GOALS IN THE EVERGLADES PROTECTION AREA

Pursuant to the Everglades Forever Act [EFA; Section 373.4592(13), Florida Statutes], this section presents an update on implementation of the Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area (Long-Term Plan) and subsequent amendments. Achieving Everglades water quality standards by implementing the Long-Term Plan is one of the strategic priorities of the District and is required by state and federal law. For this period, a cross-walk of Long-Term Plan-related reporting is presented in Appendix 5-7 of this volume. A schematic of the Everglades Protection Area and Tributary basin is presented in **Figure 5-72**. Additional supporting information on Long-Term Plan reporting is available in the 2005–2012 SFERs – Volume I, Chapter 8.

BACKGROUND

In 1994, the Florida legislature enacted the EFA, which required the District to submit to the FDEP a plan by December 31, 2003, for achieving compliance with the TP criterion and other state water quality standards in the Everglades Protection Area (EPA), and to include the estimated costs, funding mechanisms, and implementation schedules associated with the plan. A plan was developed and in the EFA amendments of 2003, the Florida legislature incorporated the plan by reference into the EFA. The legislature also amended the EFA to include two phases for the Long-Term Plan; the initial phase which was developed in October 2003 (Burns and McDonnell, 2003), and a second phase, which was to be developed if the elements of the initial phase were unsuccessful in achieving water quality standards in the EPA. The initial phase included STA expansions, enhancements to existing STAs, expanded best management practices (BMPs), and integration with the Comprehensive Everglades Restoration Plan (CERP) projects. The key STA expansions and enhancements described in the initial phase of the Long-Term Plan have been completed and significant stormwater quality improvements have been realized.

As of April 30, 2012, the Everglades Agricultural Area's BMPs and the Everglades Construction Project (ECP) STAs have collectively removed more than 4,060 metric tons[3] of TP that otherwise would have entered the Everglades. The STAs accounted for approximately 1,560 mt of TP since 2004 and BMPs were responsible for removing approximately 2,500 mt. As described in Chapter 3A of this volume, the effectiveness of the BMP and STA TP removal efforts is demonstrated by the decreased TP loading to the WCAs in recent periods compared to the baseline period, despite increased flows to the EPA. Despite STA enhancements and continued decreases in discharge TP concentrations, the existing STAs in combination with BMPs did not achieve compliance with the Everglades numeric criterion during WY2012.

[3]The inception-to-date numbers for the STAs include start-up flows and loads.

