Chapter 5B: Performance of the Everglades Stormwater Treatment Areas

Edited by Michael Chimney

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 Everglades STAs [STA-1 East (STA-1E), STA-1 West (STA-1W), STA-2, STA-3/4, and STA-5/6] were built south of Lake Okeechobee to reduce total phosphorus (TP) concentration in surface water runoff prior to discharging this water into the Everglades Protection Area (EPA) (**Figure 5B-1**). The STAs are managed by the South Florida Water Management District (District or SFWMD). The total area of the STAs, including infrastructure components, is roughly 68,000 acres, with approximately 57,000 acres of effective treatment area currently permitted to operate including recently completed treatment cells in Compartments B and C. This chapter and related appendices (Appendices 5B-1 through 5B-3 of this volume) summarize short- and long-term STA treatment performance, conditions relevant to STA treatment performance, facility status, operational challenges, and enhancements made during Water Year 2014 (WY2014) (May 1, 2013–April 30, 2014). A detailed analysis of annual STA treatment performance in terms of permit compliance is reported in Volume III, Appendix 3-1. A status update on implementing the Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area (Long-Term Plan) (Burns and McDonnell, 2003) is covered in Appendix 5B-4 of this volume. More information about the STAs is available at www.sfwmd.gov/sta. Highlights from this chapter are as follows:

- Over their combined operational histories, the STAs have treated approximately 14.8 million ac-ft of water (~ 4.8 trillion gallons) and retained 1,874 metric tons (mt) of TP with a 75 percent TP load reduction. The overall outflow flow-weighted mean (FWM) TP concentration from these treatment wetlands has been 34 micrograms per liter (µg/L) [or parts per billion (ppb)].
- During WY2014, the STAs treated a combined 1.3 million ac-ft of water and retained 147 mt of TP, which equated to an 81 percent TP load reduction and produced an outflow FWM TP concentration of 21 ppb. Notably, this is one of the lowest combined annual outflow FWM TP concentrations recorded in the STAs to date.
- STA-3/4 over its 11-year operational history has treated the most runoff (~4,670,000 ac-ft), retained the second largest amount of TP load (526 mt), achieved the highest % TP load retained (84 percent), and discharged water at the lowest outflow FWM TP concentration (17 ppb) of all the STAs.
- The outflow FWM TP concentrations for individual STAs in WY2014 ranged from 14 (STA-3/4) to 41 ppb (STA-1E), while the percent TP load retained ranged from 76 (STA-1E and STA-2) to 88 percent (STA-5/6).

- The Eastern Flow-way in STA-1E, Flow-way 5 in STA-2, and Flow-way 5 in STA-5/6 were offline for at least part of WY2014. In addition, the Central and Western Flow-ways in STA-1E, the Eastern and Northern Flow-ways in STA-1W, Flow-ways 2 and 3 in STA-2, the Central Flow-way in STA-3/4, and Flow-way 4 in STA-5/6 were online with restrictions for at least part of the year.
- With the completion of construction of Compartment C in WY2013, the original footprints of STA-5 and STA-6 have been combined with Compartment C into an integrated treatment facility, referred to as STA-5/6. Construction of Compartment B also was completed in WY2013, which substantially increased the treatment area of STA-2.
- Bird surveys were conducted in all the STAs during the 2013 and 2014 nesting seasons to document the presence of nesting black-necked stilts (*Himantopus mexicanus*) as required under the District's Avian Protection Plan. Utilizing survey results, operational priorities were adjusted in all the STAs this year to avoid flooding active nests. Bird survey results are summarized in Appendix 5B-2 of this volume.
- Everglade snail kites (*Rostrhamus sociabilis*), an endangered species, were found nesting in STA-1E Cells 2, 4N, and the Eastern Distribution Cell and STA-5/6 Cells 2A, 3B, and 4A in WY2014. Operation of STA-1E and STA-5/6 was adjusted to avoid disturbing the nests.
- With the exception of the Eastern Flow-way in STA-1E and Flow-ways 6, 7, and 8 in STA-5/6, all other cells in the STAs remained hydrated during the dry season this year. The dry-out in STA-5/6 occurred at the very end of WY2014 and did not affect the STA's treatment performance. The Eastern Flow-way of STA-1E was kept dry throughout WY2014 due to construction activities associated with the removal of the PSTA Demonstration Project in Cell 2.
- Cell 4S in STA-1E experienced an enormous population increase of the island applesnail (*Pomacea maculata*) between July and August 2013. Island applesnail feeding defoliated most of the cell's SAV, which led to TP export from the cell. The island applesnail population had declined and TP treatment performance was returning to normal levels by the end of WY2014.
- Supplemental water from Lake Okeechobee was delivered to Cell 5 of STA-1E, Flow-way 4 of STA-2, and Cells 1B, 2B, 3B, and 4B of STA-5/6 during the dry season in WY2014 to maintain water levels at target stages and keep their plant communities hydrated.
- Approximately 175,000 ac-ft of Lake Okeechobee regulatory releases were treated in the STAs for delivery south to the Everglades Protection Area during WY2014.
- Runoff from Tropical Storm Andrea and rainfall events immediately following the storm increased water depths in STA-1E, STA-1W, and STA-3/4 to their maximum operating levels. In response to these high-water conditions, runoff was diverted around these STAs for five to seven days in June 2013.

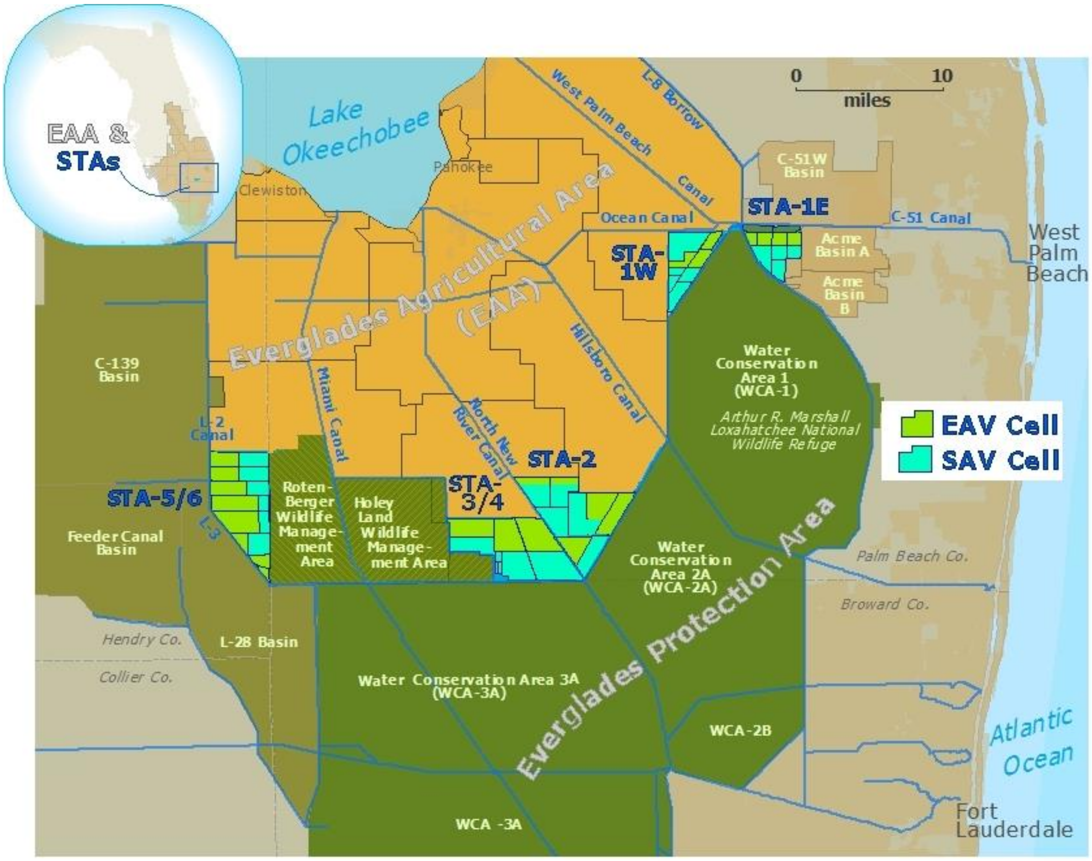

Figure 5B-1. Location of the Everglades Stormwater Treatment Areas (STAs) 1 East (1E), 1 West (1W), 2, 3/4, and 5/6 in relation to the Everglades Protection Area, the dominant STA vegetation communities in the STAs [i.e., emergent vegetation (EAV) or submerged aquatic vegetation (SAV)], and major drainage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

INTRODUCTION

As a major component of Everglades restoration, the Everglades Stormwater Treatment Areas (STAs) were built and operated to reduce total phosphorus (TP) concentration in surface water runoff prior to these waters entering the Everglades Protection Area (EPA). STAs are constructed wetlands that retain nutrients through plant and microbial nutrient uptake, particulate settling, chemical sorption, and ultimately accretion of plant and microbial biomass to the sediments. This chapter describes the treatment performance and condition of the Everglades STAs (STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6, respectively; **Figure 5B-1** and Appendix 5B-1 of this volume) and the operational challenges related maintaining treatment performance in STAs. The South Florida Water Management District (District or SFWMD) operates all the 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 length of operation, the STAs are shallow freshwater marshes divided into cells by interior levees (Appendix 5B-1 of this volume). Water flows through these systems via water control structures, i.e., pump stations, gates, and culverts. Aquatic plants in the STA are categorized based on their growth habit: emergent aquatic vegetation (EAV), submerged aquatic vegetation (SAV), or floating aquatic vegetation (FAV). While all cells contain a mixture of these vegetation types, cells differ as to their dominant community, i.e., cells are classified as either SAV or EAV-dominated. Periphyton—the community of attached algae and other microbes growing on substrates in aquatic systems—is ubiquitous throughout the STAs.

STA treatment performance, which has varied temporally in each STA and spatially among STAs, is influenced by factors such as weather conditions, antecedent land use, nutrient and hydraulic loading, vegetation condition, soil type, cell topography, hydropattern (continuously flooded versus periodic dryout), maintenance and enhancement activities, and regional flood control operations. The District uses an adaptive approach to manage the STAs based on weekly evaluation of interior stage (i.e., water levels), outflow TP concentrations, hydraulic and TP loading, vegetation condition, and any operation restrictions related to protection of wildlife.

This chapter reports on STA treatment performance; information on STA operational status, maintenance activities, and enhancements; and updates on applied scientific studies relevant to the STAs. Supporting information on protected birds in the STAs during the 2014 nesting season and on EAV and SAV coverage in the STAs is presented in Appendices 5B-2 and 5B-3 of this volume, respectively. Discussion of recreational facilities and activities and implementation of the Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area is provided in Volume II, Chapter 6B, and Appendix 5B-4 of this volume, respectively. Details on the District's Restoration Strategies Program and Science Plan for the Everglades STAs are provided in Chapters 5A and 5C, respectively, of this volume. Further details on the water quality-based effluent limitations for TP that are mandated for the STAs is presented in Volume III, Appendix 3-1.

OVERVIEW OF WATER YEAR 2014 STA TREATMENT PERFORMANCE

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The STAs over their combined operational history have treated approximately 14.8 million acre-feet (ac-ft) of water (~4.8 trillion gallons) and retained 1,874 metric tons (mt) of TP or 75 percent of the TP load that entered these facilities. The period of record (POR) inflow flow-weighted mean (FWM) TP concentration for all the STAs was 137 micrograms per liter (µg/L) [or parts per billion (ppb)], while the POR outflow FWM TP concentration was 34 ppb (**Table 5B-1**)[1].

[1] The District typically reports several measurements in non-SI units: TP concentration in parts per billion (ppb), surface area in acres (ac), flow in cubic feet per second (cfs), and water volume in acre-feet (ac-ft). The conversion factors to express these measurements in SI units are presented in the Units of Measurement table in the front matter of the final 2015 SFER (www.sfwmd.gov/sfer).

All the STAs received a combined 1.3 million ac-ft of inflow and retained 147 mt of TP (**Table 5B-1**) during WY2014. The overall inflow and outflow FWM TP concentrations decreased from 113 to 21 ppb, respectively, which represented an 81 percent reduction in the total TP load that entered the STAs. This was one of the lowest overall annual outflow FWM TP concentrations recorded (**Figure 5B-2**, panel A). The combined water and TP loads received by the STAs this year were comparable in magnitude to inflow loads in past water years (**Figure 5B-2**, panels A and B).

STA-2, STA-3/4, and STA-5/6 all had annual outflow FWM TP concentrations less than 24 ppb in WY2014, while annual outflow FWM TP concentrations in STA-1E and STA-1W were 41 and 24 ppb, respectively (**Figure 5B-3**, panel B). STA-3/4 received the largest water load and STA-1W the largest TP load this year, while STA-5/6 received the lowest water and TP loads (**Figure 5B-3**, panels A and C). The hydraulic loading rates (HLR) in all the STAs during WY2014 were greater than 2 cm/day except for STA-5/6, which had a HLR of only 0.6 cm/day (**Figure 5B-3**, panel E). The corresponding P loading rates (PLR) were 1.6 and 1.8 $g/m^2/yr$ in STA-1E and STA-1W, respectively, and 0.7, 0.6, and 0.5 $g/m^2/yr$ in STA-2, STA-3/4, and STA-5/6, respectively. The TP removal coefficient (k value) ranged from 12.4 to 21.8 m/yr in all STAs except for STA-5/6, which had a k value of only 5.2 m/yr (**Figure 5B-3**, panel D). It should be noted that STA-5/6 was the only STA in which cells dried out during WY2014. The treatment performance in the STAs described above was achieved despite the fact that several flow-ways were offline or under restricted operation during the water year (**Table 5-2**).

FLOW-WAY OPERATIONAL STATUS

Operation of a flow-way may be suspended entirely (operational status: offline) in response to environmental conditions that may adversely affect P uptake, to allow for construction, or to allow the completion of critical rehabilitation activities. Operation of a flow-way may also be flow and stage restricted (operational status: online with restrictions) to protect vulnerable vegetation or to avoid impacts on bird nesting for protected and endangered species. Flow-ways designated as online with restrictions would be exposed to deep water or high velocities only during emergencies, e.g., large storm events. During moderate storm events, stormwater would be partially or fully diverted to other flow-ways for treatment. The treatment performance summarized in this chapter was achieved despite the fact that a least one flow-way in each STA was offline or under restricted operation during WY2014. The Eastern Flow-way in STA-1E, Flow-way 5 in STA-2, and Flow-way 5 in STA-5/6 were offline for at least part of the year (**Table 5B-2**). In addition, the Central and Western Flow-ways in STA-1E, the Eastern and Northern Flow-ways in STA-1W, Flow-ways 2 and 3 in STA-2, the Central Flow-way in STA-3/4, and Flow-way 5 in STA-5/6 were online with restrictions for at least part of the year. Details of operational status of each flow-way are included under the individual STA sections within this chapter.

Table 5B-1. Summary of treatment performance in each STA and all STAs combined for Water Year 2014 (WY2014: May 1, 2013–April 30, 2014) and the period of record for each STA and all STAs combined.

Parameter	STA-1E	STA-1W	STA-2	STA-3/4[a]	STA-5/6	All STAs
Effective Treatment Area (acres)	4,994	6,544	15,495	16,327	13,685	57,045
Adjusted Effective Treatment Area (acres)[b]	3,912	6,544	14,197	16,327	13,032	54,012
WY2014 Inflow						
Inflow Water Volume (ac-ft)	127,469	227,633	376,122	467,461	103,111	1,301,796
Inflow TP Load (mt)	26.0	48.8	39.9	41.2	25.1	181.1
Flow-weighted Mean Inflow TP (ppb)	166	174	86	71	198	113
Hydraulic Loading Rate (HLR) (cm/d)	2.7	2.9	2.2	2.4	0.6	2.0
TP Loading Rate (PLR) ($g/m^2/yr$)	1.6	1.8	0.7	0.6	0.5	0.8
WY2014 Outflow						
Outflow Water Volume (ac-ft)	124,518	241,103	402,474	466,010	105,655	1,339,760
Outflow TP Load (mt)	6.3	7.0	9.6	8.3	3.0	34.3
Flow-weighted Mean Outflow TP (ppb)	41	24	19	14	23	21
TP Retained (mt)	19.7	41.8	30.3	32.9	22.2	146.8
TP Removal Rate ($g/m^2/yr$)	1.2	1.6	0.5	0.5	0.4	0.7
TP Load Retained (%)	76%	86%	76%	80%	88%	81%
Period of Record						
Start Date	Sep 2004[c]	Oct 1993	Jun 1999	Oct 2003	Dec 1997	WY1994-WY2014
Inflow Water Volume (ac-ft)	910,362	3,650,679	3,461,849	4,666,783	2,076,109	14,765,782
TP Inflow Load (mt)	199.0	787.8	431.7	624.9	460.7	2,504.2
Flow-weighted Mean Inflow TP (ppb)	177	175	101	109	180	137
Outflow Water Volume (ac-ft)	887,173	3,756,900	3,741,600	4,749,377	1,739,395	14,874,445
TP Outflow Load (mt)	54.9	224.5	99.5	98.9	152.5	630.4
Flow-weighted Mean Outflow TP (ppb)	50	48	22	17	71	34
TP Retained (mt)	144.2	563.3	332.2	526.0	308.2	1,873.9
% TP Retained	72%	72%	77%	84%	67%	75%

[a] Excludes outflow from G-388.
[b] Adjusted effective treatment area is time and area-weighted to exclude cells that were are temporarily off-line for plant rehabilitation, infrastructure repairs, or Long-Term Plan enhancements (refer to **Table 5B-2**).
[c] STA-1E was operated in WY2005 for emergency flood control purposes and to establish wetland vegetation; it became fully operational in WY2006.

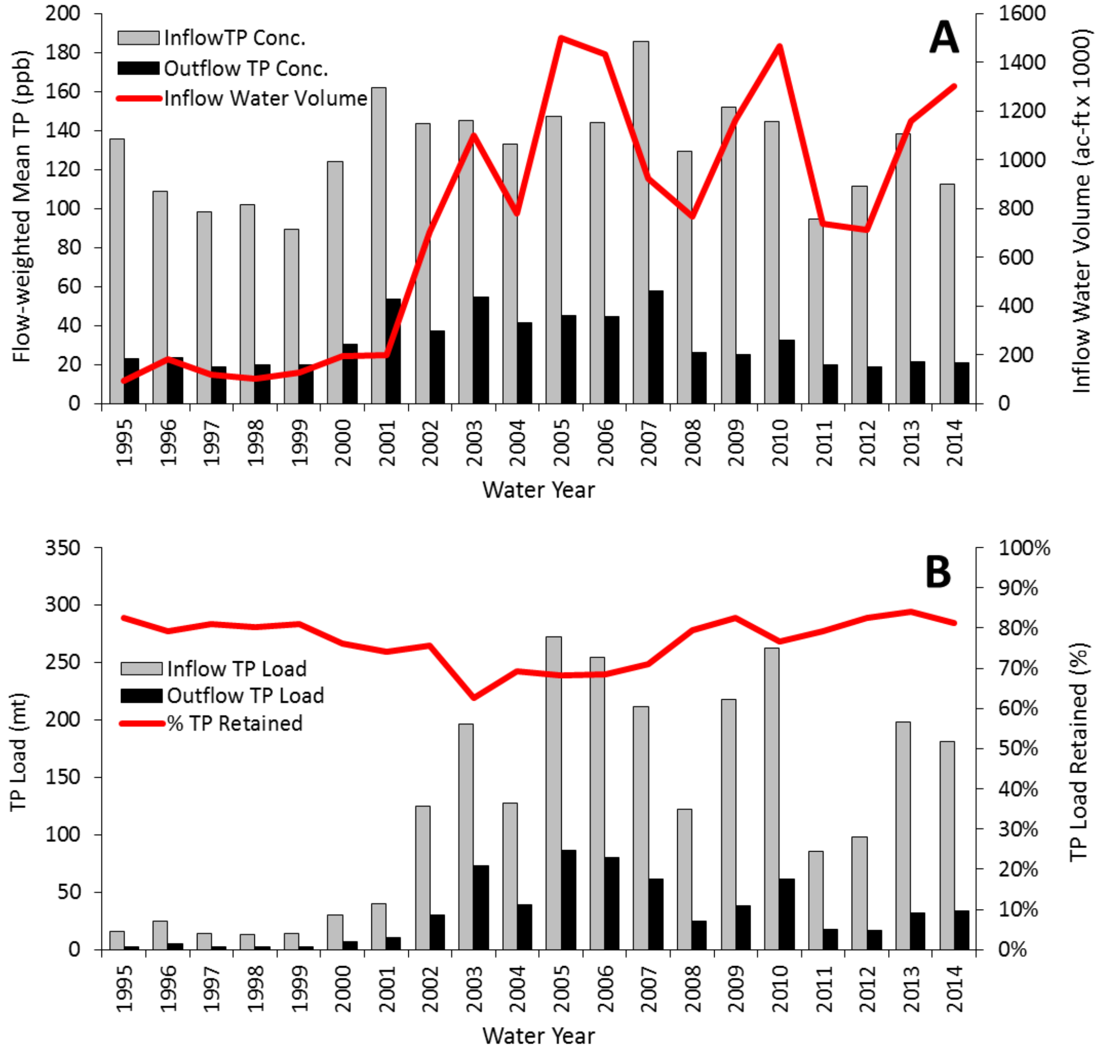

Figure 5B-2. Period of record time series for all the STAs combined of (A) annual inflow and outflow flow-weighted mean total phosphorus (TP) concentrations with corresponding inflow water volumes and (B) annual inflow and outflow TP loads with percent TP load retained.