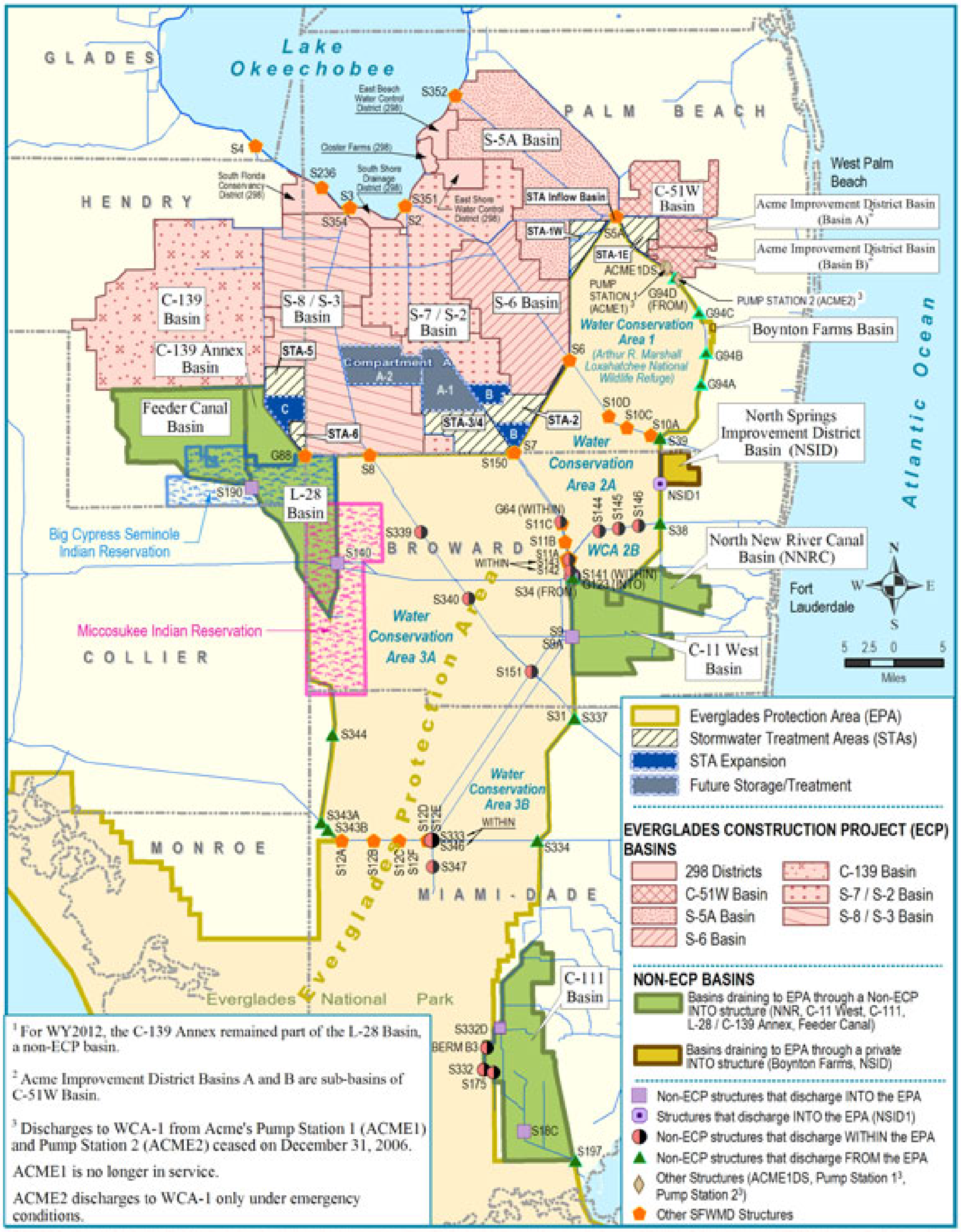

Figure 5-72. Overview of the Everglades Protection Area and tributary basins.

To improve the performance of the initial phase of the Long-Term Plan STAs, a science-based and adaptive implementation approach was used to develop nine revisions to the initial Long-Term Plan between 2004 and 2007. These revisions were vetted with stakeholders and approved by the FDEP (see 2005–2009 SFERs – Volume I, Chapter 8).

In 2008, in Miccosukee Tribe v. U.S. Environmental Protection Agency (USEPA), the court determined that portions of the 2003 amendments to the EFA and Florida's Everglades TP rule constituted improper changes in water quality standards and were invalid under the Clean Water Act. In general, the court invalidated provisions allowing the discharge of TP concentrations above the phosphorus criterion even if the District was implementing the requirements of the Long-Term Plan. [Note: The District was not a party to that case.] Although the Long-Term Plan may no longer be used as a moderating provision, it was a District planning document for WY2012 and its implementation continues to be mandated under state law until the EFA is amended directing otherwise. The court further determined that a two-part Water Quality Based Effluent Limit (WQBEL) for each STA is a critical component of a framework to ensure compliance with the numeric criterion in the EPA.

STATUS OF THE WATER QUALITY BASED EFFLUENT LIMIT IMPLEMENTATION

During this reporting period, the District, FDEP, and USEPA jointly develop a consensus WQBEL for the STAs and a new suite of projects that, based on the best available science and experience derived through operation of the existing STAs, is intended to achieve the WQBEL. These projects comprise the second phase of the Long-Term Plan, which must be approved by the Florida legislature and codified in the EFA prior to implementation. These projects are expected to be discussed in the 2014 SFER.