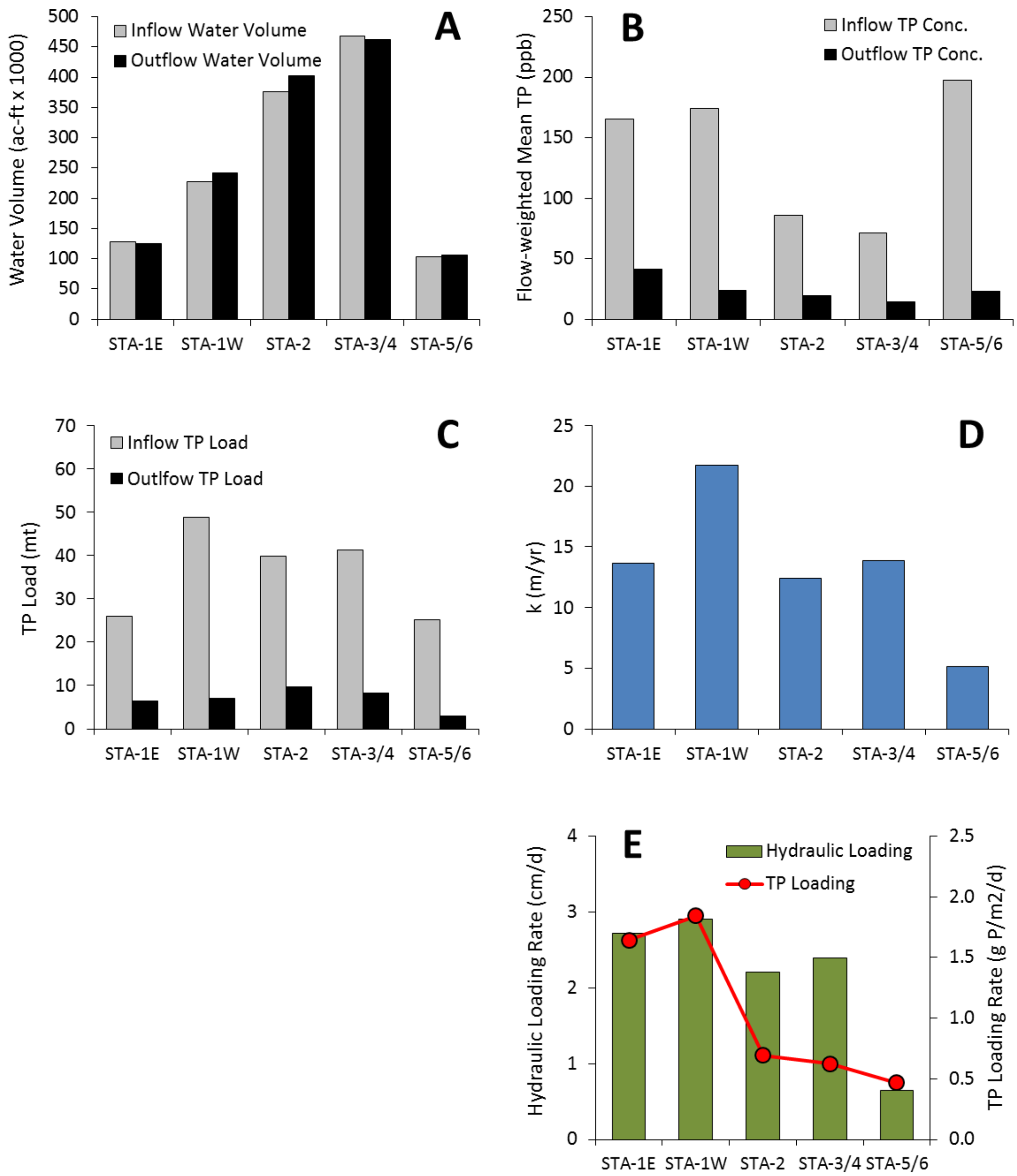

Figure 5B-3. Comparison of (A) inflow and outflow water volumes, (B) inflow and outflow flow-weighted mean TP concentrations, (C) inflow and outflow TP loads, (D) TP removal coefficients (k values), and (E) hydraulic and TP loading rates during WY2014 in the STAs. TP removal coefficients were calculated as:
$k = \ln(TP\ conc_{in} / TP\ conc_{out}) \times [((Flow_{in}+Flow_{out})/2)/STA\ Area]$

ADJUSTMENT OF THE EFFECTIVE TREATMENT AREA VALUES

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

- Hydraulic loading late (HLR)
- Phosphorus loading rate (PLR)
- TP removal rate

Effective treatment areas in WY2014 were adjusted using to the following equation based on the operational period of each flow-way (**Table 5B-2**):

$$Adjusted\ Effective\ Treatment\ Area = Total\ Area \times \frac{\sum_{1}^{365} Daily\ Online\ Percentage}{365} \quad (1)$$

Effective treatment areas were adjusted for STA-1E (the Eastern Flow-way was offline the entire year), STA-2 (Flow-way 5 was offline from May 1 to 16, 2013 and December 10, 2013 to April 30, 2014), and STA-5/6 (Flow-way 5 was offline from May 1, 2013 to July 29, 2013).

CALCULATION OF ANNUAL LOADS AND FLOW-WEIGHTED MEAN CONCENTRATIONS

TP loads and FWM TP concentrations were calculated based on surface water inflow to and outflow from the STAs over the entire water year as follows:

$$Load = \sum_{1}^{n}(C_iV_i + C_{i+1}V_{i+1} + \ldots\ C_{i+n}V_{i+n}) \quad (2)$$

$$FWM\ Conc. = Load/\sum_{1}^{n}(V_i + V_{i+1} + \ldots\ V_{i+n}) \quad (3)$$

where:

C_i = TP concentration for the ith sampling interval during the water year (g/m^3);
V_i = Water volume for the ith sampling interval during the water year (m^3).

VEGETATION MANAGEMENT

Vegetation management in the STAs includes herbicide applications and mechanical removal (on a limited scale) to control undesired FAV, SAV, and emergent herbaceous and woody species[2]. Controlling FAV, such as water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*), is necessary, particularly in SAV cells, where FAV can form dense beds that shade out the SAV species underneath. Dense FAV can also impede flow through cells. Woody species, such as primrose willow (*Ludwigia* spp.), are controlled because they tend to displace cattail (*Typha* spp.) and do not provide the same level of P removal as cattail or sawgrass (*Cladium jamaicense*). The District uses U.S. Environmental Protection Agency-registered herbicides applied by licensed applicators at the dosages recommended by the manufacturers. None of these products bioaccumulate and none are restricted category herbicides. While these products are certainly toxic to plants, toxicity is negligible to non-plant organisms at the application rates used in the STAs and elsewhere throughout the District. The District's

[2] Widespread harvesting has been suggested as a way to manage vegetation in the STAs. However, harvesting is not under consideration for several reasons, including: (1) mechanical removal is very expensive and would be disruptive to the STA ecosystem if done on a large scale, (2) the lack of biomass disposal locations and high associated costs, (3) a viable market for plant byproducts, such as conversion to biofuel, has not materialized in South Florida, and (4) harvesting removes carbon from the system that may be critical to P removal processes.

vegetation management program is regulated by the Florida Department of Protection (FDEP) and fully complies with our NPDES operating permit regulations. An accounting of herbicide application rates and quantities used, the acreage treated in each STA, and the species targeted during WY2014 is provided in Volume III, Appendix 3-1, Attachment E.

Vegetation management also includes planting EAV, primarily giant bulrush (*Schoenoplectus californicus*) and alligator flag (*Thalia geniculata*), and inoculations of SAV, such as southern naiad (*Najas quadalupensis*) and muskgrass (*Chara* sp.). Giant bulrush and alligator flag were planted in linear strips to eliminate hydraulic short-circuits, buffer other plants from uprooting caused by high wind and discharge events, or provide plant cover at locations where the water is too deep for sustained growth of cattail. The compartmentalization of SAV cells with EAV strips also provides functional redundancy[3] for sustaining optimal treatment performance. In EAV cells, the most desired species are cattail (*T. latifolia* and *T. domingensis*), giant bulrush, alligator flag, and sawgrass. Other desirable native species that thrive in certain areas of the STAs are arrowhead (*Sagittaria latifolia*), duck potato (*S. lancifolia*), and spikerush (*Eleocharis* sp.). In SAV cells, the most desired species are coontail (*Ceratophyllum demersum*), muskgrass, pondweed (*Potamogeton illinoensis*), and southern naiad. Another species commonly found in the STAs is hydrilla (*Hydrilla verticillata*); however, despite this species' ability to remove P, it is not a desired species due to its tendency for sudden population crashes. Hydrilla, which thrives in areas of high water column TP concentrations, was a common SAV species in STA-1E and STA-5/6 during WY2014.

VEGETATION SURVEYS

The areal coverage of EAV and SAV (+ open-water[4]) was estimated based on analysis of digital aerial imagery captured for each STA (see method description in Appendix 5B-3 of this volume). Vegetation coverage based on imagery taken in March 2013 is presented in this chapter as the percent of EAV coverage relative to the entire cell and compared with EAV coverage in previous years. Because there were only two vegetation classes in these analyses, a positive or negative change in EAV coverage would be balanced by the opposite percent change in SAV coverage. Vegetation coverage maps for each STA are provided in Appendix 5B-3 of this volume. The image resolution and mapping units used for vegetation mapping were 1 ft. Note that the areal coverage values derived in these analyses are not estimates of relative abundance.

Ground surveys were conducted by airboat within SAV-dominated cells on a periodic basis to map the distribution and relative abundance of SAV species. Assessments were made at a network of fixed geo-referenced sites established within each cell where the relative abundance of each SAV species was assessed by visual inspection using a 4 or 5-point ordinal scale.

[3] Treatment functional redundancy refers to a strategy for enhancing or providing additional P removal pathways to complement the existing P uptake mechanisms dominant in SAV communities, e.g., allowing EAV to colonize a portion of a SAV cell.

[4] It was often impossible to distinguish in the aerial imagery between open-water areas with no SAV in the water column and areas that contained SAV; therefore, some portion of areas mapped as SAV in the STAs may have been open-water without plants.

Table 5B-2. Operational status of STA flow-ways and adjusted effective treatment area during WY2014.

STA	Flow-way	Effective Treatment Area (acre)	Offline (OFF) or Online with Restriction (ONR) Schedule	Reasons for Cell Being OFF or ONR	% Time Online	Adjusted Effective Treatment Area (acre)
STA-1E	Entire STA	4,994			78.3	3,912
	Eastern FW	1,082	OFF: 10/12 - 04/14	PSTA cell decommissioning.	0	
	Central FW	1,939	ONR: WY2014	Structure repairs (USACE), island apple snail herbivory, vegetation planting, bird nesting*	100	
	Western FW	1,973	ONR: WY2014	Structure repairs (USACE), vegetation planting, bird nesting*	100	
STA-1W	Entire STA	6,544			100	6,544
	Eastern FW	2,171	ONR: 11/13 - 04/14	Vegetation planting	100	
	Western FW	1,369	ONR: 05/13 - 06/13	Bird nesting*	100	
	Northern FW	3,004	ONR: 12/13; 04/14	Vegetation planting, bird nesting*	100	
STA-2	Entire STA	15,494			91.6	14,197
	Flow-way 1	1,840			100	
	Flow-way 2	2,373	ONR: 04/4	Structure inspections	100	
	Flow-way 3	2,296	ONR: 05/13 - 06/13; 03/14 - 04/14	Bird nesting*, vegetation planting, and structure inspections	100	
	Flow-way 4	5,990	ONR: 05/13 - 06/13	Bird nesting*	100	
	Flow-way 5	2,995	OFF: 05/13 - 05/13; 12/13 - 04/14	Passed start-up criteria on 05/17/13; OFF for Cell 8 regrading	56.7	
STA-3/4	Entire STA	16,324			100	16,327
	Eastern FW	6,476			100	
	Central FW	5,349	ONR: 01/13 - 06/14	Cattail planting, bird nesting*	100	
	Western FW	4,502	ONR: 05/13 - 06/13	Bird nesting*	100	
STA-5/6	Entire STA	13,685			95.2	13,032
	Flow-way 1	2,418	ONR: 05/13 - 06/13	Bird nesting*	100	
	Flow-way 2	2,068	ONR: 05/13 - 06/13, & 03/14 - 04/14	Bird nesting*	100	
	Flow-way 3	1,922	ONR: 05/13 – 10/13 & 02/14 – 04/14	Bird nesting*	100	
	Flow-way 4	1,871	ONR: 05/13 - 07/13 & 03/14 – 04/14	SAV inoculation, bird nesting*	100	
	Flow-way 5	2,642	OFF: 05/13 - 07/13; ONR: 05 /13 - 06/13, 04/14	Passed start-up criteria on 07/30/13, bird nesting*	75.3	
	Flow-way 6	1,900	ONR: 04/14		100	
	Flow-way 7	621			100	
	Flow-way 8	242			100	

* STA operations and maintenance activities that were modified during WY2014 due to migratory bird nesting are detailed in Appendix 5B-2, Table 2, of this volume.

DRYOUT IMPACTS

One of the challenges in managing the STAs is dealing with periodic dryout. During the region's dry season, particularly during prolonged droughts, portions of or entire STA cells can dry out. This is especially problematic for cells that have a higher ground elevation than surrounding areas (seepage loss issues) and cells that are not capable of receiving supplemental water to keep them hydrated. Dryout is known to affect STA treatment performance and the health of their vegetation communities, as well as encourage bird nesting that can result in conflicts with the operation of flow-ways. Dry conditions promote the rapid oxidation of soil organic matter and subsequent reflooding results in outflow P spikes due to the flux of mineralized soil P to the water column (Bostic and White, 2007; DeBusk and Reddy, 2003; Martin et al., 1996). The impact of dryout on outflow TP concentrations from the STAs is influenced by factors such as the extent and duration of dry conditions, soil characteristics, type of vegetation, and the lag time between reflooding and cell discharge following the dryout. Operational experience indicates that brief dryout periods in peat-based STA cells usually do not result in large outflow TP spikes, likely due to the ability of the peat material to retain water within the soil matrix. However, in areas where the substrate has a higher mineral content, such as the soil found in STA-5/6, the upper soil column dries out much more quickly upon loss of surface water and is prone to fluxing soil P upon rewetting. The impact of annual cycles of dryout and reflooding in Cells 6-3 and 6-5 of STA-5/6 has been discussed in the 2010 SFER – Volume I, Chapter 5 (Pietro et al., 2010).

While prolonged dryout conditions in SAV cells can be detrimental to the plant community, dryout in EAV cells for short periods does not appear to have negative impacts and actually may benefit the plants. For example, managed water-level drawdowns have been effective in encouraging recruitment of new of cattail in STA-3/4. Extended periods of dryout, however, have visibly affected EAV communities causing die-off of wetland vegetation and invasion of terrestrial plants. When dried cells are rehydrated. EAV generally recovers more quickly than SAV. Operation plans for the STAs set the minimum target stages in EAV and SAV cells during drought conditions at 6 inches below and 6 inches above the average ground elevation, respectively.

The District has implemented the Drought Contingency Plan (DCP) since 2008 to minimize dryout during periods of drought (SFWMD, 2008). When dry conditions are anticipated, the DCP provides guidance regarding raising cell target stages before the end of the wet season to increase storage volume in SAV cells, the use of temporary pumps to deliver water to the STAs from nearby sources when available, and the delivery of supplemental water when available from Lake Okeechobee to the STAs. The DCP prioritizes hydration of SAV cells over EAV cells to minimize impact to the SAV community. The DCP is reviewed annually, and lessons learned from previous years are incorporated into the plan for use during future droughts. Flow Equalization Basins (FEBs), scheduled to be constructed as part of the Restoration Strategies Program, are anticipated to increase the supply of water for the STAs during the dry season. The FEBs also may allow the District to hold water longer in the STAs at the onset of the wet season without discharging from flow-ways that have dried out and therefore allow more of the flux of soil P to be reassimilated before water is released.

South Florida received slightly more than the long-term average amount of rainfall for the region in WY2014. Supplemental water from Lake Okeechobee was delivered to Cell 5 of STA-1E and Flow-way 4 of STA-2 during the dry season this year to maintain water levels at their target stage. These water deliveries and timely dry season rainfall events were sufficient to keep all the STAs, with the exception of Flow-ways 6, 7, and 8 in STA-5/6, hydrated throughout the year. The Eastern Flow-way of STA-1E was kept dry throughout WY2014 due to construction activities associated with the removal of the PSTA Demonstration Project in Cell 2.

MIGRATORY BIRD AND SNAIL KITE NESTING

The District, in cooperation with the U.S. Fish and Wildlife Service (USFWS), finalized an Avian Protection Plan (APP) in 2008 for the Everglades STAs focusing on black-necked stilts (*Himantopus mexicanus*) and Florida burrowing owls (*Athene cunicularia floridana*) (Pandion Systems, 2008). These two species are afforded protected status under the Migratory Bird Treaty Act (MBTA) of 1918. Additional protected status has been given to the burrowing owl since it is also listed as a species of special concern in the state of Florida. The APP provides the District with a framework to modify STA operations to minimize potential impacts to active nests of either species. This is accomplished by diverting water around cells with nests or regulating inflow to these cells to avoid raising water levels and flooding nests[5]. Although the District is committed to mortality reduction measures, there may be situations where bird mortality is unavoidable as the District fulfills its flood control and water quality responsibilities. Specifically, during storm events, the District seeks to minimize sending untreated water directly to the Water Conservation Areas (WCAs). Operation of the STAs at these times may result in the inadvertent taking of migratory birds or nests. Standardized black-necked stilt nesting surveys were conducted in all the STAs from May–June 2013 and April–July 2014[6] following protocols outlined in the APP. Survey results are summarized in each STA section of this chapter and reported in more detail in Appendix 5B-2 of this volume. No active burrowing owl nests were observed within any of the STAs in WY2014.

The University of Florida conducts Everglade snail kite (*Rostrhamus sociabilis*) nest surveys annually in the STAs. The USFWS is consulted on modifying construction, maintenance, and STA operations to avoid disturbing any active nests. Survey results are summarized in each STA section of this chapter and reported in more detail in Appendix 5B-2 of this volume.

STA-1E

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STA-1E is located approximately 20 miles west of West Palm Beach, just south of State Road 80 and Canal C-51, adjacent to the northeast boundary of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), and directly east of the STA-1 Inflow and Distribution Works (referred to as the STA-1 Inflow Basin) (**Figure 5B-1**). It was flooded in WY2005 to establish wetland vegetation and began treating water in WY2006. STA-1E provides a total effective treatment area of 4,994 acres arranged into three parallel treatment paths, or flow-ways, with eight cells flowing from north to south (Piccone et al., 2013; **Figure 5B-4**). It should be noted that the East and West distribution Cells are not considered part of STA-1E effective treatment area. STA-1E receives inflow primarily from the C-51 West basin and smaller volumes from the L-8 and S-5A basins, Lake Okeechobee regulatory releases, and the Rustic Ranches subdivision. In WY2007, STA-1E started receiving inflows from a new source, runoff from Wellington Acme Basin B. During the dry season, supplemental water is delivered from Lake Okeechobee, when available, to maintain hydration of priority cells, i.e., cells dominated by SAV. The flow-way nomenclature for STA-1E is as follows:

[5] The District is not obligated to alleviate flooding in cells with nests that is caused by direct rainfall.
[6] These periods constituted the 2013 and 2014 nesting seasons for black-necked stilts in South Florida. Survey results for both seasons are reported in this chapter even though May, June, and July 2014 are in WY2015.

- Eastern Flow-way = Cells 1 and 2,
- Central Flow-way = Cell 3, 4N, and 4S, and
- Western Flow-way = Cell 5, 6, and 7.

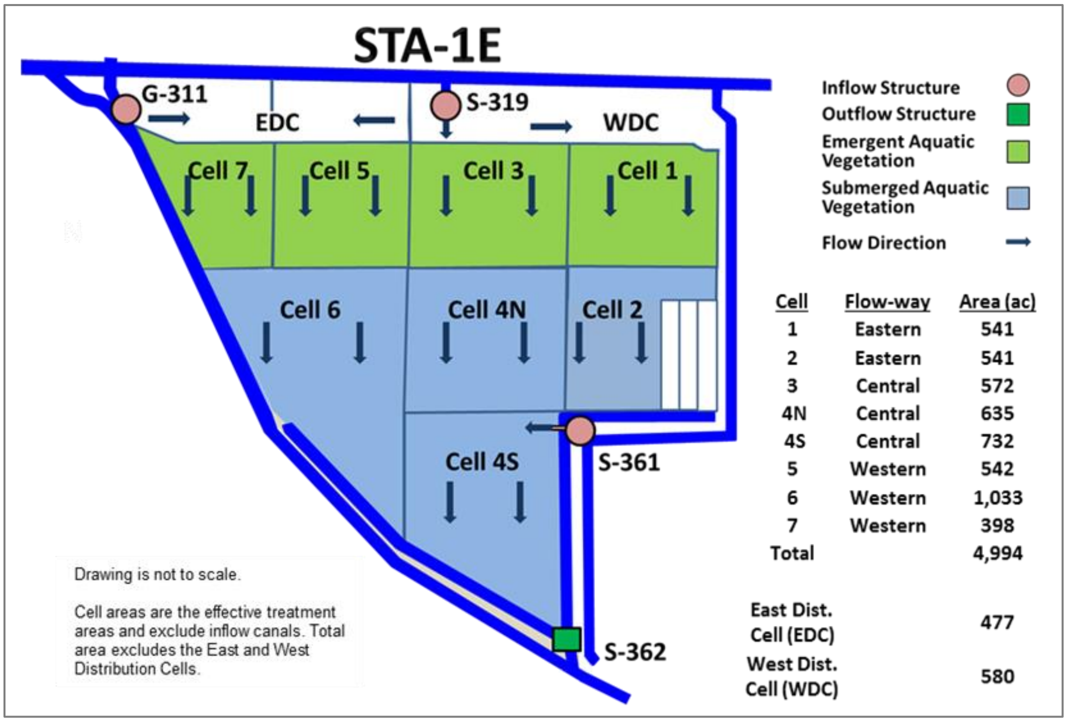

Figure 5B-4. Simplified schematic of STA-1E showing major inflow and outflow water-control structures, effective treatment area of each cell, flow direction, and dominant/target vegetation types. [Note: A detailed structure map of STA-1E is provided in Appendix 5B-1 of this volume; effective treatment areas do not include pump stations, levees, roads, or other upland areas.]

Several issues have affected STA-1E operations over its POR, including high hydraulic loadings during large storm events (particularly Hurricane Wilma in 2005, an unnamed storm in February 2006, and Tropical Storm Isaac in 2012), the repair of internal water control structures by the USACE, uneven topography causing excessively deep water and hydraulic short-circuiting (particularly in Cells 5 and 7), dryout of cells during dry periods, and vegetation die-off [i.e., the gradual decline of cattail in Cell 7 over time, the sudden hydrilla die-off in Cell 6 during WY2010, and damage to SAV in Cell 4S from herbivory by the exotic island applesnail (*Pomacea maculata*) in July 2013].

STA TREATMENT PERFORMANCE

Over its POR, STA-1E has treated approximately 910,000 ac-ft of water and retained 144 mt of TP or 72 percent of the inflow TP load (**Table 5B-1**). The POR inflow FWM TP concentration to this facility was 177 ppb, while the POR outflow FWM TP concentration was 50 ppb.

STA-1E received relatively high inflow TP and water loads during WY2014 (26 mt and 127,000 ac-ft, respectively) compared to previous annual inflow TP and water loads (**Figure 5B-5**). STA-1E retained 20 mt of TP, or 76 percent, of the inflow TP load this year.

Inflow and outflow FWM TP concentrations were 166 and 41 ppb, respectively, while the HLR and PLR were 2.7 cm/day and 1.6 g/m^2/yr, respectively (**Table 5B-1**).

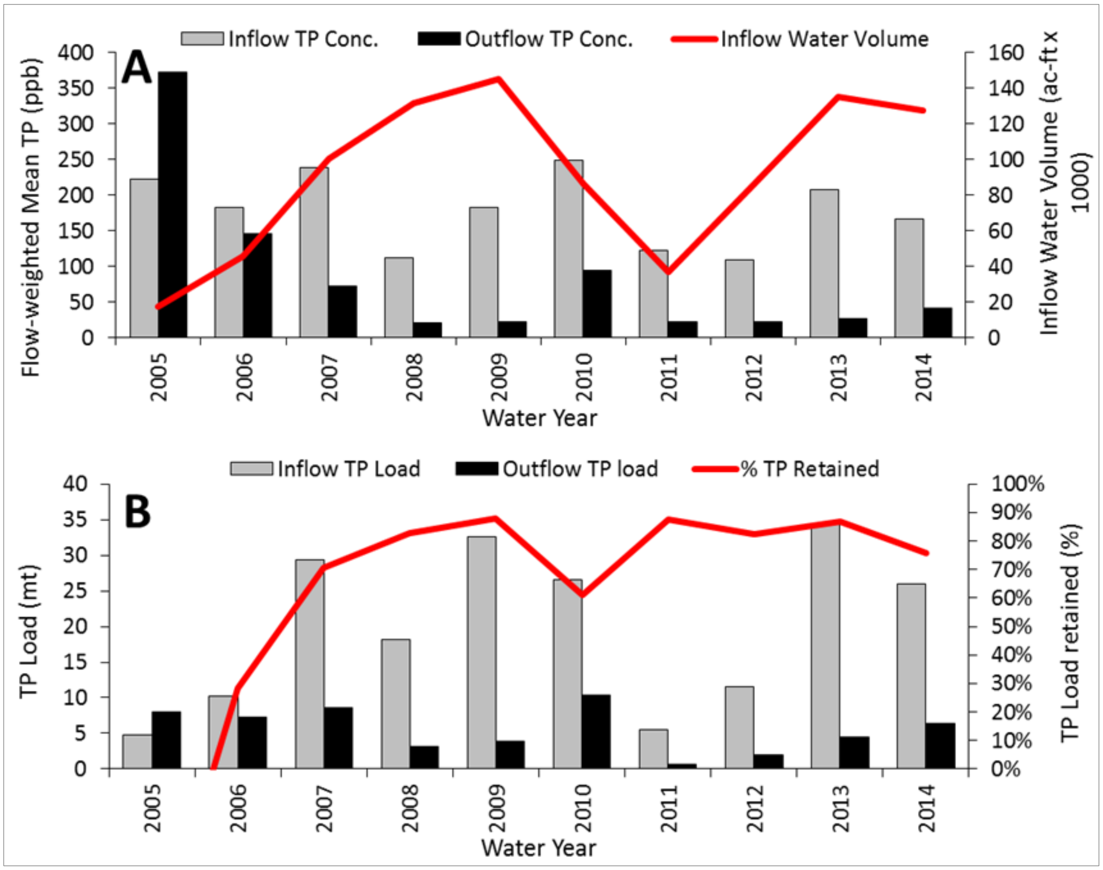

Figure 5B-5. Period of record time series in STA-1E of (A) annual inflow and outflow flow-weighted mean TP concentrations with corresponding inflow water volumes and (B) annual inflow and outflow TP loads with percent TP load retained.

FACILITY STATUS AND OPERATIONAL ISSUES

The Eastern Flow-way of STA-1E was offline in WY2014 due to decommissioning of the USACE PSTA Demonstration Project in Cell 2 (**Table 5B-2**). As of June 2014, the USACE had completed the Cell 2 grading work and all construction equipment had been removed. As of July 2014, Cell 2 had been reflooded but remained offline to allow its aquatic plant community to become reestablished. Approximately 29,000 ac-ft of Lake Okeechobee regulatory releases were directed to STA-1E via S-5A and G-311 for treatment prior to discharge to WCA-1 in May and August to December 2013, and January to April 2014. During November 2013, Lake Okeechobee releases were used as supplemental water to raise Cell 5 to its target stage.

The Central and Western Flow-ways remained online but under operational restrictions throughout WY2014 due to structure repairs, vegetation enhancement activities, and changes in operations to protect nesting bird (**Table 5B-2**). For a brief period during the dry season of WY2014, stages in Cells 4S, 6, and 7 were lowered 0.5 ft to benefit both EAV and SAV recruitment. Stage in Cell 4N was restricted from May to November 2013 and March to April 2014 due the presence of nesting snail kites and in Cell 5 from May to June 2013 due to nesting black-necked stilts.

Cell 4S experienced an enormous population increase of the island applesnail between July and August 2013. These mollusks feed primarily on SAV and their density became so high that they quickly defoliated virtually all the SAV (primarily hydrilla) in the cell. With the sudden loss of SAV biomass, Cell 4S stopped removing TP from the water column and began to export TP on a net basis. In an effort to control the island applesnail population, water levels in the Central Flow-way were first increased in an attempt to drown the snail egg clutches, and then lowered to near ground level in November 2013 and January 2014 to facilitate predation by birds. Starting in February 2014, the flow-way was dewatered for two months. Water levels in the Central Flow-way were then brought back to target stage in April 2014. While these water level manipulations undoubtedly increased bird predation on the island applesnails, it is assumed that starvation played a significant role in reducing their population. In spring 2014, the District inoculated the cell with SAV to reestablish the SAV community.

The District continued to monitor STA-1E for island applesnails for the remainder of 2014. As of August 2014, the population appeared to be at a normal density and water-column TP concentrations within Cell 4S had returned to historic levels.

Life history information for island applesnails indicates that under ideal conditions they can reproduce rapidly (Barnes et al. 2008). This species has a life span of three to four years, reaches reproductive age in six weeks after hatching, and can produce an egg clutch containing 800 to 1,200 eggs every week when water temperatures exceed 23.3° C (74° F) (Bernatis 2014). Water temperatures typically exceed this threshold throughout the spring, summer, and fall in south Florida.

Field surveys were conducted in August and September 2013 to estimate of the number of live island applesnails and egg clutches in Cell 4S. Observations indicated that the snails had consumed approximately 600 of the 700 acres of SAV that had once occupied the cell. This cell also contained 150 acres of EAV and 500 acres of open water.

An estimate of juvenile and adult island applesnail densities in Cell 4S within the remaining SAV beds was made on August 6, 2013, by counting snails in 30 haphazardly thrown 1-m^2 quadrats. Snails were collected by hand from within each quadrat for approximately two minutes. The estimated average density of juvenile and adult island applesnails was 35 snails/m^2. Extrapolating to the remaining 100 acres of SAV in the cell, the total number of island applesnails present in Cell 4S SAV was approximately 14 million individuals at this time.

A month later, on September 13, 2013, an estimate of snail densities was made for three habitat types: EAV, SAV, and open-water areas lacking vegetation. Snails were collected using a 0.35-mm mesh D-framed sweep net and two 0.5-m linear sweeps were made in each area. Snail densities of 74.7, 14.7, and 324 snails/m^2 were found in EAV, SAV and open water, respectively. Similar sweep-net sampling in a SAV cell in nearby STA-1W found no island applesnails. Extrapolating from the limited Cell 4S sweep-net sampling to the acreage of EAV, the remaining SAV, and open water yielded approximately 45 million, 6 million and 655 million snails, respectively, making the estimated total number of island applesnails in Cell 4S approximately 700 million.

The density of egg clutches on emergent vegetation stems was estimated on August 6, 2013, in areas containing bulrush, cattail, and torpedo grass based on 50 1-m^2 quadrat samples. Bulrush, cattail, and torpedograss stems contained an average of 67, 60, and 88 egg clutches/m^2, respectively. Extrapolating to 150 acres of EAV in the cell, the estimated number of egg clutches averaged over all three plant species was approximately 43 million clutches. Each egg clutch may have contained 800 to 1,200 eggs.

Plausible reasons for the snail population explosion include (1) a reduction in snail predation, (2) stabilization of water levels in Cell 4S from January through June 2013 to protect upstream Everglade snail kite nests, (3) unusual water quality conditions within the cell, or (4) a snail seed source from the operation of the S-361 pump station, which brings stormwater into the cell from a nearby housing sub-division. The District sampled potential predator fish (electro-shocking) and invertebrate populations (sweep-nets) in September and October 2013 but found no apparent differences in potential predator populations between Cell 4S and nearby SAV cells. A review of inflow water quality data did not reveal differences between Cell 4S and nearby SAV cells. Water levels in Cell 4S and Cell 6, an adjacent SAV cell, did not reveal differences in water level changes, which might have led to an increase in egg clutch survival in Cell 4S. Finally, an inspection of canals in the sub-division upstream of S-361 failed to identify a population of island applesnails that may have been introduced into Cell 4S. In summary, the District could not identify a single factor or multiple factors to explain the sudden snail population increase in Cell 4S. The District will continue to monitor island applesnail populations in Cell 4S and nearby cells and plans to implement a study of this invasive species and its occurrence in the STAs, with the goal of identifying future potential control measures.

Runoff from tropical Storm Andrea and rainfall events immediately following the storm increased water depth in STA-1E to its maximum operating level. In response to the deepwater conditions, some storm runoff was diverted directly into WCA-1 from June 7 to 11, 2013.

The USACE continued with repairs to several water control structures in the Western and Central Flow-ways during WY2014. At the District's request, only one structure in each cell was taken off-line at a time for repairs, which allowed for partial operation of both flow-ways. As of July 1, 2014, structures S-366B, S-367A, S-368B, S-370B, S-373A, S-371A, S-371B, S-374B, and S-374C have been repaired, while S-366C, S-367D, S-368D, and S-369D remain off-line. The reconstruction of S-375, the conveyance structure between the East and West Distribution Cells, was completed and as-built drawings were submitted to the FDEP on February 2013. The FDEP conducted a field inspection and concurred that the S-375 structure had been repaired in substantial accordance with the submitted as-built plans. Accordingly, this action satisfied Specific Condition No. 6 in FDEP permit number 0311207.

Dryout Impacts

All cells in the Western and Central Flow-ways of STA-1E were hydrated in WY2014 and not subject to dryout impacts. The Eastern Flow-way was dry due to removing the USACE's PSTA Demonstration Project in Cell 2.

Migratory Bird and Snail Kite Nesting

Twenty-three black-necked stilts nests were observed in STA-1E between April and July 2013 (the 2013 nesting season). Most nests were observed in Cell 2 from June to July 2013. Single nests were observed in the Eastern Distribution Cell (EDC) and Cell 5 in April 2013 and May 2013, respectively. No other nesting activity by black-necked stilts occurred during WY2014. While nests were being incubated, the stage in the EDC and Cell 5 were held at or below 17.60 and 15.20 ft NGVD, respectively, to avoid flooding nests. Cell 2 was not in operation while black-necked stilts were nesting, so no adjustments to cell stage were required.

Everglade snail kites were confirmed nesting in STA-1E Cell 4N on January 22, 2013, the first time nesting by this species had been observed in STA-1E. From May 1, 2013 to April 30, 2014, twenty-one nests in Cell 4N were monitored by the University of Florida Snail Kite Lab. A restricted range of water stages that would protect snail kite nests was established for Cell 4N in consultation with USFWS (see Appendix 5B-2 of this volume). Snail kite nesting continued beyond the end of WY2014, with the last snail kite nest in Cell 4N on May 21, 2014. Further information on STA-1E operational adjustments related to nesting during WY2014 is presented in Appendix 5B-2.

VEGETATION MAINTENANCE AND ENHANCEMENTS

Due to decommissioning of the PSTA Project and associated re-grading of Cell 2 in WY2014 (see Appendix 5B-1, Figure 1), vegetation management in the Eastern Flow-way was limited to control of FAV near the inflow and outflow structures. In the Central Flow-way, over 800 acres of water lettuce and water hyacinth were treated in Cell 4N to maintain conditions conducive for sustained growth of SAV. Infestations of these two FAV species were exacerbated by delayed herbicide treatments due to snail kite nesting in the southern end of the cell. Giant bulrush was planted to establish new emergent vegetation strips in Cell 4S and repair gaps in an existing strip in Cell 4N. Southern naiad was inoculated in Cell 4S in an effort to restore the SAV community damaged by the island applesnail. Continued efforts were undertaken to improve the coverage of the plant community in the Western Flow-way. A dry-season water-level drawdown in 2012 has led to marked recruitment and increased cover of cattail over the eastern half of Cell 5. Thirteen acres of floating mats of primarily primrose willow in the north-central portion of Cell 7 were mechanically harvested and replaced with plantings of giant bulrush in March 2014. Harvested tussocks were hauled to a disposal site along the eastern side of STA-1E that was not part of the treatment area. Southern naiad has continued to colonize Cell 6 and has replaced hydrilla as the dominant SAV species in this cell; southern naiad was inoculated in remaining open water areas starting in February 2013 and continued throughout WY2014.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

There was relatively little net change in EAV coverage in the EAV Cells 1, 3, 5, and 7 of STA-1E over the last seven years (2007 to 2013; **Figure 5B-6**); their average EAV coverages were 92, 85, 83, and 62 percent, respectively. However, EAV coverage in the SAV Cells 4N, 4S, and 6 increased markedly from less than 7 percent in 2007 to approximately 20 to 40 percent by 2013 (overall average = 26, 11, and 18 percent, respectively).

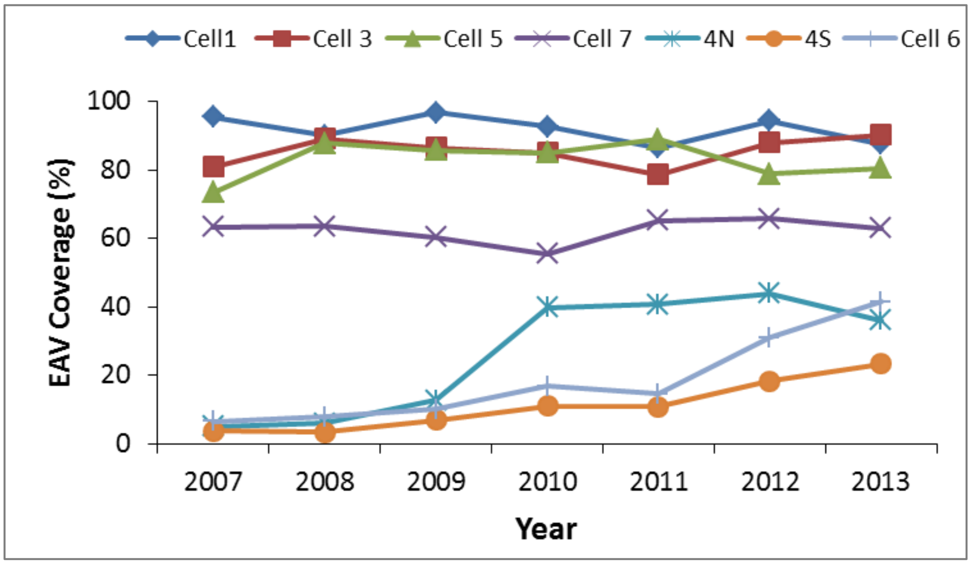

Figure 5B-6. Temporal change in percent coverage of emergent aquatic vegetation (EAV) within each cell of STA-1E.

Ground Surveys for Submerged Aquatic Vegetation

Analysis and interpretation of SAV ground surveys conducted in STA-1E during WY2014 is presented in the *Applied Scientific Studies*: *Submerged Aquatic Vegetation Decline in STA-1 East* section of this chapter.

STA-1W

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Contributors: Shi Kui Xue, Kathy Pietro and Neil Larson

STA-1W, which began operation in 1994 as the Everglades Nutrient Removal (ENR) Project, is located northwest of the Arthur R. Marshall National Wildlife Refuge (**Figure 5B-1**). This STA presently encompasses 6,544 acres of effective treatment area arranged into three flow-ways with eight treatment cells (Piccone et al., 2013; **Figure 5B-7**). The Eastern and Western Flow-ways comprised the ENR Project and the Northern Flow-way was added in 1999. Compartmentalization of former Cells 1 and Cell 2 was completed in 2007, creating Cells 1A, 1B, 2A, and 2B. This STA receives inflow primarily from the S-5A drainage basin. During dry months, supplemental water is delivered from Lake Okeechobee, when available, to maintain hydration of priority cells, i.e., cells dominated by SAV. The flow-way nomenclature for STA-1W is as follows:

- Eastern Flow-way = Cells 1A, 1B and 3,
- Western Flow-way = Cell 2A, 2B, and 4, and
- Northern Flow-way = Cells 5A and 5B.

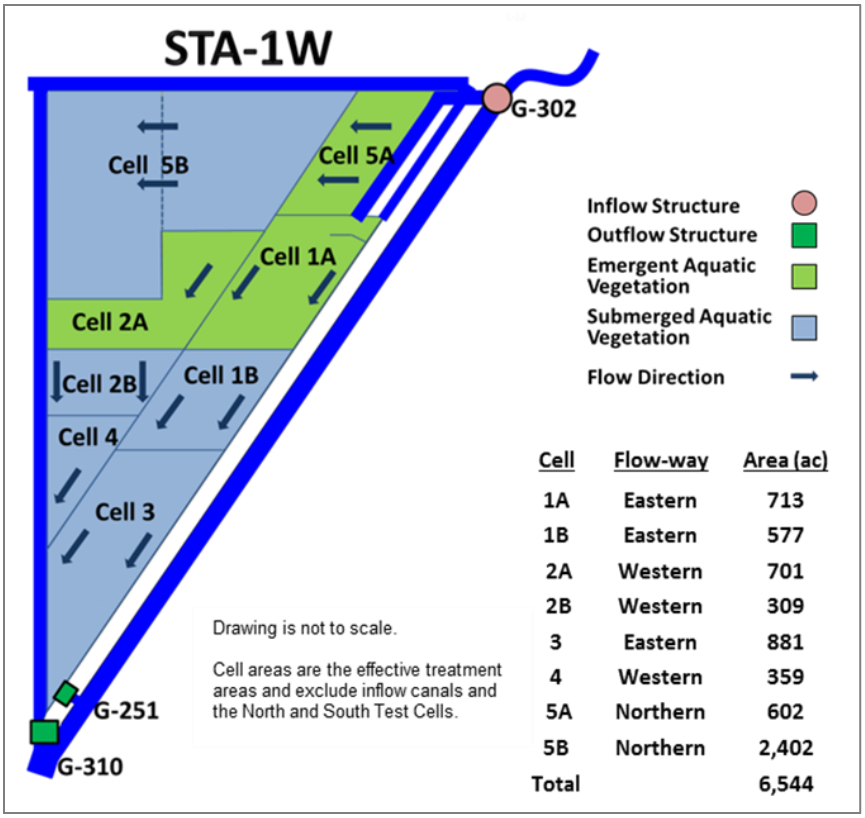


Figure 5B-7. Simplified schematic of STA-1W showing major inflow and outflow water-control structures, effective treatment area of each cell, flow direction, and dominant/target vegetation types. [Note: A detailed structure map of STA-1W is provided in Appendix 5B-1 of this volume; effective treatment areas do not include pump stations, levees, roads, or other upland areas.]

Over its operational history, STA-1W has been affected by extreme weather events (regional droughts and large storms), enhancement activities that included water level drawdowns and construction, and high hydraulic and nutrient loadings. The restrictions on operation of STA-1E discussed above also affected STA-1W in that the District treated some of the runoff that ordinarily would have been processed in STA-1E in STA-1W and thereby increased the water and nutrient loading in STA-1W. A series of major rehabilitation activities was implemented in STA-1W between 2005 and 2007 to reestablish the vegetation communities that were damaged by hydraulic overloading in previous years and restore the treatment performance of all cells.

STA TREATMENT PERFORMANCE

Over its POR, STA-1W has treated approximately 3.65 million ac-ft of water and retained 563 mt of TP (the largest amount of any STA) or 72 percent of the total inflow TP load (**Table 5B-1**). The POR inflow FWM TP concentration was 175 ppb, while the POR outflow FWM TP concentration was 48 ppb.

In WY2014, STA-1W treated approximately 228,000 ac-ft of runoff with an inflow FWM TP concentration of 174 ppb and an outflow FWM TP concentration of 24 ppb (**Table 5B-1**). STA-1W retained 42 mt of TP or 86 percent of the inflow TP load this year and had a HLR and a PLR of 2.9 cm/day and 1.8 g/m^2/day, respectively. Treatment performance in STA-1W has fully recovered from the dramatic decline that occurred from WY2001 to WY2006 as demonstrated by the increase in % TP load retained since WY2006, (**Figure 5B-8**). The % TP load retained in STA-1W has been 80 percent or greater since WY2009, which is comparable to the treatment performance in the period preceding WY2001.

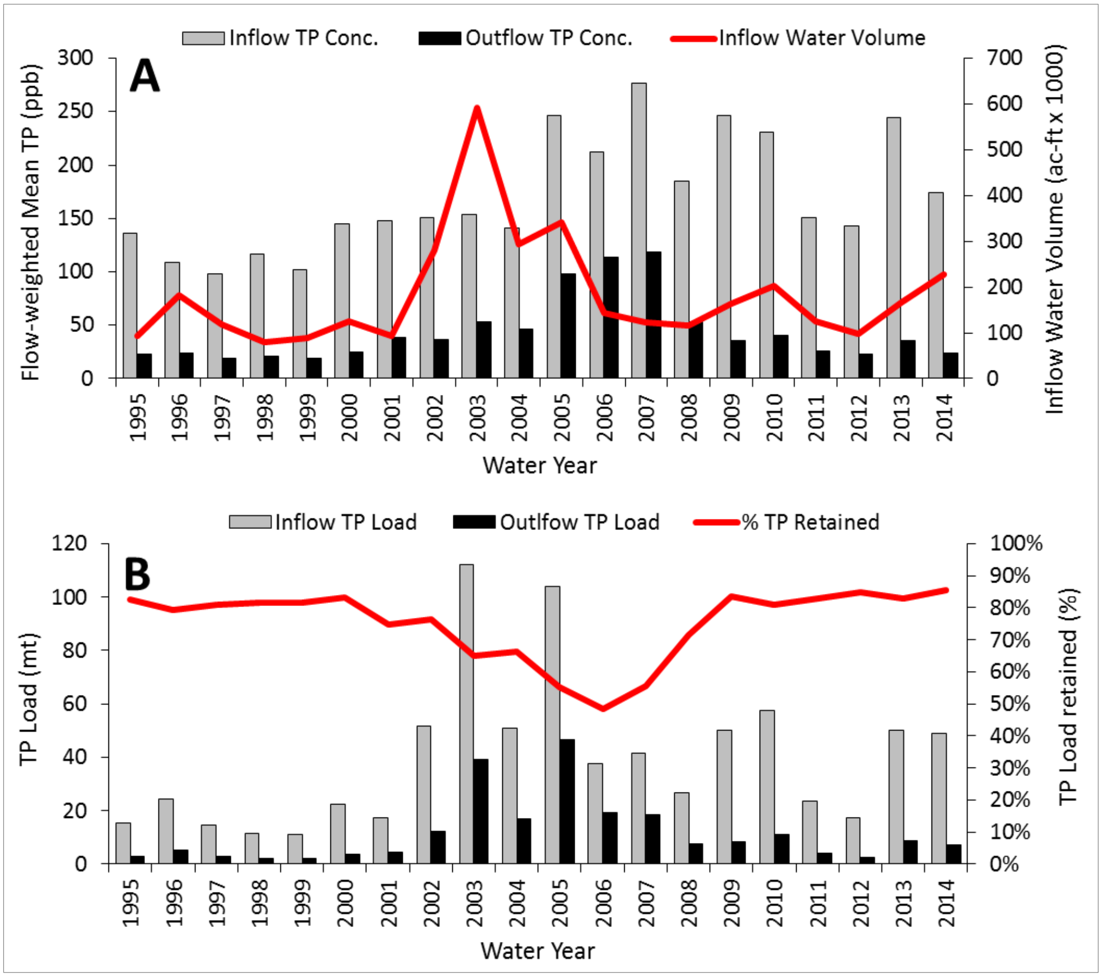


Figure 5B-8. Period of record time series in STA-1W of (A) annual inflow and outflow flow-weighted mean (FWM) TP concentrations with corresponding inflow water volumes and (B) annual inflow and outflow TP loads with percent TP load retained.

FACILITY STATUS AND OPERATIONAL ISSUES

All flow-ways in STA-1W were operational during WY2014, although the Eastern and Northern Flow-ways were online with restrictions for part of the year for vegetation planting (**Table 5B-2**). Due to operational issues in STA-1E, STA-1W treated the majority of basin flow this year. For a portion of the dry season in WY2014, the target stages in Cells 1A, 2A, and 5A were lowered 0.5 ft to benefit the establishment of both EAV and SAV. Similarly, the target stage in the Western Flow-way was lowered 0.5 ft in September 2013 to reduce stress on the vegetation resulting from prolonged exposure to deep-water conditions. Approximately 45,000 ac-ft of Lake Okeechobee regulatory releases were directed to STA-1W via S-5A for treatment prior to delivery to WCA-1 in August to December 2013 and April 2014.

Runoff from Tropical Storm Andrea and rainfall events immediately following the storm raised water depth in STA-1W to its maximum operating level. In response to the high-water conditions, runoff was diverted directly into WCA-1 from June 7 to 11, 2013. To relieve high water levels in WCA-1, G-300 was opened on June 30, 2013 to release water from WCA-1 for discharge to the ocean via S-5AS, S-5AE, and S-155A.

Work on hardening the S-5A Pump Station from storm damage was initiated in November 2012 and is currently ongoing. Operations in the Western Flow-way were restricted in May and June 2013 and in the Northern Flow-way during April 2014 due to black-necked stilt nesting. The north seepage return canal was operated at a stage of 7.0 to 7.5 ft NGVD for most of WY2014 to accommodate farming operations north of STA-1W. This canal is an inflow to STA-1W. As of April 2014, the farm lease had expired and stage in the north seepage return canal was back within its normal operating range.

Dryout Impacts

All cells in STA-1W were hydrated in WY2014 and not subject to dryout impacts.

Migratory Bird and Snail Kite Nesting

Thirteen black-necked stilt nests were observed in STA-1W between May and July 2013 (the 2013 nesting season); all nests were located in Cells 2B and 4. The District attempted to maintain stages in Cells 2B and 4 at or below 11.00 ft NGVD in these cells during this period to minimize potential impacts to nests. However, heavy rainfall in June 2013 associated with Tropical Storm Andrea potentially flooded some nests due to direct rainfall. Based on the date when the nests were first observed and the date of the storm event, it is believed that at least four nests hatched and fledged young black-necked stilts, while the other nests likely failed due to flooding. No other black-necked stilt nesting activity in STA-1W occurred during the 2013 nesting season. Sixteen black-necked stilt nests were observed in Cell 5B during the 2014 nesting season (this period encompasses both WY2014 and WY2015). Four of these nests were observed during WY2014. The District attempted to maintain stage in Cell 5B at or below 10.0 ft to NGVD to minimize potential impacts to nests. No active Everglade snail kite nests were observed in STA-1W during WY2014. Further information on STA-1W operational adjustments related to nesting during WY2014 is presented in Appendix 5B-2.

VEGETATION MAINTENANCE AND ENHANCEMENTS

Alligator flag was planted during WY2014 in a hydraulic short circuit at the northern end of STA-1W Cell 5A, and giant bulrush and alligator flag were planted to repair gaps in existing EAV strips in Cell 5B. Approximately 560 acres of FAV were treated to maintain conditions conducive for growth of SAV in Cell 5B, and southern naiad was inoculated in an open-water area in the southwest portion of this cell. Revitalization efforts continued in Cell 1A where alligator flag and giant bulrush were planted in an unvegetated area in the north-central portion of the cell, and in a major short circuit extending from the northwest to southeast corner. Floating plants in this area (332 acres) were treated to facilitate establishment of these plantings. A new strip of giant bulrush was planted in the northern end of Cell 1B, and inoculations of southern naiad were completed to assist in the reestablishment of SAV beds in Cell 3, where coverage of the dominant species, muskgrass, disappeared between December 2013 and January 2014. New strips of giant bulrush were planted in Cell 2B of the Western Flow-way and gaps in existing emergent vegetation strips in Cell 4 were repaired with giant bulrush plantings.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

There was relatively little net change in EAV coverage in the EAV Cells 2A and 5A of STA-1W from 2007 to 2013 (**Figure 5B-9**); their average EAV coverages over this period were 85 and 58 percent, respectively. EAV coverages in Cells 1A, 1B, 2B, 3 and 4 were close to 100 percent in 2007 shortly after these cells were reflooded following rehabilitation activities in STA-1W. Subsequently, SAV Cells 1B, 2B, 3, and 4 were converted from EAV to SAV communities. The EAV coverage in Cells 1B, 2B, and 4 decreased to 15 percent or less by 2008 and then varied from 5 to 28 percent in the following years (average after 2007 = 23, 7, and 14 percent, respectively). In contrast, EAV coverage in Cell 3 decreased to only 42 percent by 2008 and varied little thereafter (average after 2007 = 41 percent). EAV coverage in SAV Cell 5B averaged 11 percent over the period, but reached 26 percent in 2012. Conversely, EAV coverage in EAV Cell 1A increased steadily from 59 percent in 2008 to 83 percent by 2013 (average after 2007 = 74 percent).

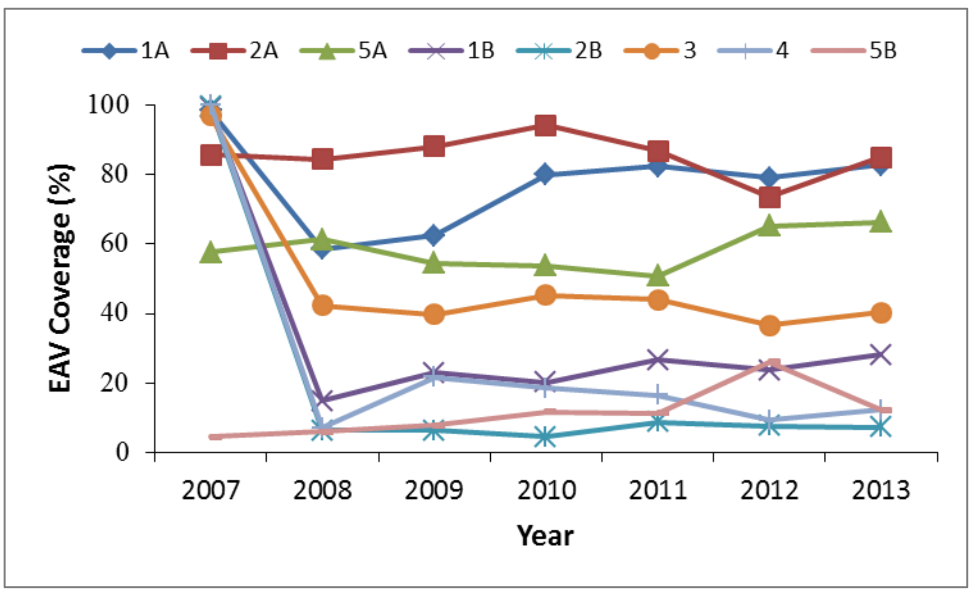


Figure 5B-9. Temporal change in percent coverage of emergent aquatic vegetation (EAV) within each cell of STA-1W.

Ground Surveys for Submerged Aquatic Vegetation

Analysis and interpretation of SAV ground surveys conducted in STA-1W during WY2014 is presented in the *Applied Scientific Studies: Submerged Vegetation Decline in the STA-1W Eastern Flow-Way* and *Evaluation of Spatial Patterns of Phosphorus Removal in STA-1W Cell 5B* sections of this chapter.

STA-2

Hongying Zhao, Brian Garrett, Yaoyang Yan, Michael Chimney and Lou Toth

Contributors: Shi Kui Xue, Holly Andreotta, Kathy Pietro and Neil Larson

STA-2 is located in western Palm Beach County immediately west of Water Conservation Area 2A (WCA-2A; **Figure 5B-1**). STA-2 originally consisted of three treatment cells (Cells 1, 2, and 3) and began operation in 2000. This facility was expanded with the construction of Cell 4, which was flow capable by December 2006; however, Cell 4 went off-line in WY2010 during the construction of Compartment B. With the recent completion of Compartment B, STA-2 now has eight treatment cells arranged into five flow-ways with a total effective treatment area of 15,495 acres (Piccone et al., 2013; **Figure 5B-10**). STA-2 receives agricultural runoff from three basins: runoff primarily comes from the S-6 and (a portion of the) S-2 basins but also can come from the S-7 and (the remaining portion of the) S-2 basins. During dry months, supplemental water is delivered from Lake Okeechobee, when available, to maintain hydration of priority cells, i.e., cells dominated by SAV. The flow-way nomenclature for STA-2 is as follows:

- Flow-way 1 = Cell 1,
- Flow-way 2 = Cell 2,
- Flow-way 3 = Cell 3,
- Flow-way 4 = Cell 4 and new Cells 5 and 6 in Compartment B, and
- Flow-way 5 = new Cells 7 and 8 in Compartment B.

Like the other STAs, STA-2 has been affected by regional droughts and storm events over its POR. The District seeks to improve operation of the STAs to minimize impacts from such events. For example, Cells 1 and 2 have dried out, either partially or entirely, during past droughts when the supply of supplemental water was limited. Starting in WY2011 as a proactive measure, stage throughout STA-2 was increased to hold more water in the system in advance of the dry season, which has helped minimize dryout. One feature of STA-2 thought partly responsible for its good treatment performance is that all of Cell 1 and part of Cell 2 were never farmed prior to these areas becoming part of the STA. The hypothesis is that there is reduced P flux from the unfarmed soils back to the water column, which leads to lower outflow TP concentrations from these cells. In WY2009, the vegetation community in approximately 300 acres at the southern end of Cell 2 was converted from cattail to SAV to improve treatment performance.

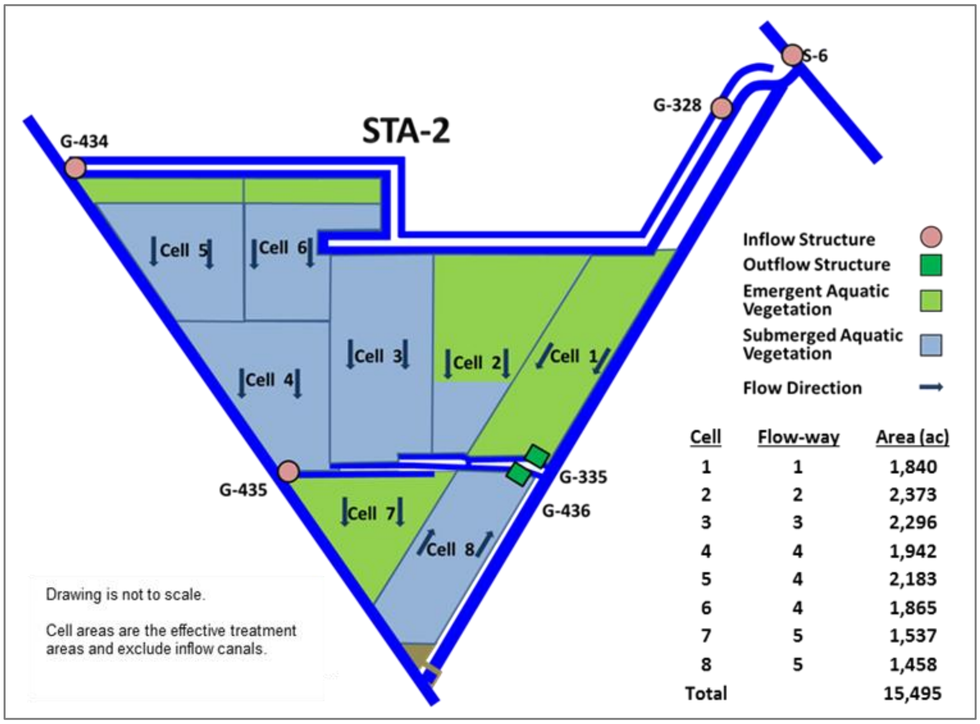


Figure 5B-10. Simplified schematic of STA-2 showing major inflow and outflow water-control structures, effective treatment area of each cell, flow direction, and dominant/target vegetation types. [Note: A detailed structure map of STA-2 is provided in Appendix 5B-1 of this volume; effective treatment areas do not include pump stations, levees, roads, or other upland areas.]

STA Treatment Performance

STA-2, over its operational history, has treated approximately 3,460,000 ac-ft of water and retained 332 mt of TP or 77 percent of the TP load that entered this facility (**Table 5B-1**). The POR inflow FWM TP concentration to this facility was 101 ppb, while the POR outflow FWM TP concentration was 22 ppb.

STA-2 treated approximately 376,000 ac-ft of runoff in WY2014 that had an inflow FWM TP concentration of 86 ppb and produced an outflow FWM TP concentration of 19 ppb (**Table 5B-1**). This facility retained 30 mt of TP, or 76 percent of the inflow TP load received this year and had a HLR and PLR of 2.2 cm/day and 0.7 $g/m^2/yr$, respectively. The treatment performance of STA-2 in WY2014, as measured by its outflow FWM TP concentration and % TP load retained, was within the range of values observed in this STA over its POR (**Figure 5B-11**).

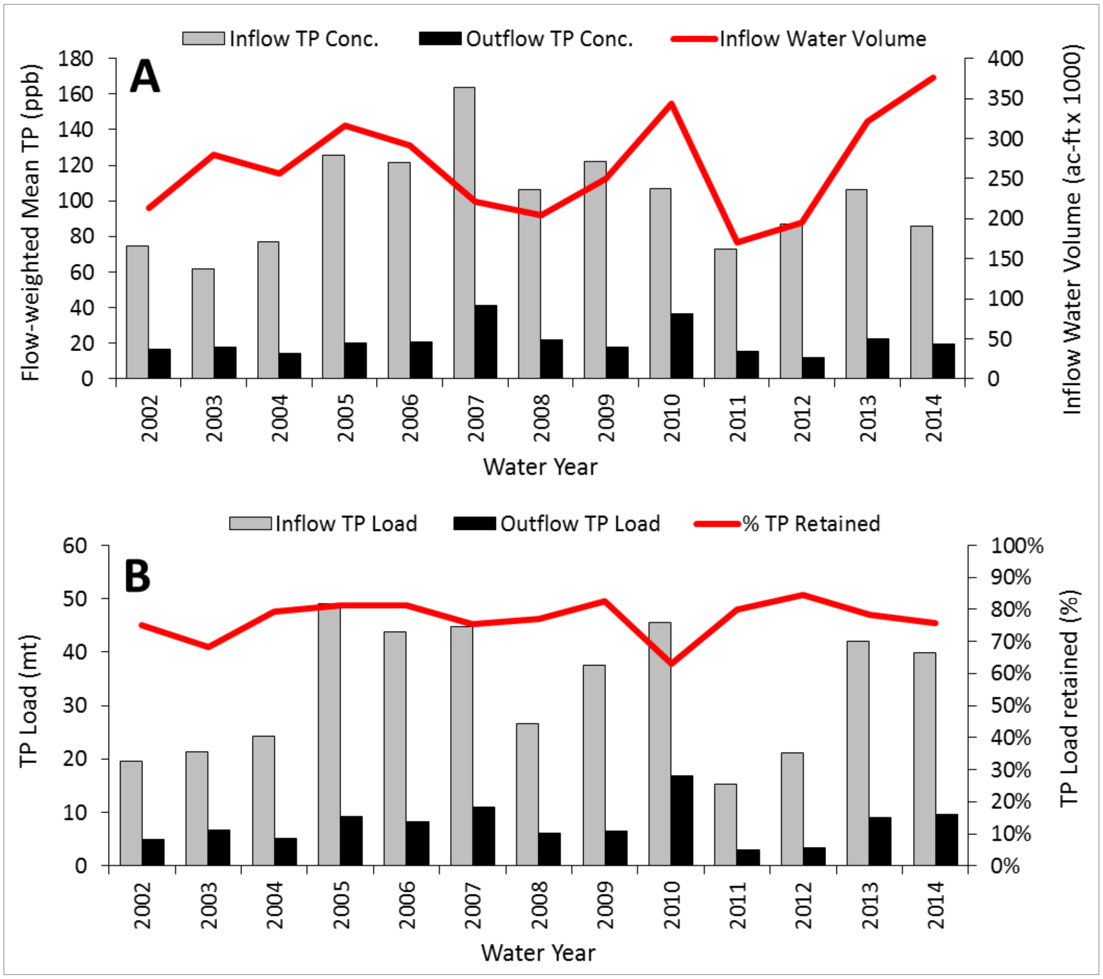


Figure 5B-11. Period of record time series in STA-2 of (A) annual inflow and outflow flow-weighted mean TP concentrations with corresponding inflow water volumes and (B) annual inflow and outflow TP loads with percent TP load retained.

FACILITY STATUS AND OPERATIONAL ISSUES

Flow-ways 1, 2, 3, and 4 in STA-2 were operational throughout WY2014, although Flow-ways 2 and 3 were online with restrictions for part of the year. Flow-way 5 passed its start-up criteria in May 2013, but was off-line from December 2013 through April 2014 for grading in Cell 8. Grading was completed by July 1, 2014; however, Flow-way 5 remained offline to allow for vegetation grow-in. (**Table 5B-2**). Supplemental water from Lake Okeechobee was delivered to Flow-way 4 in November 2013 to maintain its stage at target levels. Approximately 50,000 ac-ft of Lake Okeechobee regulatory releases were sent through STA-2 for treatment prior to delivery south to WCA-2 starting in October 2013. Treatment of Lake Okeechobee regulatory releases continued throughout WY2014. This water was distributed evenly among Flow-ways 1, 2, 3 and 4 to avoid overloading any one flow-way.

To help quantify the role that vegetation resistance plays in STA flow dynamics, a hydraulic test was performed in Cell 3 in October 2013. A requirement of the experiment was to maintain near-steady flow of 200 cfs through the cell. To accomplish this, water was recycled from the Cell 3 outflow back to the Cell 3 inflow via the G-339 structure. This study was part of the

District's Restoration Strategies Science Plan (see Chapter 5C of this volume). Stage fluctuation at G-434 was increased from 7.0 - 7.5 ft NGVD to 7.5 - 8.0 ft NGVD. This change reduced the District's pumping costs at this structure but still limited seepage from STA-2 to accommodate adjacent farming operations.

Runoff from Tropical Storm Andrea and rainfall events immediately following the storm in June 2013 raised the stages in the treatment cells of STA-2 to high levels. However, no diversion of water around STA-2 was necessary.

Operations in Cells 3, 5 and 6 were restricted in May and June 2013 due to black-necked stilt nesting in these cells. Structure maintenance in WY2014 included repair of the Cell 2 inflow gates (G-331A, C, F, and G) and inspection of the Cell 3 inflow gates (G-333 structures). In addition, earthen plugs were installed at the east and west ends of the northernmost vegetation strip in Cell 3 to fill in bottom depressions that were causing hydraulic short circuits in the cell.

Compartment B Build-out

The Compartment B Build-out Project was located in Palm Beach County, west and south of the original boundaries of STA-2 (Cells 1, 2, 3, and 4; **Figures 5B-1** and **5B-10**) and greatly expanded the treatment area of this facility. All construction activities on the project have been completed. As-built Certification Forms for the South Build-out components (Flow-way 5: Cells 7 and 8) were submitted to the FDEP in May 2013. The FDEP acknowledged in May 2013 that a net reduction in TP concentration had occurred from inflow to outflow in Flow-way 5 and, therefore, discharge activities could commence from the G-441 structure.

The Cell 8 Discharge Obstruction Project was an effort to address high ground surface elevations over an area of approximately 50 acres at the north end of Cell 8. Incremental conversion of Cell 8 from EAV to SAV began in June 2013 when 230 acres of cattail in the northern (downstream) end of the cell were treated with an aerial herbicide application.

Dryout Impacts

All cells in STA-2 were hydrated in WY2014 and not subject to dryout impacts.

Migratory Bird and Snail Kite Nesting

Twelve black-necked stilt nests were detected within STA-2 Cells 3, 5, and 6 in May 2013. The District attempted to maintain stage in STA-2 Cells 3, 5, and 6 during this period at or below 10.90, 10.70, and 10.70 ft NGVD, respectively, to minimize potential impacts to nests. Heavy rainfall in early-June from a tropical weather system inundated many nests that were still active. Based on the time between the dates when nests were first observed and the date of the storm event, as well as the presence of several black-necked stilt chicks observed in June, it is believed that several nests hatched and fledged young black-necked stilts, while some nests were likely flooded by means of direct rainfall and failed. Further information on STA-2 operational adjustments related to nesting during WY2014 is presented in Appendix 5B-2.

VEGETATION MAINTENANCE AND ENHANCEMENTS

No significant maintenance or enhancement work was required in Cell 1 in WY2014. Incremental conversion of the southern (downstream) half of Cell 2 continued with inoculations of southern naiad over a 400-acre area where cattail was removed by a herbicide treatment last year. Deep gaps in the northernmost emergent vegetation strip in Cell 3 were partially filled with muck and planted with plantings of alligator flag and giant bulrush; another gap in the east-central portion of this strip also was planted with these species. Continued efforts were made to enhance the recently completed north build-out (Cells 5 & 6) of Compartment B where regrowth of willow and primrose willow was treated with an aerial herbicide application and southern (downstream) portions of these cells were inoculated with southern naiad. To assist with grading work in Cell 8, roughly 200 acres of cattail in the cell's north end were treated with herbicide.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

The composition of the aquatic plant community in Cell 1 of STA-2 was almost entirely EAV over the past seven years; EAV coverage averaged 96 percent during this period (**Figure 5B-12**). Cell 2 had 75 percent EAV coverage from 2007 to 2009, which then decreased to approximately 64 percent coverage following the conversion of the cell's outflow region to SAV (overall average = 68 percent). The EAV coverage in the SAV Cell 3 has increased steadily from 24 percent in 2007 to 35 percent by 2013 (overall average = 29 percent). The extent of EAV coverage in the SAV Cell 4 decreased from its maximum in 2007 (72 percent) to 5 percent in 2008 after the cell was converted to SAV (overall average = 32 percent). Cell 4 was then taken off-line and dewatered in 2010 for the construction of Compartment B. Subsequently, EAV coverage increased in the following years and reached 56 percent in 2011.

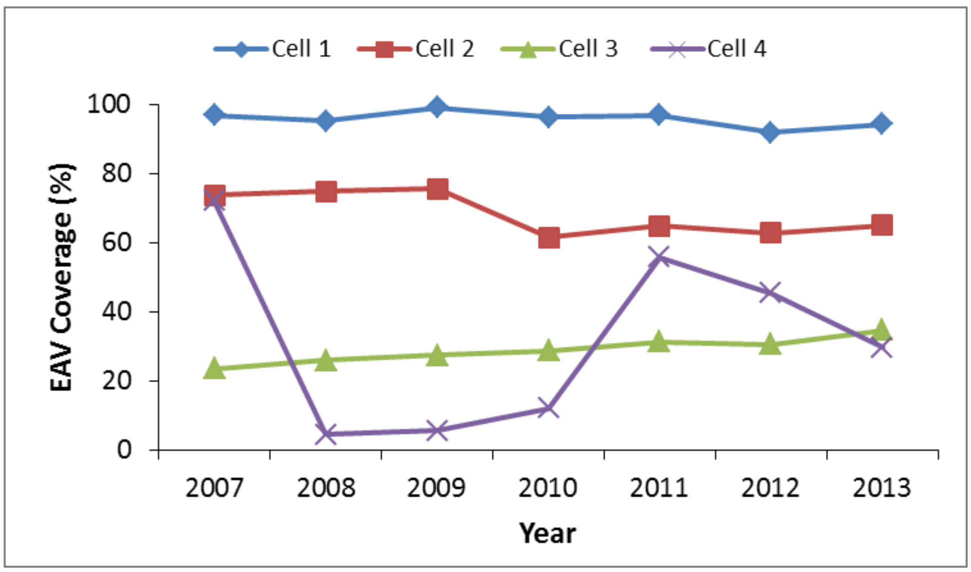


Figure 5B-12. Temporal change in percent coverage of emergent aquatic vegetation (EAV) within each cell of STA-2.

Ground Surveys for Submerged Aquatic Vegetation

Analysis and interpretation of SAV ground surveys conducted in STA-2 during WY2014 is presented in the *Applied Scientific Studies*: *Submerged Aquatic Vegetation Condition in STA-2* and *STA-5/6* section of this chapter.

STA-3/4

Hongying Zhao, Brian Garrett, Yaoyang Yan, Michael Chimney and Lou Toth

Contributors: Shi Kui Xue, Kathy Pietro and Neil Larson

STA-3/4 is located northeast of the Holey Land Wildlife Management Area and north of Water Conservation Area 3A (WCA-3A) (**Figure 5B-1**). This STA is comprised of six treatment cells arranged into three flow-ways with a total effective treatment area of 16,327 acres (Piccone et al., 2013; **Figure 5B-13**). A 445-acre section of Cell 2B is the site of the District's STA-3/4 PSTA Project, constructed as the first phase of implementing the PSTA treatment technology in this STA. STA-3/4 treats stormwater runoff from the S-2/S-7, S-3/S-8, S-236, and C-139 basins, and releases from Lake Okeechobee. During the dry season, supplemental water is delivered from Lake Okeechobee, when available, to maintain hydration of priority cells, i.e., cells dominated by SAV. The flow-way nomenclature for STA-3/4 is as follows:

- Eastern Flow-way = Cells 1A and 1B,
- Central Flow-way = Cell 2A and 2B, and
- Western Flow-way = Cell 3A and 3B.

Similar to the other STAs, STA-3/4 has been affected by extreme weather events (regional droughts and large storms). This STA has received high hydraulic loads during and following large storms, which resulted to excessively deep water for extended periods in cells at the top of the flow-ways. Persistent deep-water conditions stressed the cattail populations in Cells 1A and 2A causing widespread mortality, especially at the inflow regions of these cells.

STA TREATMENT PERFORMANCE

STA-3/4 over its operational history has treated the largest volume of water (4,670,000 ac-ft) and retained the second largest amount of TP (526 mt) with the greatest treatment efficiency, based on its % TP load retained (84 percent) of all the STAs (**Table 5B-1**). The POR inflow FWM TP concentration STA-3/4 was 109 ppb, while the POR outflow FWM TP concentration was 17 ppb, which is the lowest POR outflow TP concentration among the STAs. Based on these metrics, STA-3/4 has been the best performing STA over its POR.

STA-3/4 treated approximately 467,000 ac-ft of runoff in WY2014 that had a FWM TP concentration of 71 ppb and produced an outflow FWM TP concentration of 14 ppb (**Table 5B-1**). This facility retained 33 mt of TP, or 80 percent of the inflow TP load received this year and had a HLR and PLR of 2.4 cm/day and 0.6 g/m^2/yr, respectively. The treatment performance of STA-3/4 in WY2014, as measured by its outflow FWM TP concentration and % TP load retained, was within the range of annual values observed in this STA over its POR (**Figure 5B-14**) and ranked STA-3/4 among the best performing STAs this year (**Table 5B-1**).

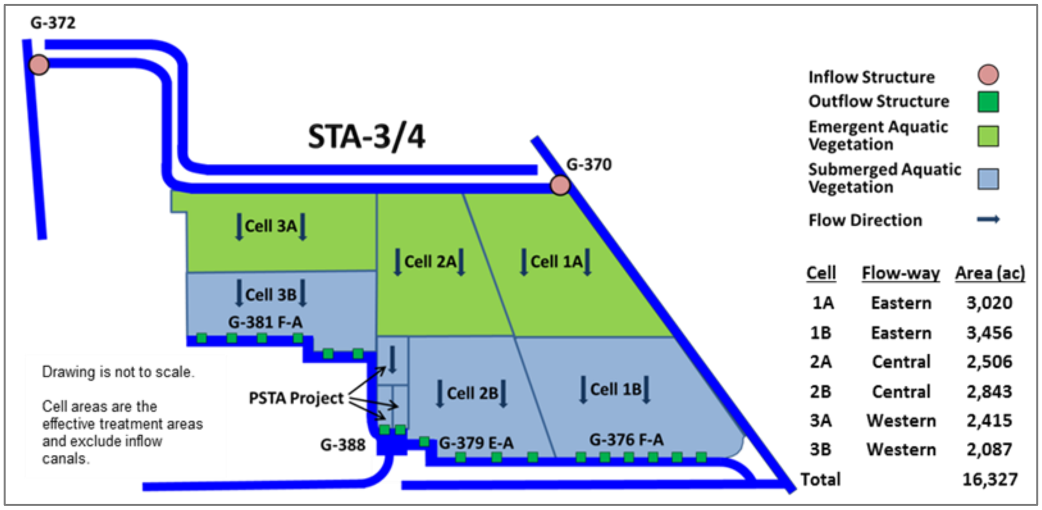


Figure 5B-13. Simplified schematic of STA-3/4 showing major inflow and outflow water-control structures, effective treatment area of each cell, flow direction, and dominant/target vegetation types. [Note: A detailed structure map of STA-3/4 is provided in Appendix 5B-1 of this volume; effective treatment areas do not include pump stations, levees, roads, or other upland areas. Cell 2B area includes the area of the PSTA Project.]

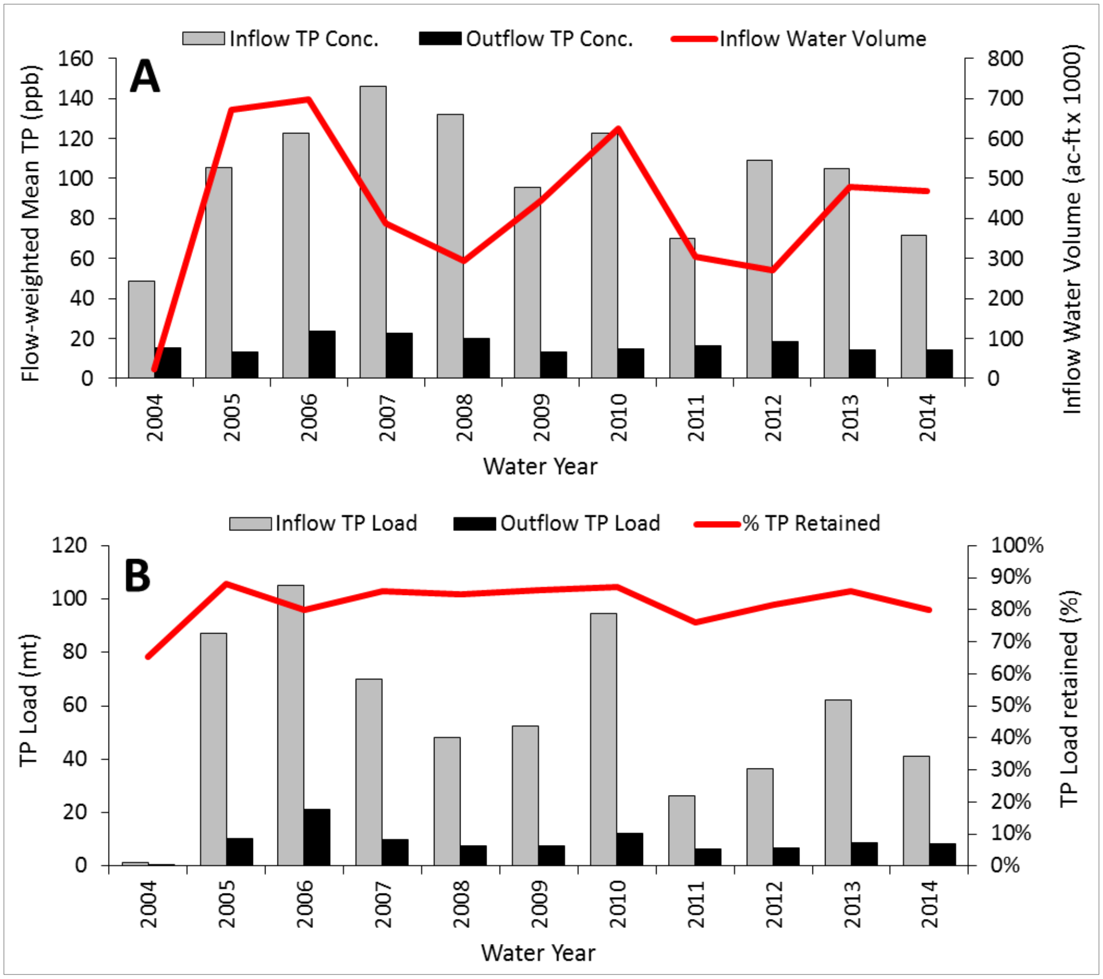


Figure 5B-14. Period of record time series in STA-3/4 of (A) annual inflow and outflow flow-weighted mean TP concentrations with corresponding inflow water volumes and (B) annual inflow and outflow TP loads with percent TP load retained.

FACILITY STATUS AND OPERATIONAL ISSUES

All flow-ways in STA-3/4 were operational in WY2014, although the Central Flow-way was offline with restrictions for part of the year for vegetation rehabilitation (**Table 5B-2**). The Central Flow-way returned to normal operations in June 2014. During the period of operational restrictions, the small pump station located on the levee between Cells 2A and 2B (G-386) was operated to maintain shallow water depths in Cell 2A by moving water from Cell 2A into Cell 2B. Two temporary pumps deployed in March 2013 to assist with the Cell 2A drawdown were removed in June 2013. The target stage in the Central Flow-way was lowered 0.5 ft in August and September 2013 to provide extra treatment capacity in these cells to accommodate future rain events and minimize depth-related stress on the newly established vegetation.

Approximately 52,000 ac-ft of Lake Okeechobee regulatory releases were sent mainly through the Western Flow-way of STA-3/4 for treatment prior to delivery south to WCA-3A in May and August to December 2013, and January to April WY2014.

Runoff from Tropical Storm Andrea and rainfall events immediately following the storm raised water depths in the treatment cells in STA-3/4 to their maximum operating levels. In response to the high water conditions, runoff was diverted around STA-3/4 through G-373 from June 7 to 13, 2013.

Operations in Cells 2A and 3B were restricted in May and June 2013 due to black-necked stilt nesting. Structure maintenance in STA-3/4 this year included replacement of the headwater and tailwater stage sensors and their associated stilling wells at G-380E.

Dryout Impacts

All the cells in STA-3/4 were hydrated in WY2014 and not subject to dryout impacts.

STA-3/4 PSTA Project

The STA-3/4 PSTA Project was constructed as the first phase of implementing this treatment technology in STA-3/4. The project comprises 400 acres in the far western side of Cell 2B (**Figure 5B-13**) that is divided into a single 200-acre upper SAV Cell and two side-by-side downstream 100-acre cells (the lower SAV and PSTA Cells). All cells have been managed to promote a SAV community and associated periphyton assemblage. All the sediment in the PSTA Cell was removed exposing the underlying caprock (i.e., the limestone bedrock).

To assess the PSTA Cell's treatment performance, data from its POR (WY2008 to WY2014) were used to calculate the cell's annual HLR, PLR, hydraulic retention time (HRT), and TP removal coefficient (k value) adjusted for differences the PSTA Cell's operational period each year (**Table 5B-3)**. The operational period is defined as the span of time over which one or both of the PSTA Cell's inflow structures (G-390A and G-390B) were open. Days when both gates were closed due to protective measures for nesting birds, structure maintenance, or to preserve water during droughts were excluded from the operational period. The PSTA Cell's operational periods were as follows:

- WY2008: July 5 to December 12, 2007, n = 161 days
- WY2009: July 9 to December 23, 2008, n = 168 days
- WY2010: May 25, 2009 to April 30, 2010, n = 341 days
- WY2011: May 1 to June 1, 2010; August 3 to December 7, 2010, n = 159 days
- WY2012: July 19, 2011 to April 5, 2012, n = 262 days
- WY2013: May 1, 2012 to April 30, 2013, n= 365 days
- WY2014: May 1, 2013 to April 30, 2014, n= 365 days

The annual HLR, PLR, HRT, and k value for the PSTA Cell were calculated as follows:

$$\text{HLR} = \frac{Q_{in}}{A} \times 100 \text{ cm/m} \quad (1)$$

$$\text{PLR} = \frac{\left[\left(C_{in} \times \frac{10^3 L}{m^3} \times \frac{g}{10^6 \mu g}\right) \times (V_{load})\right]}{A} \quad (2)$$

$$\text{HRT} = \frac{V}{(Q_{in} + Q_{out})/2} \quad (3)$$

$$k = \frac{\frac{(V_{in}+V_{out})\times N}{2}}{A} \times \left(\left(\frac{C_{in}-C^*}{C_{out}-C^*}\right)^{\frac{1}{N}} - 1\right) \quad (4)$$

where HLR is the surface-water hydraulic loading rate (cm/day); PLR is the TP loading rate ($g/m^2/yr$); HRT is the nominal hydraulic residence time (day); k is the TP removal coefficient (m/yr); V is the PSTA Cell's average storage volume during the operational period (m^3); V_{in} is the total surface-water inflow volume (m^3/yr); V_{out} is the total surface-water outflow volume (m^3/yr);

V_{load} is the total surface-water inflow water volume during the operational period in a water year (m^3/yr); Q_{in} is the average daily surface-water inflow rate during the operational period (m^3/day); Q_{out} is the average daily surface-water outflow rate during the operational period (m^3/day); A is the PSTA Cell effective treatment area (m^3); N is the number of continuously stirred tanks-in-series (= 6)[7]; $C*$ is the background TP concentration (= 4 µg/L)[8]; C_{in} is the surface-water inflow FWM TP concentration during the operational period (µg/L); and C_{out} = surface water outflow FWM TP concentration during the operational period (µg/L).

The PSTA Cell's annual inflow FWM TP concentration in WY2014 was 24 ppb while the corresponding outflow TP concentration was 13 ppb, which was comparable to the range of outflow concentrations (8 to 12 ppb) achieved in the six previous years (**Table 5B-3**). The relatively low inflow and outflow water volumes in WY2014 (~ 4,200 and 3,800 ac-ft, respectively) resulted from constrained operations in the STA-3/4 Central Flow-way due to the vegetation management activities. Starting on April 2, 2013, the target stage in the PSTA Cell was increased from 10.0 to 10.5 ft NGVD. This change was made to reduce the head difference between the PSTA Cell and the adjacent cells in STA-3/4 in an attempt to reduce the amount of groundwater seepage that entered the PSTA Cell. The PSTA Cell in WY2014 had a HLR, PLR, and k value of 3.5 cm/day, 0.31 g/m^2/yr, and 10.3 m/yr, respectively. The PLR and k value were within the range of values observed in previous years; however, this year's HLR was markedly lower than previous values, reflecting the constrained STA-3/4 operations noted above. Based on a new topographic survey of the PSTA Cell, the average ground elevation was revised from 8.1 to 8.8 ft NGVD. The new average ground elevation was then used to recalculate HRTs. As a result, the average HRT for the seven-year POR decreased from 10.4 days to 7.2 days. The HRT of 16.7 days in WY2014 was more than twice the duration of previous HRTs, which reflected the relatively small inflow and outflow water volumes and the increased target stage in the PSTA Cell this year.

Table 5B-3. Summary of annual hydraulic and treatment performance parameters in the STA-3/4 PSTA Cell during each operational period from WY2008 to WY2014.

Water Year	HLR (cm/d)	HRT (d)	Q_{in} (ac-ft)	Q_{out} (ac-ft)	FWM TP_{in} (ppb)	FWM TP_{out} (ppb)	PLR (g/m^2/yr)	Operational Period (day)	k (m/yr)
WY2008	5.5	5.8	2,919	5,201	27	12	0.24	161	14.2
WY2009	6.0	5.9	3,309	6,105	14	8	0.14	168	13.8
WY2010	6.2	6.2	7,022	10,078	20	10	0.42	341	27.4
WY2011	6.1	6.7	3,198	3,933	18	11	0.17	159	7.3
WY2012	8.6	4.4	7,454	9,610	17	12	0.39	262	12.5
WY2013	7.7	5.1	9,326	11,166	16	11	0.45	365	17.8
WY2014	3.3	16.7	4,030	3,794	24	13	0.29	365	10.0

[7] A tanks-in-series value of 6 was based on the findings of DB Environmental, Inc. (2009).
[8] A concentration of 4 µg/L typically has been used for the wetland background TP concentration in STA design.

Migratory Bird and Snail Kite Nesting

Four black-necked stilt nests were detected in STA-3/4 Cells 2A, 3B, and the PSTA Cell during May of 2013. A lone nest was observed in the PSTA Cell in April 2013 and the stage was held at or below 10.50 ft NGVD to minimize impact to this nest until May 15, 2013. The other three stilt nests were observed in STA-3/4 Cells 2A and 3B during May 2013. Stages in these cells during the nesting period were held at or below 9.50 and 11.10 ft NGVD, respectively, to minimize potential impacts to nests. There were no other black-necked stilt nests during WY2014. Further information on STA-3/4 operational adjustments related to nesting during WY2014 is presented in Appendix 5B-2.

VEGETATION MAINTENANCE AND ENHANCEMENTS

Following the 2011 water-level drawdown and plantings, enhancement measures continued in Cell 1A during WY2014 with herbicide treatments (278 acres) of FAV (particularly water hyacinth and pennywort) to facilitate expansion of giant bulrush plantings (May and June 2013) in the northern half of the cell. In Cell 1B of the Eastern Flow-way, 150 acres of cattail that had colonized the lower portion of this SAV cell were treated with an aerial herbicide application. Tapegrass (*Vallisneria americana*) and southern naiad were inoculated in the northern portion of Cell 1B to assist in the reestablishment of SAV, which disappeared throughout this cell between January 2013 and February 2014. Extensive plantings of giant bulrush and alligator flag, and 142 acres of associated FAV herbicide treatments, were completed in the northern end of Cell 2A to supplement EAV recruitment initiated by a water-level drawdown in spring 2013. Herbicide treatments of cattail expansion (100 acres) and inoculations of southern naiad were completed in Cell 2B, where SAV disappeared between February and March 2014. In Cell 3B, inoculations of tapegrass were completed to enhance recovery of SAV, which also disappeared during the 2014 dry season.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

There has been relatively little net change in EAV coverage in EAV-dominated Cells 2A and 3A of STA-3/4 from 2007 to 2013 (**Figure 5B-15**); their average EAV coverages were 81 and 94 percent, respectively. In contrast, EAV coverage in Cell 1A increased from 62 percent in 2007 to 87 percent by 2013 (overall average = 74 percent). EAV coverage in SAV-dominated Cell 1B decreased from 62 percent in 2007 to 40 percent by 2013 (overall average = 54 percent), was relatively constant in Cell 3B (overall average = 36 percent), and increased in Cell 2B from 16 to 40 percent during this period (overall average = 36 percent).

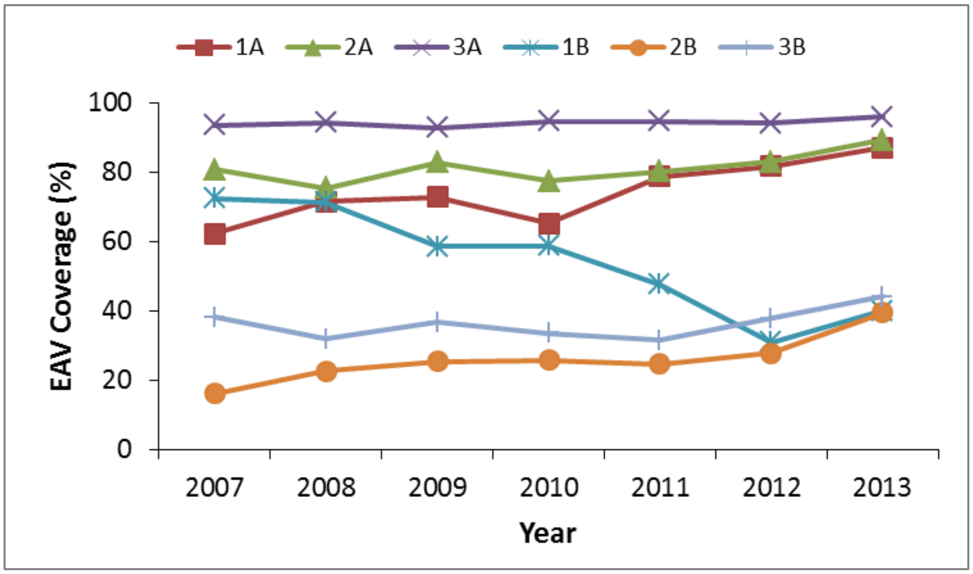


Figure 5B-15. Temporal change in percent coverage of emergent aquatic vegetation (EAV) within each cell of STA-3/4.

Ground Surveys for Submerged Aquatic Vegetation

Analysis and interpretation of SAV ground surveys conducted in STA-3/4 during WY2014 is presented in the *Applied Scientific Studies*: *Submerged Aquatic Vegetation Coverage and Abundance in STA-3/4* section of this chapter.

STA-5/6

Hongying Zhao, Brian Garrett, Yaoyang Yan, Michael Chimney and Lou Toth

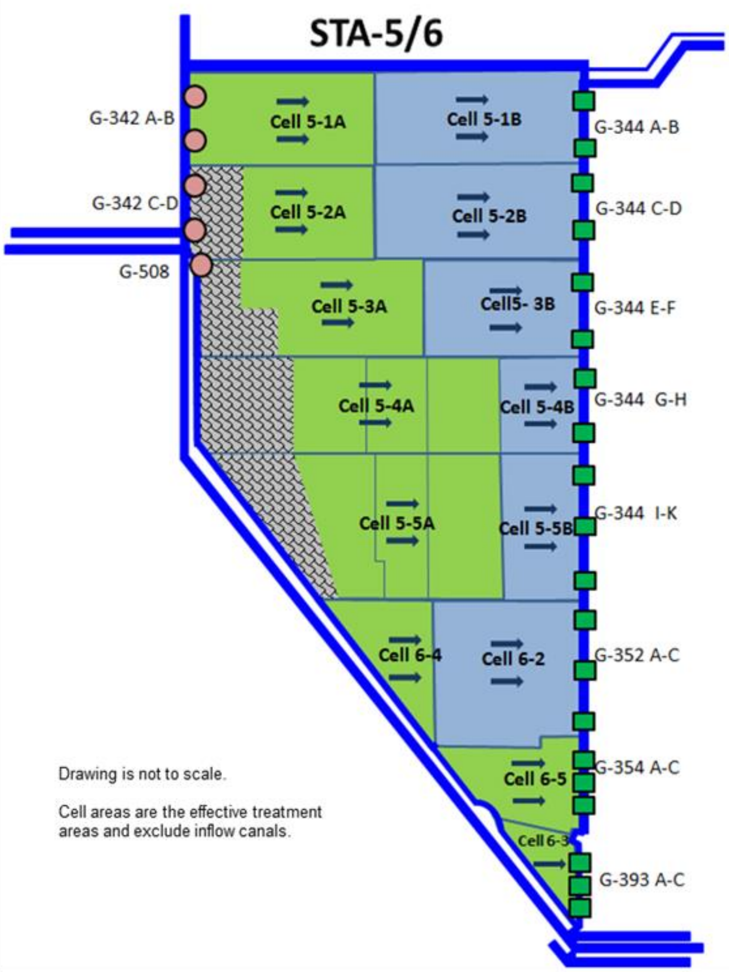
Contributors: Shi Kui Xue, Holly Andreotta Kathy Pietro and Neil Larson

STA-5, which receives inflows primarily from the C-139 Basin, is located in Hendry County and bordered by the C-139 and C-139 Annex Basins on the west and the Rotenberger Wildlife Management Area on the east (**Figure 5B-1**). The original STA-5 (Flow-ways 1 and 2) began operating in 2000. STA-6, also located in Hendry County, is south of STA-5, east of the L-3 borrow canal, and west of the Rotenberger Wildlife Management Area (**Figure 5B-1**). The original STA-6, which consisted of Cells 6-3 and 6-5, began operation in 1997 and treated agricultural runoff from the United States Sugar Corporation's Southern Division Ranch, Unit 2. After Unit 2 was purchased for restoration purposes and farming operations ended, this area became known as Compartment C. In 2006, Section 2 (now Cell 6-2) was added to STA-6, and a third flow-way (Flow-way 3) was added to STA-5 on a portion of what was to become Compartment C. In 2012, construction of treatment facilities was completed on the remaining portion of Compartment C. The STA-5/6 complex, consisting of the former STA-5, Compartment C, and the former STA-6, has 14 treatment cells arranged into eight flow-ways with a total effective treatment area of 13,685 acres (Piccone et al., 2013; **Figure 5B-16**) and is operated as an integrated facility to treat runoff from the C-139 Basin. The analysis of treatment performance in this section is based on past and present operation of the integrated facility. Performance measures for STA-5 and STA-6 that were reported individually in past annual reports have been recalculated as STA-5/6 for this year's analysis.

The flow-way nomenclature for STA-5/6 is as follows:

- Flow-way 1 = Cells 5-1A and 5-1B (former STA-5 Northern Flow-way)
- Flow-way 2 = Cells 5-2A and 5-2B (former STA-5 Central Flow-way)
- Flow-way 3 = Cells 5-3A and 5-3B (former STA-5 Southern Flow-way)
- Flow-way 4 = Cells 5-4A and 5-4B (new cells in Compartment C)
- Flow-way 5 = Cells 5-5A and 5-5B (new cells in Compartment C)
- Flow-way 6 = Cells 6-4 and 6-2 (new cell in Compartment C and former STA-6 Section 2)
- Flow-way 7 = Cell 6-5 and
- Flow-way 8 = Cell 6-3

Over its period of operation, STA-5/6 has been affected by high inflow TP concentrations and extreme weather events (regional droughts and large storms). The EAV cells in this STA have dried out almost every dry season, and WY2014 was no exception. High soil P flux has followed rehydration of these cells, usually resulting in temporary spikes in outflow TP concentration.



Cell	Flow-way	Area (ac)
5-1A	1	1,195
5-1B	1	1,223
5-2A	2	835
5-2B	2	1,233
5-3A	3	1,002
5-3B	3	920
5-4A	4	1,403
5-4B	4	468
5-5A	5	1,938
5-5B	5	704
6-4	6	539
6-2	6	1,361
6-5	7	621
6-3	8	242
Total		13,685

Figure 5B-16. Simplified schematic of STA-5/6 showing major inflow and outflow water-control structures, effective treatment area of each cell, flow direction, and dominant/target vegetation types. [Note: A detailed structure map of STA-5/6 is provided in Appendix 5B-1 of this volume; effective treatment areas do not include pump stations, levees, roads, or other upland areas.]

STA TREATMENT PERFORMANCE

STA-5/6 over its operational history has treated approximately 2,080,000 ac-ft of water and retained 308 mt of TP or 67 percent of the POR inflow TP load (**Table 5B-1**). The POR inflow FWM TP concentration was 180 ppb, while the POR outflow FWM TP concentration was 71 ppb. Based on the rank order of its overall outflow FWM TP concentration and % TP load retained, STA-5/6 has been the poorest performing STA during its operational history.

STA-5/6 treated approximately 103,000 ac-ft in WY2014 and retained 22 mt of TP with 88 percent of the inflow TP load retained (**Table 5B-1**). The inflow FWM TP concentration this year was 198 ppb while the outflow FWM TP concentration was just 23 ppb. This was one of the lowest annual outflow TP concentrations and highest annual treatment efficiency recorded in STA-5/6 (**Figure 5B-17**). The HLR and PLR in STA-5/6 were quite low with rates (0.6 cm/day and 0.5 g/m^2/yr, respectively) that were less than rates observed in other STAs this year (**Figure 5B-3**). Furthermore, the inflow TP loads to STA-5/6 over the last several water years were much lower than most of the inflow TP loads from WY2002 to WY2010 (**Figure 5B-17**).

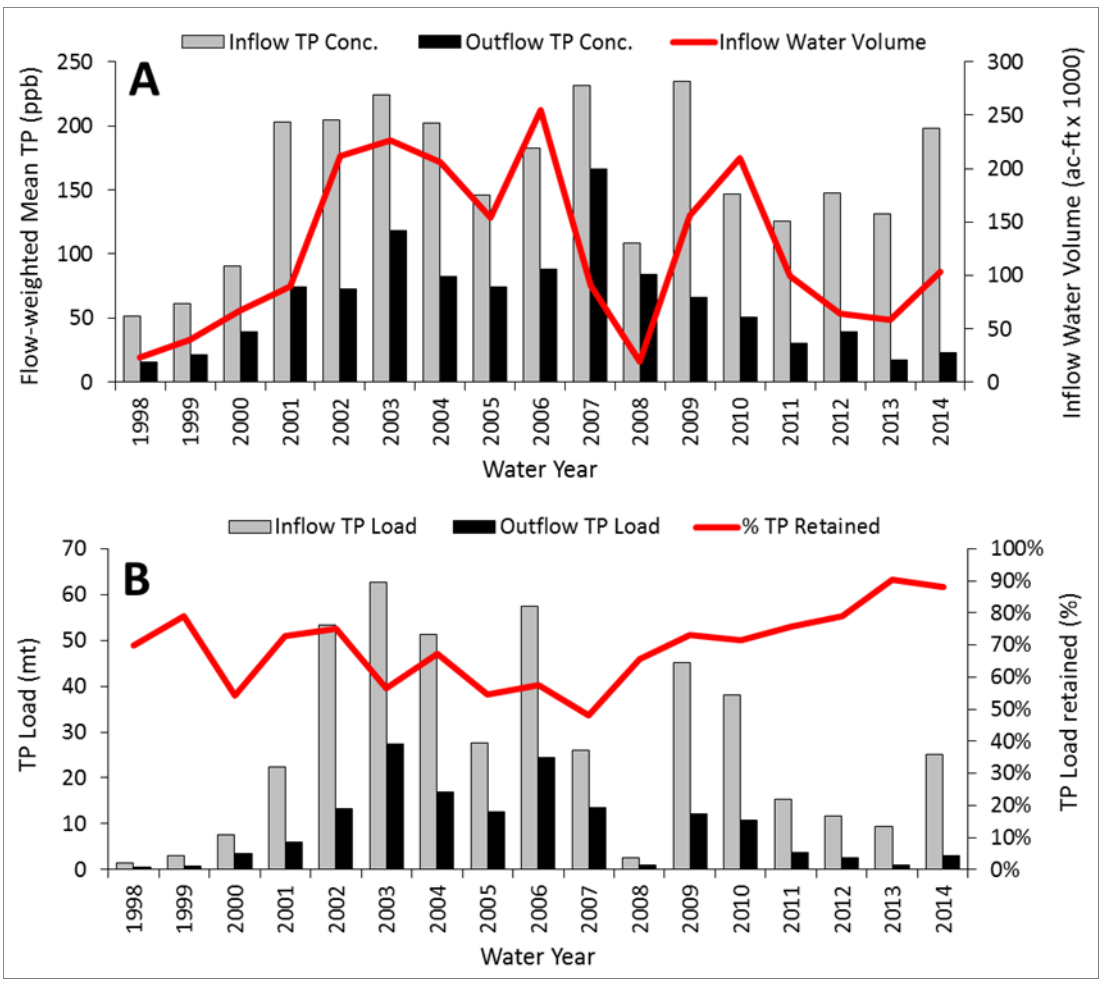


Figure 5B-17. Period of record time series in STA-5/6 of (A) annual inflow and outflow flow-weighted mean (FWM) TP concentrations with corresponding inflow water volumes and (B) annual inflow and outflow TP loads with percent TP load retained.

FACILITY STATUS AND OPERATIONAL ISSUES

All the flow-ways of STA-5/6 (1 through 8) were operational for most of WY2014; Flow-way 5 passed its start-up criteria on July 30, 2013 (**Table 5B-2**). Flow-way 4 was online with restrictions for approximately one month for SAV inoculation. Operations in Cells 1B, 2A, 2B, 3B, 4A, 4B, 5B, and 6-4 were restricted at some point during WY2014 due to stage limitations intended to protect nesting black-necked stilts and/or snail kites. As of July 1, 2014, Cells 3A, 4A, 4B, and 5B remained under restrictions due to continued snail kite nesting.

The G-715 gate was damaged this year and is scheduled for repair during next dry season (WY2015). The structure can be operated manually in the interim. A broken gate calibration stem at G-352B and a clogged tailwater sensor at G-342M were repaired. Repairs to the clogged tailwater sensor at G-342L were ongoing as of July 1, 2014.

Dryout Impacts

With the exception of Flow-ways 6, 7 and 8 (Cells 6-2, 6-3, 6-4 and 6-5), all cells in STA-5/6 were hydrated in WY2014 and not subject to dryout impacts. Flow-ways 6, 7, and 8 were declared dry on April 10, 2014. Because dryout in these cells occurred so late in the year and they remained dry until the start of WY2015, there was no effect on treatment performance in WY2014. Supplemental water from Lake Okeechobee was delivered to Cells 1B, 2B, 3B, and 4B to keep their SAV beds hydrated during the dry season.

Migratory Bird and Snail Kite Nesting

Sixty-one stilt nests were found in STA-5/6 during WY2014. Nests were detected and monitored in Cells 5-1B, 5-2B, 5-3B, 5-4A, 5-4B, and 5-5B from May to June 2013. Stages in these cells during the nesting period were held at or below 12.50, 12.30, 13.60, 13.30, 13.20, and 13.60 ft NGVD, respectively, to minimize potential impacts to nests. Nests were detected and monitored in Cells 5-3B, 5-4A, 5-4B, and 6-4 during April 2014. Stage restrictions were imposed in Cells 5-3B and 5-4A to protect nesting endangered Everglade snail kites. There appeared to be a high level of nesting by black-necked stilts throughout STA-5/6 based on the large number of chicks observed in June and July of both 2013 and 2014.

Thirty-three Everglade snail kites nests were confirmed in STA-5/6 Cells 2A, 3B, and 4A by the University of Florida Snail Kite Laboratory during WY2014. Twenty-two of these nests were in Cell 3B from May 8, 2013 to October 15, 2013. The other 11 nests were confirmed by the Snail Kite Laboratory between February 15 and April 30, 2014. A range of water stages to protect snail kite nesting efforts was established for Cells 2A, 3B, and 4A in consultation with USFWS (Appendix 5B-2 of this volume). Snail kite nesting continued beyond the end of WY2014 and there were as many as 44 snail kite nests at one time in STA-5/6 during June 2014. Further information on STA-5/6 operational adjustments related to nesting during WY2014 is presented in Appendix 5B-2.

Compartment C Build-out

The Compartment C Build-out Project was located in Hendry County between the original footprints of STA-5 and STA-6 (**Figures 5B-1** and **5B-16**) and greatly expanded the treatment area of these two facilitates. All construction activities on this project have been completed and this area is now part of STA-5/6.

Efforts continued in WY2014 to establish an effective vegetation-based treatment system in Compartment C. Aerial herbicide applications were done to eliminate willow and primrose willow from Cell 5-4A (190 acres), Cell 5-5A (1220 acres) and Cell 6-4 (240 acres). Conversion of Cell 5-5B to SAV was initiated with a herbicide treatment of 250 acres of cattail.

Environmentally Sensitive Areas in Compartment C Build-out

The District in cooperation with the Seminole Tribe of Florida, the Miccosukee Tribe of Indians of Florida, USACE, and Florida's State Historic Preservation Office completed construction of permanent protective measures for Environmentally Sensitive Areas (ESAs) found in Flow-way 5 of STA-5/6. In addition, Flow-way 5 was placed on restricted operations to reduce inflow into these cells, dependent upon the District's flood-control obligations. The District will continue to evaluate STA-5/6 operations in a concerted effort to preserve the ESAs in their current state and protect them from inundation in the future. As-built Certification Forms were submitted to the FDEP in March 2013.

VEGETATION MAINTENANCE AND ENHANCEMENTS

Management measures in WY2014 focused on enhancements to Compartment C cells and on reducing chronic encroachment of willow and primrose willow, which results from seasonal dryout of EAV cells in this STA. Aerial herbicide applications (November 2013 and April 2014) were used to treat 1850 acres of primrose willow and willow in Cells 1A, 2A, 3A, 4A, 5A and 6-4. Paragrass (*Urochloa mutica*) and torpedo grass (*Panicum repens*) were treated in Cell 5A in May 2013. Aerial herbicide applications also were used to treat 250 acres of cattail to facilitate conversion of Cell 5B to a SAV community and 350 acres of water lettuce in Cell 4A. Expansive growth of FAV (728 acres), particularly water lettuce, was treated to sustain SAV in Cells 1B and 2B. A new strip of giant bulrush was planted at the inflow of Cell 4B and founder sites in the western portion of Cell 3B were inoculated with southern naiad. Alligator flag was planted in Cell 2A.

VEGETATION SURVEYS

Vegetation Coverage Estimates Based on Aerial Imagery

There was relatively little net change in EAV coverage in the EAV Cells 5-2A, 5-3A, 6-3, and 6-5 of STA-5/6 from 2007 to 2013 (**Figure 5B-18**); their average EAV coverages were 93, 79, 92, and 97 percent, respectively. EAV coverage in the EAV Cell 5-1A increased from 70 to 82 percent during this period (overall average = 81 percent). The SAV Cells 5-1B and 5-2B experienced an increase in EAV coverage over the period from 6 and 20 percent, respectively, in 2007 to 35 and 42 percent, respectively, in 2013 (overall average = 17 and 27 percent, respectively). The aquatic plant community in the other two SAV cells, Cell 5-3B and 6-2, was largely EAV (overall average = 84 and 74 percent, respectively).

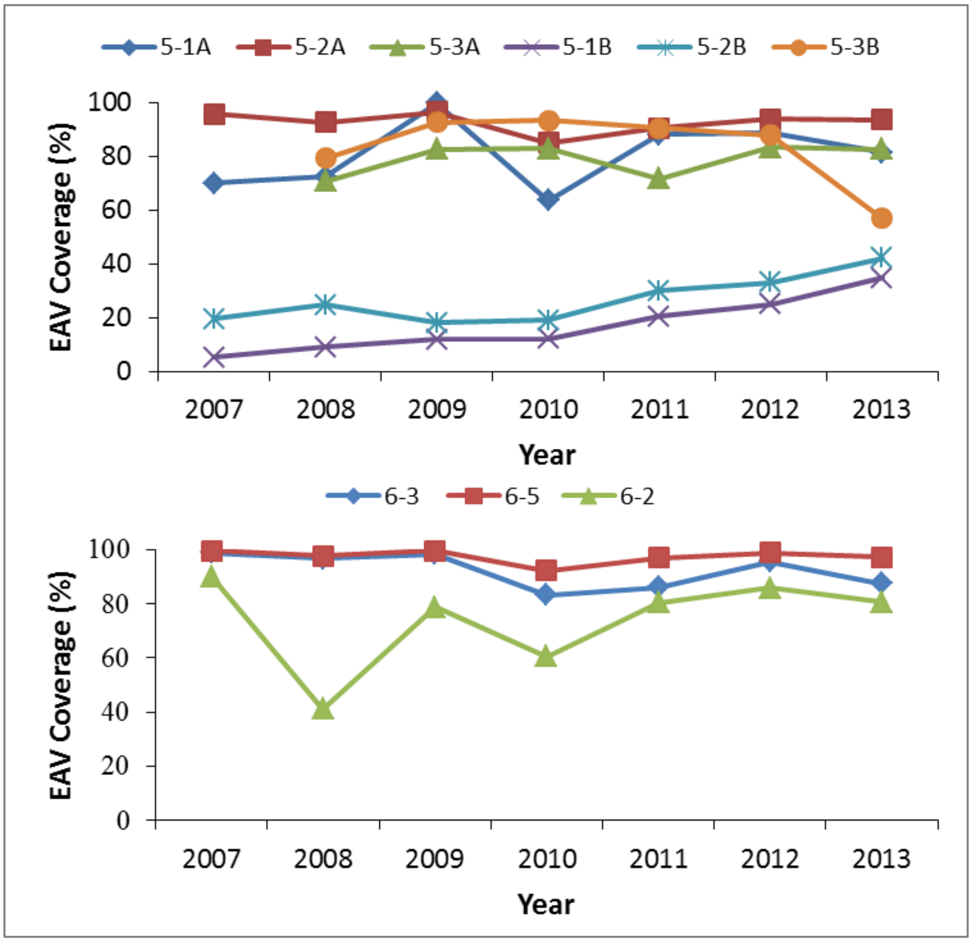


Figure 5B-18. Temporal change in percent coverage of emergent aquatic vegetation (EAV) within each cell of STA-5/6.

Ground Surveys for Submerged Aquatic Vegetation

Analysis and interpretation of SAV ground surveys conducted in STA-5/6 during WY2014 is presented in the *Applied Scientific Studies*: *Submerged Aquatic Vegetation Condition in STA-2 and STA-5/6* section of this chapter.

APPLIED SCIENTIFIC STUDIES

Research and monitoring efforts associated with the Everglades STAs are conducted to help document their complexity, better understand the many challenges related to their operation, and help achieve mandated treatment performance. These activities include short- to long-term studies that range in size from mesocosm to field-scale, as well as analysis of existing data. Projects are conducted to address key issues including (1) documenting the condition of the STAs during the water year, (2) evaluating proposed and completed STA enhancements, (3) evaluating impacts of extreme weather events, (4) investigating failing or poor treatment performance, and (5) devising strategies to improve nutrient removal. Some studies are linked to ongoing implementation of management strategies (e.g., STA-3/4 Cell 1A water-level drawdown evaluation), while other studies are linked to operating permit requirements such as STA optimization activities described in the Long-Term Plan (e.g., vegetation surveys).

No new research projects were started in WY2014, although studies initiated in previous water years continued. Preliminary findings for several studies are presented in this section, while some STA-specific findings are incorporated in the individual STA sections of this chapter (e.g., vegetation surveys or maintenance and STA enhancements). All future research in the STAs will be conducted as part of the District's Restoration Strategies Science Plan (see Chapter 5C of this volume). District staff spent much of WY2014 developing study plans for several new STA-related initiatives that either started this year or are planned to start in WY2015.

INTERNAL STA MONITORING

Introduction

Prior observations have indicated that P removal in the STA flow-ways is related to the areal coverage of the SAV community. Submerged aquatic vegetation in the STAs can be subjected to a number of disturbances, including herbivory, wind damage from tropical storms, and excessive loadings of nutrient or particle-laden waters. Because SAV communities can be detected only sporadically with aerial photography (i.e., when the plants top out in the water column), ground-level surveys are necessary to assess temporal changes in the distribution of total SAV coverage, as well as coverage of individual SAV species.

In addition to assessing vegetation coverage, monitoring of internal P concentrations along inflow to outflow transects within the STA flow-ways has been valuable for identifying regions of particularly effective, or ineffective, P reduction along the inflow-to-outflow gradient. When coupled with vegetation surveys, internal water quality monitoring enables comparisons of vegetation coverage with treatment performance. Internal monitoring can also provide information to assess the effects of various operational and management activities (e.g., P loading rate, vegetation management) on the sustainability of STA treatment performance.

During WY2014, internal monitoring assessments were performed within selected STA flow-ways to document P removal performance and/or vegetation coverage under varying conditions. Specific objectives for each assessment are described within each STA section.

General Procedures

SAV Surveys

SAV ground surveys were performed within selected SAV cells at a network of fixed geo-referenced stations. A visual assessment of both SAV speciation and areal coverage was performed at each station. The coverage of each species was scored based on semi-quantitative scales, ranging from no plants to dense coverage. ArcView Spatial Analyst (ESRI, Redlands, CA) was used to generate vegetation coverage maps, which in turn were examined for spatial patterns in the data.

Water Quality

Monthly FWM TP concentrations at each cell's inflow and outflow locations were calculated from grab samples collected biweekly at these structures by the District in WY2014. Internal water quality samples were collected at geo-referenced stations located along transects oriented perpendicular to the direction of flow. Samples collected along each transect were either composited in the field prior to analysis (to provide one sample per transect) or analyzes as individual grab samples. These samples were analyzed for total phosphorus (TP), total dissolved P (TDP) and soluble reactive P (SRP). Dissolved organic P (DOP) and particulate P (PP) were calculated using the following relationships: DOP = TDP - SRP; PP = TP -TDP. ArcView Spatial

Analyst (ESRI, Redlands, CA) was used to generate contour maps, which in turn were examined for spatial patterns in the data.

Submerged Aquatic Vegetation Decline in STA-1E

Delia Ivanoff, Tom DeBusk[9], Mike Jerauld[9] and Michelle Kharbanda[9]

Background

STA-1E was available for emergency flood control purposes and was flooded to establish wetland vegetation in WY2005. This STA became operational and began treating water in WY2006, although the Eastern Flow-way has been under restricted operation since then and is currently offline for construction purposes. SAV establishment in Cells 4N, 4S, and 6 began in WY2004 and hydrilla has historically been the dominant SAV species. With improving water quality, areal coverage of southern naiad and muskgrass also has been expanding, particularly in Cells 4S and 6. Coontail also is becoming established throughout the cells.

There was a cell-wide loss of hydrilla in Cell 6 in WY2010; this cell has been slowly recovering from that incident and there are signs of SAV expansion, including hydrilla. Cell 4S, which historically has been the best performing SAV-dominated cell in STA-1E, was invaded by a large population of the island applesnail beginning in late WY2013 and continuing into WY2014.

Objectives

The long-term objective of this monitoring effort was to document SAV coverage in STA-1E Cells 4N, 4S, and 6, and evaluate the role of SAV on P removal in these cells. It was particularly important to document the loss of SAV in Cell 4S that resulted from island applesnail herbivory. Observations of SAV growth and decline were used to facilitate our understanding of factors that potentially influence coverage and speciation of submerged plants in the STAs.

Methods

SAV surveys were performed in September and November 2013 in STA-1E Cells 4N, 4S, and 6 at a network of fixed geo-referenced sites (**Figure 5B-19**). Survey sites throughout Cell 4N and in the upper northwest portion of Cell 4S were inaccessible during September due to the presence of nesting snail kites.

Internal water quality samples were collected in Cells 4N and 4S on November 5, 2013 at stations located along transects oriented perpendicular to the direction of flow. Samples collected along each transect were composited in the field to provide one sample per transect for analysis. Transect data were plotted to produce inflow-to-outflow P concentration profiles.

Results and Discussion

Based on examination of SAV survey data, there was an overall decline in total SAV coverage and relative abundance in STA-1E Cells 4N, 4S, and 6 in WY2014 compared to the previous year. In Cell 6, the dominant species was coontail (**Figure 5B-20**). The relative abundance and spatial coverage of this species has steadily increased in the past two years, particularly after the cell-wide uprooting of hydrilla in Cell 6 in WY2010. There was a decline in

[9] DB Environmental, Inc., Rockledge, FL

hydrilla coverage and relative abundance in WY2014 when compared to the December 2012 survey when hydrilla was the dominant species in all three cells.

A cell-wide loss in SAV coverage occurred in Cell 4S beginning in early WY2014. In July 2013, a rapid population increase of the island applesnail in this cell resulted in almost complete defoliation of the SAV and increased water-column turbidity (**Figure 5B-21**). High turbidity and herbivory by island applesnails inhibited SAV regrowth through the remainder of the water year. Consequently, there was a dramatic decline in P removal in the STA-1E Central Flow-way, with outflow TP concentrations reaching as high as 159 ppb during this period (**Figure 5B-22**). While outflow TP levels coming from Cell 4N had been reduced to ~ 50 ppb or less, TP concentrations increased within Cell 4S, indicating not only loss of treatment, but P export resulting from decomposing SAV and island applesnail activity. This finding was supported by internal transect sampling in Cell 4S conducted in November 2013, which found that TP concentration increased along the inflow-to-outflow flow path by approximately 50 ppb (**Figure 5B-23**). This increase was primarily due to elevated PP concentrations in the water column.

In the Western Flow-way, the pattern of TP removal was more characteristic of a properly working STA flow-way. Specifically, water-column TP concentration decreased from the inflow sampling locations to the mid-levee after being treated in Cells 5 and 7 then declined further as water flowed through the SAV-dominated Cell 6 (**Figure 5B-24**). Although island applesnails were found in some areas of Cell 6, their population density and impacts on SAV were much less than that experienced in Cell 4S.

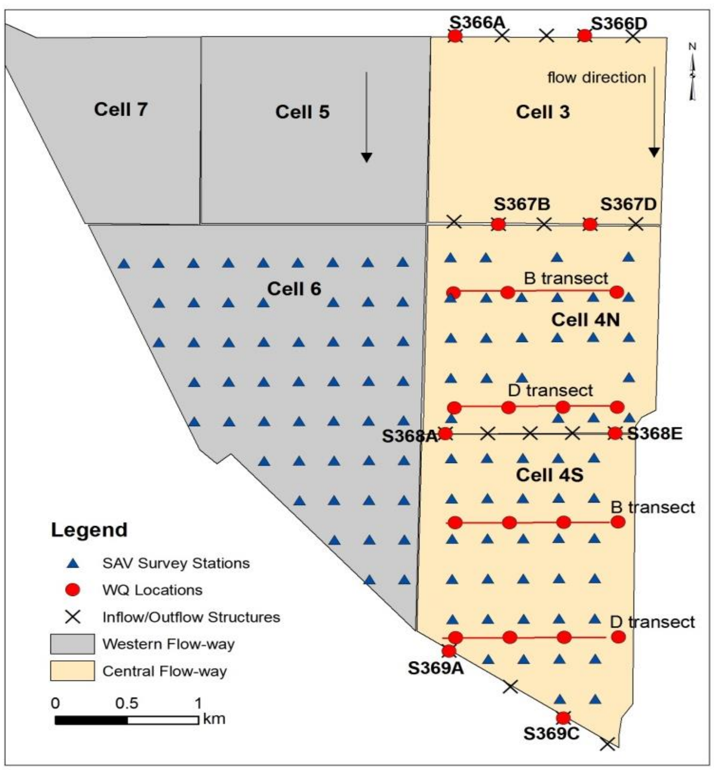


Figure 5B-19. Internal monitoring stations for submerged aquatic vegetation (SAV) and water quality sample collection in STA-1E Cells 6N, 4S, and 6.

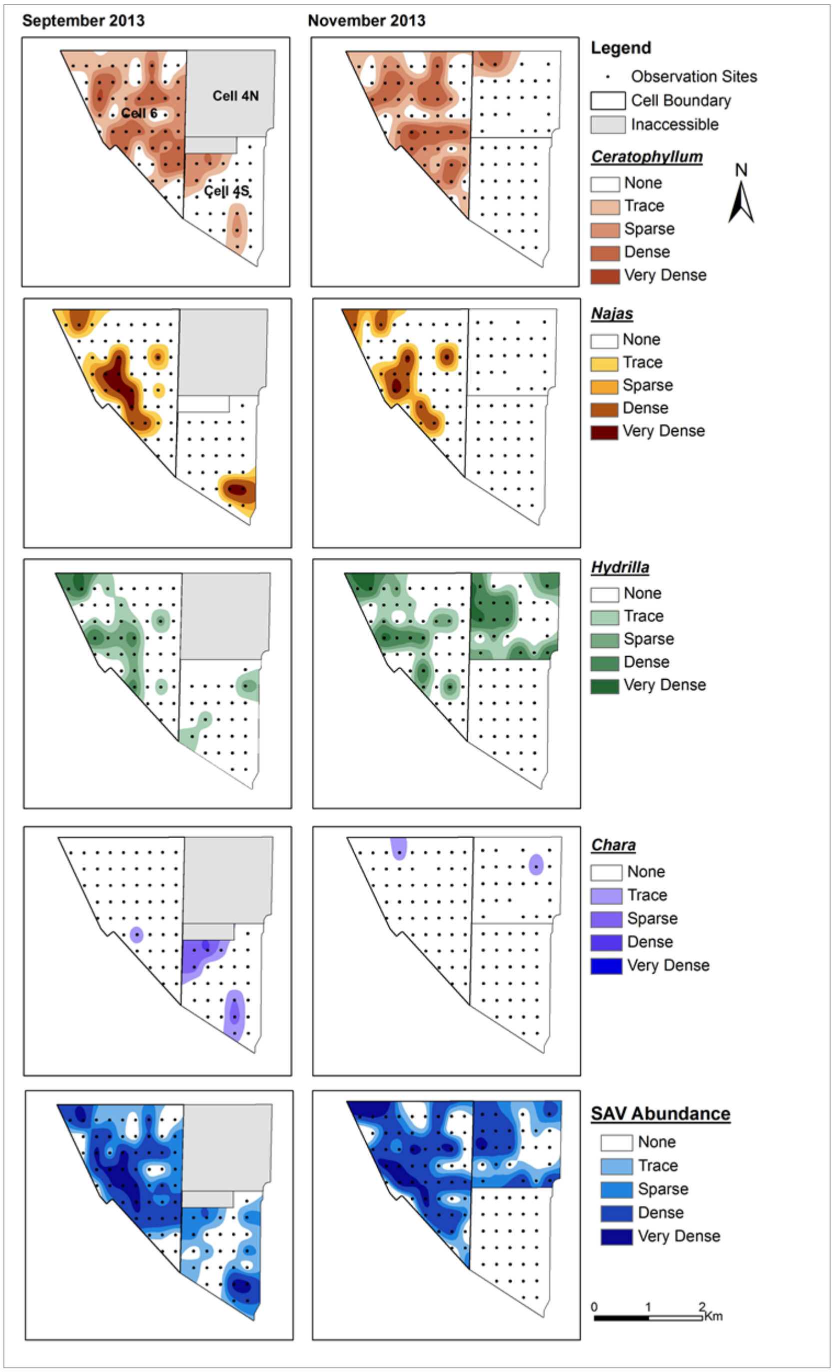


Figure 5B-20. Spatial coverage and relative abundance of coontail (*Ceratophyllum demersum*), southern naiad (*Najas guadalupensis*), hydrilla (*Hydrilla verticillata*), muskgrass (*Chara* sp.), and all SAV species grouped together in STA-1E Cells 4N, 4S, and 6 in September and November 2013. Dots indicate location of SAV ground survey sites. Cell 4N and the upper northwest portion of Cell 4S were inaccessible in September due to the presence of nesting snail kites.

Figure 5B-21. Impacts of the island applesnail (*Pomacea imaculata*) on submerged aquatic vegetation (SAV) in Cell 4S of STA-1E; photos taken in August 2013. Photos: top left = dense snail egg clusters on emergent grasses; top right = an island applesnail on a giant bulrush stalk, bottom photos = SAV stems that have been defoliated by applesnails.

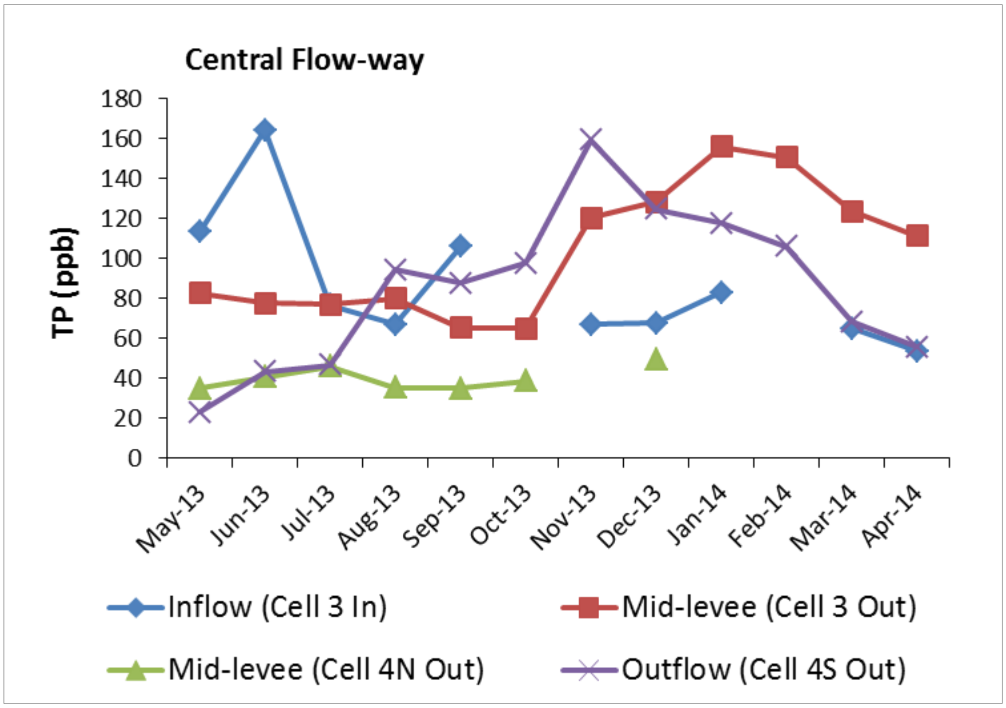


Figure 5B-22. Inflow and outflow total phosphorus (TP) flow-weighted mean concentrations for cells in the Central Flow-way of STA-1E in WY2014. Submerged aquatic vegetation surveys were conducted on September 3 and November 5, 2013.

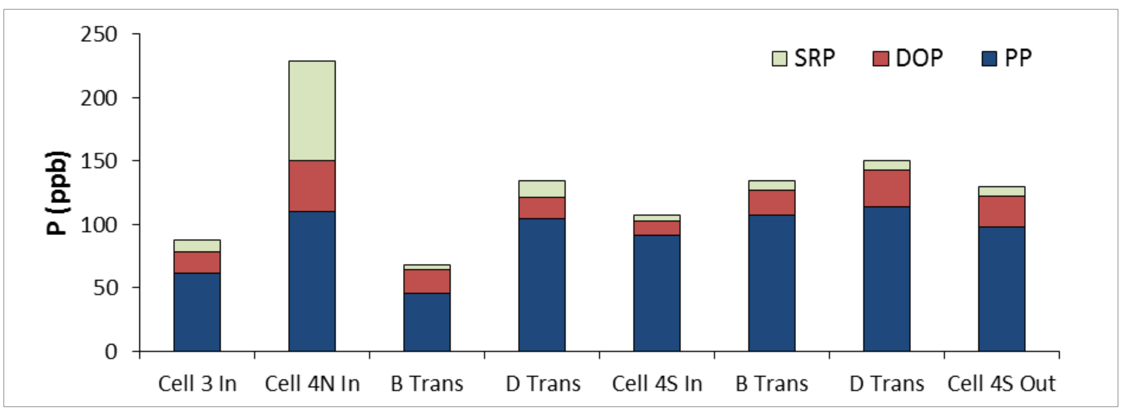


Figure 5B-23. Phosphorus species concentration profiles along the inflow-to-outflow flow path in the Central Flow-way of STA-1E on November 5, 2013. Data points represent values from composited water samples collected along each transect.

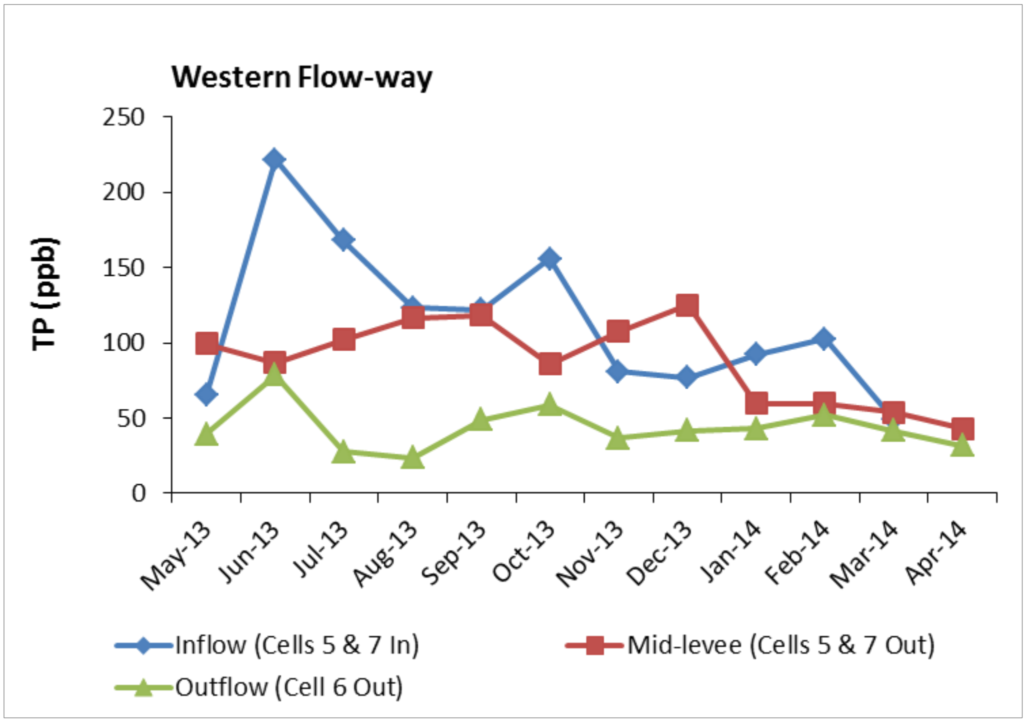


Figure 5B-24. Inflow and outflow total phosphorus (TP) flow-weighted mean concentrations for cells in the Western Flow-way of STA-1E in WY2014. Submerged aquatic vegetation surveys were conducted on September 3 and November 5, 2013.

Submerged Aquatic Vegetation Decline in the STA-1W Eastern Flow-way

Michelle Kharbanda[9], Dawn Sierer-Finn[9] and Tom DeBusk[9]

Background

In January 2014, a helicopter survey by District scientists indicated that a substantial loss of muskgrass had occurred in the SAV-dominated Cells 1B and 3 of the Eastern Flow-way of STA-1W. A ground survey subsequently was conducted to better assess and document SAV coverage status using a semi-quantitative technique.

Objectives

The long-term objectives of this monitoring effort were to document the severity of the recent SAV decline in Cells 1B and 3 and evaluate its impact on TP removal by these cells. This investigation also was used to facilitate understanding of factors that potentially influence coverage and speciation of SAV in the STAs, and their effect on long-term STA treatment performance.

Methods

A SAV ground survey was performed in February 2014 in STA-1W Cells 1B and 3 at pre-established locations (**Figure 5B-25**) and compared with a previous survey conducted on July 10, 2013. In February 2014, water quality grab samples were collected at stations located along transects oriented perpendicular to the direction of flow (**Figure 5B-25**) and analyzed for TP. Concentration data from each transect were averaged and the mean values plotted as an inflow-to-outflow TP concentration profile. This profile was then compared with TP profiles from three previous sampling events performed in 2010, 2012, and 2013 under similar (moderate or high) flow conditions.

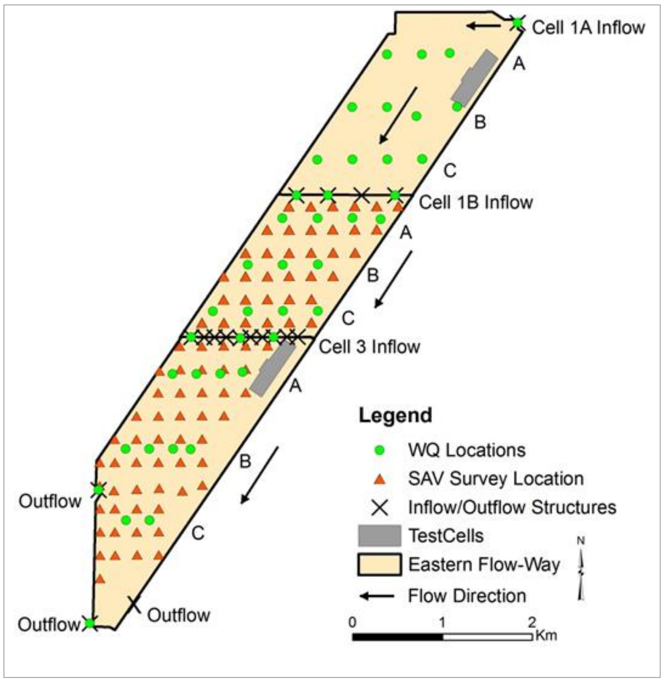


Figure 5B-25. Internal submerged aquatic vegetation (SAV) and water quality monitoring stations in the STA-1W Eastern Flow-way (Cells 1B and 3).

Results and Discussion

The ground survey performed in February 2014 confirmed a dramatic decline of SAV in the Eastern Flow-way, with the majority of the loss attributed to reduction of the dominant species, muskgrass (**Figure 5B-26**). However, other SAV species, including coontail southern naiad, and bladderwort (*Utricularia* sp.), also exhibited declines in cover since mid-2013.

Inspection of treatment performance in the Eastern Flow-way of STA-1W indicated less TP removal in February 2014 compared to previous monitoring events under similar flow conditions (**Figure 5B-27**). While water-column TP levels within Cell 1B were reduced to <40 percent of the inflow concentration during previous monitoring events, TP removal within the upper portion of Cell 3 remained at ~80 percent of the inflow concentration in February 2014. Additionally, Cell 3 outflow FWM TP concentrations were relatively high (~30 ppb) between November 2013 and May 2014 (**Figure 5B-28**), indicating decreased TP removal performance in the Eastern Flow-way. While inflow FWM TP concentrations to the flow-way were also elevated during this dry season period relative to those of the prior wet season, the dry season mass P load to the cell was comparatively low (**Figure 5B-28**), suggesting that the high internal (and outflow) flow-way TP concentrations were likely due to internal processes (e.g., poor plant health), rather than a overloading of P via the inflow waters. Results of the coordinated internal water quality and SAV surveys therefore suggest a linkage between impaired TP removal and reduced standing crop of SAV in the STA-1W Eastern Flow-way.

Large-scale die-backs of muskgrass stands have been observed in other STA cells (**Figure 5B-29**. The reasons for these periodic declines are unknown, and this phenomenon currently is being investigated. Fortunately, open areas created by SAV declines, such as observed in this flow-way, typically are re-colonized by various SAV species within several months.

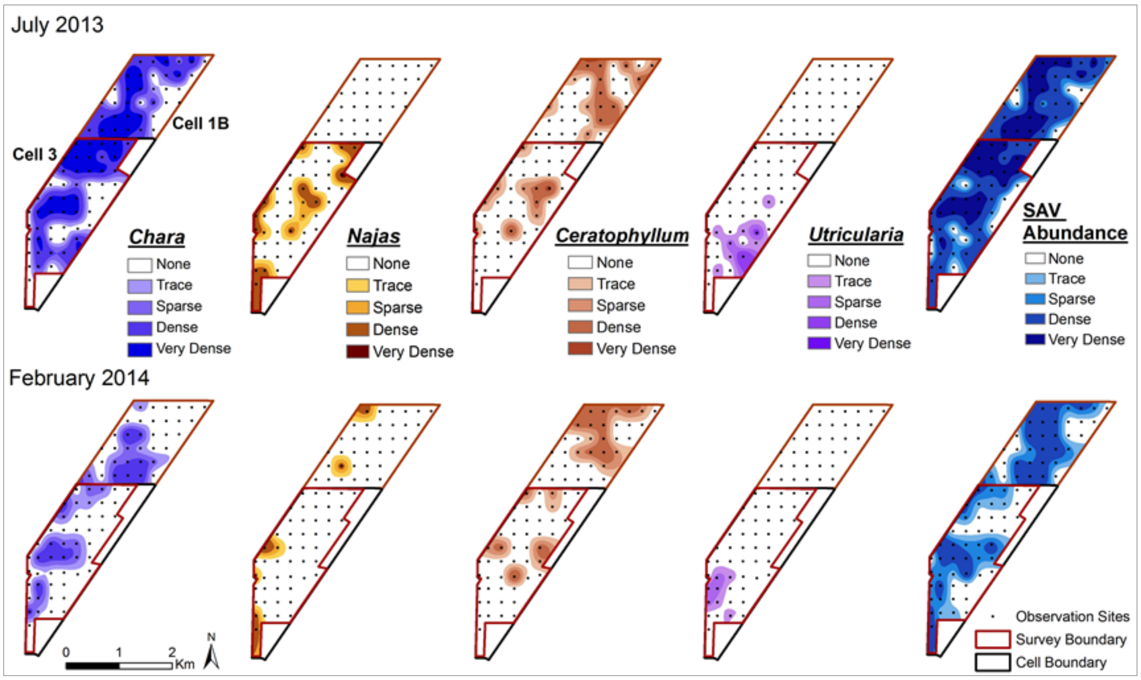


Figure 5B-26. Spatial coverage and relative abundance of muskgrass (*Chara* sp.), southern naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), bladderwort (*Utricularia* sp.), and all SAV species grouped together in STA-1W Cells 1B and 3 during July 2013 and February 2014. Dots indicate locations of SAV ground survey sites.

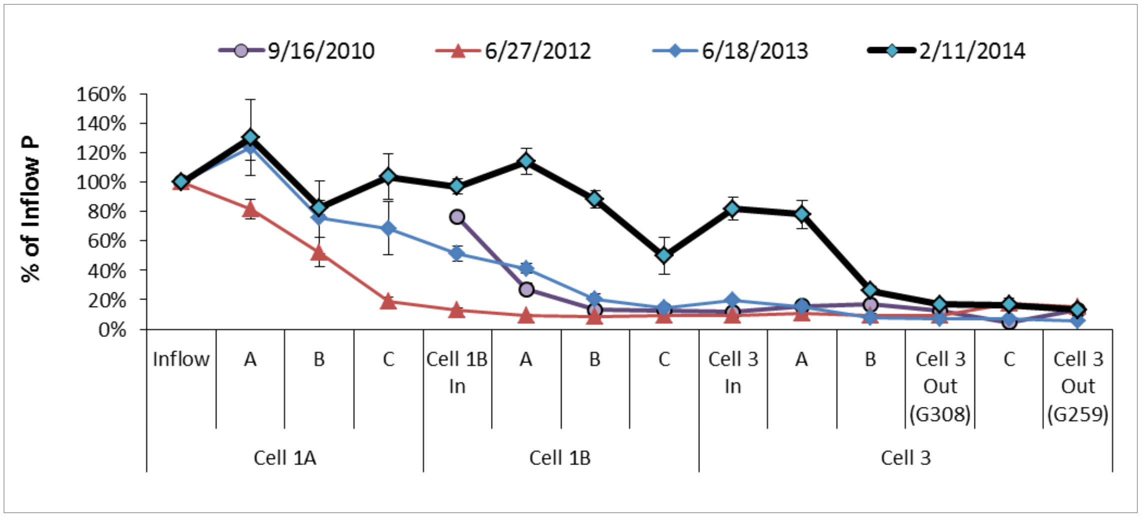


Figure 5B-27. Spatial and temporal comparison of internal total phosphorus (TP) reduction relative to inflow concentration in the Eastern Flow-way of STA-1W during 2010, 2012, 2013, and 2014 under moderate or high flow conditions. Data points represent mean values (± S.E.) for stations along each monitoring transect.

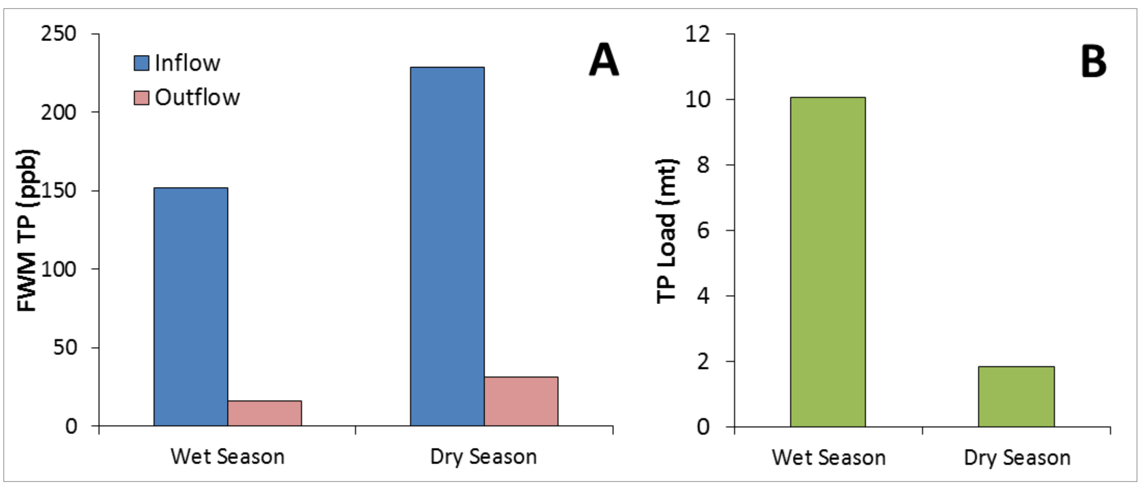


Figure 5B-28. Inflow and outflow flow-weighted mean (FWM) total phosphorus (TP) concentrations for the "wet season" (May 1, to October 31, 2013) and the "dry season" (November 1, 2013 to April 30, 2014) in the Eastern Flow-way of STA-1W (Panel A). Mass TP loads to the Eastern Flow-way for the same periods (Panel B). Data source: the District's DBHYDRO water quality database

Figure 5B-29. Photographs of a healthy muskgrass (*Chara* sp.) bed (left) and a muskgrass bed experiencing a die-back, exposing the underlying wetland soil (right) (photos by the SFWMD).

Evaluation of Spatial Patterns of Phosphorus Removal in STA-1W Cell 5B

Michelle Kharbanda[9], Jaimee Henry[9] and Tom DeBusk[9]

Background

STA-1W Cell 5B is an SAV-dominated wetland situated at the outflow end of the Northern Flow-way of STA-1W and downstream from the EAV-dominated Cell 5A (**Figure 5B-7**). The Northern Flow-way was added to STA-1W in 1999.

Objectives

The long-term objectives of this monitoring effort were to characterize the spatial pattern of P concentrations within STA-1W Cell 5B and relate these findings to spatial patterns in other water quality constituents, SAV coverage, and cell hydraulics.

Methods

Internal water quality sampling was performed in Cell 5B during June and August 2013 under flowing and non-flowing conditions, respectively. Monitoring transects in Cell 5B were oriented perpendicular to the direction of flow, and alternated between grab (samples from each station analyzed separately) and composited (all samples field-composited into a single sample) transects (**Figure 5B-30**). Grab samples also were collected from three outflow culverts (G306A, C, and H) and analyzed individually.

All samples were analyzed for TP, TDP, SRP, and dissolved calcium (Ca). ArcView Spatial Analyst (ESRI, Redlands, CA) was used to generate contour maps using the spline/tension method. These maps were examined for spatial patterns in the data.

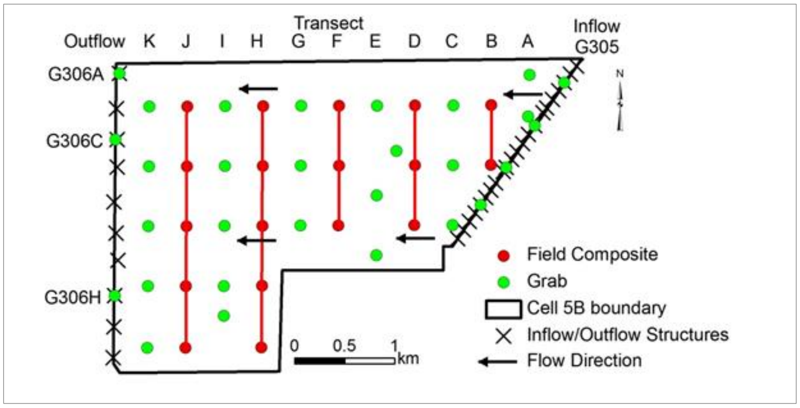


Figure 5B-30. Water quality monitoring transects and stations in STA-1W Cell 5B.

Results and Discussion

Results from both monitoring events depicted a downstream decrease in TP concentrations along the Cell 5B flow path, with the exception of a slight increase in concentration toward the bottom end of the cell between transect G and the outflow sampling locations (**Figure 5B-31**). Contour maps revealed elevated P levels near the southern outflow region (**Figure 5B-32**). Compared to the northern outflow region, concentrations of dissolved organic and particulate P fractions in the southern outflow region were higher during both events; SRP also was elevated at the southern outflow region during flowing conditions (June 2013). Data from both events also exhibited relatively high Ca concentrations in the southern outflow region, coincident with elevated P levels (**Figure 5B-33**).

Vegetation surveys indicated that the southern outflow region had a lower relative abundance of all SAV than the northern outflow region, primarily due to depletion of southern naiad and muskgrass (**Figure 5B-34**). In addition, a hydraulic tracer study conducted in Cell 5B in 2004 revealed relatively stagnant or impeded flow conditions in the southern outflow region (**Figure 5B-35**). The sub-optimum hydraulic characteristics of the southern outflow region, coupled with reduced vegetation, likely contributed to the higher outflow TP from this region. Low plant densities can also result in elevated Ca concentrations, as increases in water column pH by actively photosynthesizing SAV leads to Ca removal as a calcium carbonate precipitate, in turn binding and removing P from the water column. These observations are consistent with water quality data from recent (2012–2013) monitoring of individual outflow culverts in Cell 5B, which showed highest outflow P concentrations at the southern-most culvert, G306H (**Figure 5B-36**). These findings suggest that to achieve optimal P removal performance in Cell 5B, discharge through G-306H-J structures should be minimized, if possible, and that vegetation improvements to the southern outflow region of the cell are warranted.

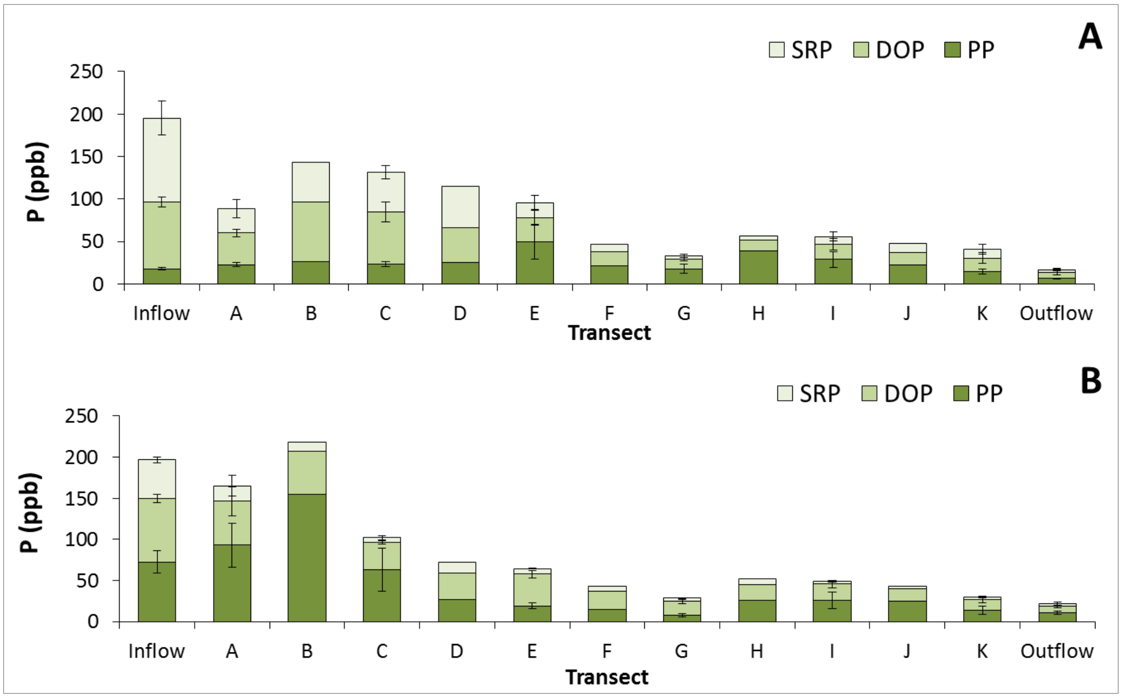


Figure 5B-31. Internal P concentrations in STA-1W Cell 5B under (A) flowing (June 2013) and (B) non-flowing (August 2013) conditions. Datapoints represent mean values (± S.E.) for stations along each internal monitoring transect.

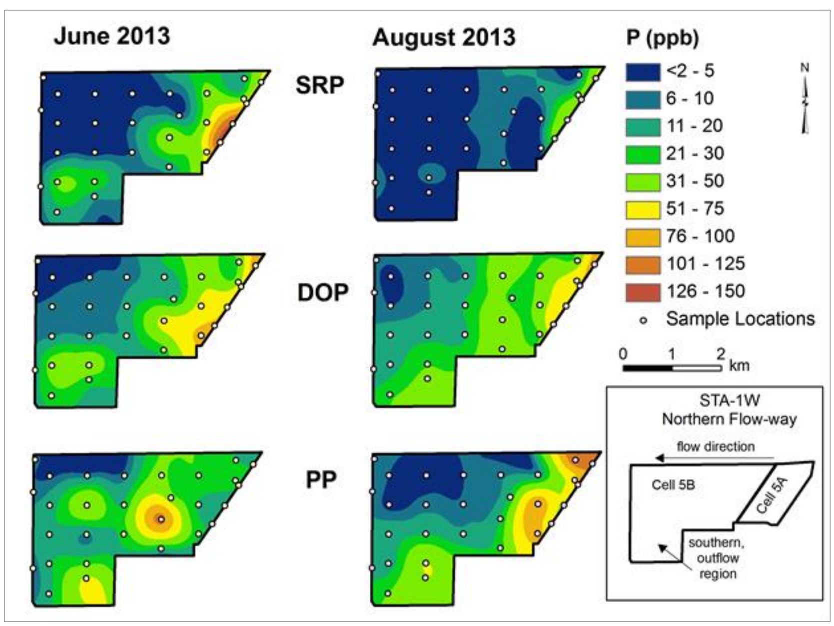


Figure 5B-32. Spatial distribution of soluble reactive P (SRP), dissolved organic P (DOP), and particulate P (PP) concentrations in STA-1W Cell 5B under flowing (June 2013) and non-flowing (August 2013) conditions.

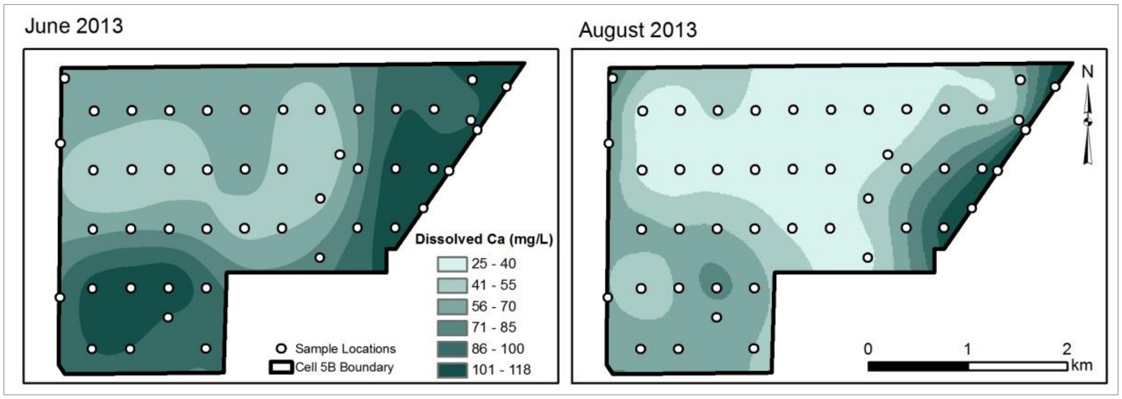


Figure 5B-33. Spatial distribution of dissolved calcium (Ca) concentrations in STA-1W Cell 5B under flowing (June 2013) and non-flowing (August 2013) conditions.