STATUS OF INITIAL PHASE LONG-TERM PLAN PROJECTS AND ACTIVITIES

The initial phase of the Long-Term Plan included 48 individual projects and processes, each having a schedule, scope, and cost estimate. As the Long-Term Plan overlaps with other agency Everglades restoration efforts, updates for Long-Term Plan projects and processes appear in other chapters of this volume, (see Appendix 5-7 of this volume).The Long-Term Plan projects that address the non-Everglades Construction Project (non-ECP) basins and source controls are discussed in Chapter 4 of this volume; the Long-Term Plan projects relating to the ECP STAs and Compartments B and C STA expansion projects are discussed in this chapter. **Figure 5-72** identifies the locations of the ECP and non-ECP basins addressed in the Long-Term Plan. Financial reporting related to the implementation of the Long-Term Plan is summarized in Appendix 5-7 of this volume. Detailed data summaries and findings related to the individual performance of the BMPs and STAs can be found in Chapter 4 and earlier sections of this chapter. A list of the basins addressed in the Long-Term Plan is presented in Appendix 5-7.

LITERATURE CITED

Abtew, W. 1996. Evapotranspiration Measurements and Modeling for Three Wetland Systems in South Florida. *Water Resources Bulletin*, 32(3):465-473.

Abtew, W., J. Obeysekera and G. Shih. 1995. Spatial Variation of Daily Rainfall and Network Design. *Transactions of the ASAE*, 38(3):843-845.

Aldous, A., P. McCormick, C. Ferguson, C. Graham and C. Craft. 2005. Hydrologic Regime Controls Soil Phosphorus Fluxes in Restoration and Undisturbed Wetlands. *Restoration Ecology,* 13:341–347

Andersen, J.M. 1976. An Ignition Method for Determination of Total Phosphorus in Lake Sediments. *Water Research*, 10:329-331.

Apfelbaum, S.I. 1985. Cattail (*Typha* spp.) Management. *Natural Areas Journal*, 5(3):9-17.

Beule, J.D. 1979. Control and Management of Cattails in Southeastern Wisconsin Wetlands. *Wisconsin Department Natural Resources Tech. Bulletin*, 112, Madison. 41p.

Bostic, E.M. and J.R. White. 2007. Soil Phosphorus and Vegetation Influence on Wetland Phosphorus Release after Simulated Drought. *Soil Science Society of America Journal*, 71(1):238-244.

Brigham Young University. 2004. The Department of Defense Groundwater Modeling System, GMS v5.1, Environmental Modeling Laboratory.

Brown and Caldwell. 2011. Stormwater Treatment Area 2 Operation Plan.

Burns and McDonnell. 2003. Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area. Prepared for the South Florida Water Management District, West Palm Beach, FL.

DB Environmental. 2009. Tracer Study: PSTA Cell, STA-3/4. A Technical Memorandum Submitted to the South Florida Water Management District.

DeBusk, W.F. and K.R. Reddy. 2003. Nutrient and Hydrology Effects on Soil Respiration in a Northern Everglades Marsh. *Journal or Environmental Quality*, 32:702-710.

Dierberg, F.E. and T.A. DeBusk. 2008. Particulate Phosphorus Transformations in South Florida Stormwater Treatment Areas Used for Everglades Protection. *Journal of Ecological Engineering*, 34(2):100-115.

Chen, H., M. Zamorano and D. Ivanoff. 2010. Effect of Flooding Depth on the Growth, Biomass, Photosynthesis, and Chlorophyll Fluorescence of Typha Domingensis. *Wetlands*, 30:957-965.

Gary Goforth, Inc. 2008. Operations Plan for the Integrated Stormwater Treatment Areas 5 & 6.

Germain, G. and K. Pietro. 2011. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2011 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL

Grace, J.B. 1989. Effects of Water Depth on *Typha latifolia* and *Typha domingensis*. *American Journal of Botany*, 76(5):762–768.Ivanoff, D.B., K.R. Reddy and S. Robinson. 1998.

Chemical Fractionation of Organic Phosphorus in Selected Histosols. *Soil Science,* 163:36-45.

Ivanoff, D.B., H. Chen and L. Gerry. 2012. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2012 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL

Juston, J.M. and T.A. DeBusk. 2011. Evidence and Implications of the Background Phosphorus Concentration in Submerged Aquatic Vegetation Wetlands in Stormwater Treatment Areas Used for Everglades Restoration. *Water Resources Research*, 47, W01500, doi:10.1029/2010WR009294.

Kadlec, R.H. and S.D. Wallace. 2009. *Treatment Wetlands*. Second Edition. Taylor and Francis Group, Boca Raton, FL.

Lal A.M.W., R. Van Zee and M. Belnap. 2005. Case Study: Model to Simulate Regional Flow in South Florida. *Journal of Hydraulic Engineering-ASCE,* 131(4):247-58.

Martin, H.W., D.B. Ivanoff, D.A. Graetz and K.R. Reddy. 1996. Water Table Effects on Histosol Drainage Water Carbon, Nitrogen, and Phosphorus. *Journal of Environmental Quality*, 6:1062-1071.

Min J. and W.R. Wise. 2010. Depth-averaged, Spatially Distributed Flow Dynamic and Solute Transport Modelling of a Large-scaled, Subtropical Constructed Wetland. *Hydrological Processes*, 24(19):2724-37.

Paudel, R., K.A. Grace, S. Galloway, M. Zamorano and J.W. Jawitz. Effects of Hydraulic Resistance by Vegetation on Stage Dynamics of a Stormwater Treatment Wetland. *Manuscript in review process.*

Pant, H.K. and K.R. Reddy. 2003. Potential Internal Loading of Phosphorus in a Wetland Constructed in Agricultural Land. *Water Resources*, 37:965–972.

Pietro, K., G. Germain, R. Bearzotti and N. Iricanin. 2010. Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas. In: *2010 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Reddy, K.R., R.G. Wetzel and R. Kadlec. 2005. Biogeochemistry of Phosphorus in Wetlands. In Phosphorus: Agriculture and the Environment. J. T. Sims and A. N. Sharpley (eds), Soil Science Society of America, pp. 263-316

Reddy, K.R. and R.D. Delaune. 2008. Biogeochemistry of Wetlands: Science and Applications. CRC Press., Boca Raton, FL, pp. 774.

Richardson, C.J. and C.B. Craft 1993. Effective Phosphorus Retention in Wetlands: Fact or Fiction. In: Constructed Wetlands for Water Quality Improvement. G.A. Moshiri (ed), Lewis Publishers, pp. 271-282

SFWMD. 2005. RSM Theory Manual – HSE v1.0. South Florida Water Management District, West Palm Beach, FL, pp. 308.

SFWMD. 2007. Operation Plan Stormwater Treatment Area-3/4. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2008. South Florida Water Management District Everglades Construction Project (ECP) Stormwater Treatment Areas (STAs) Drought Contingency Recommendations and Considerations. South Florida Water Management District, West Palm Beach, FL.

Sojda, R.S. and K.L. Solberg. 1993. Management and Control of Cattails. U.S. Fish and Wildlife Service Fish and Wildlife Leaf. 13.4.13, Washington, D.C.

Steinman, A. and M. E. Ogdahl. 2011. Does Converting Agricultural Fields to Wetlands Retain or Release P? *Journal of the North American Benthological Society*, 30(3):820-830.

Sutron Corporation. 2007. Updated STA-2 Hydraulic Analyses. Final Report submitted to the South Florida Water Management District, West Palm Beach, FL, pp. 68.

USACE. 2012. Stormwater Treatment Area 1 East, Palm Beach County, Florida, Environmental Assessment and Finding of No Significant Impact, Decommission of Field Scale Periphyton Stormwater Treatment Area Demonstration Project, U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL.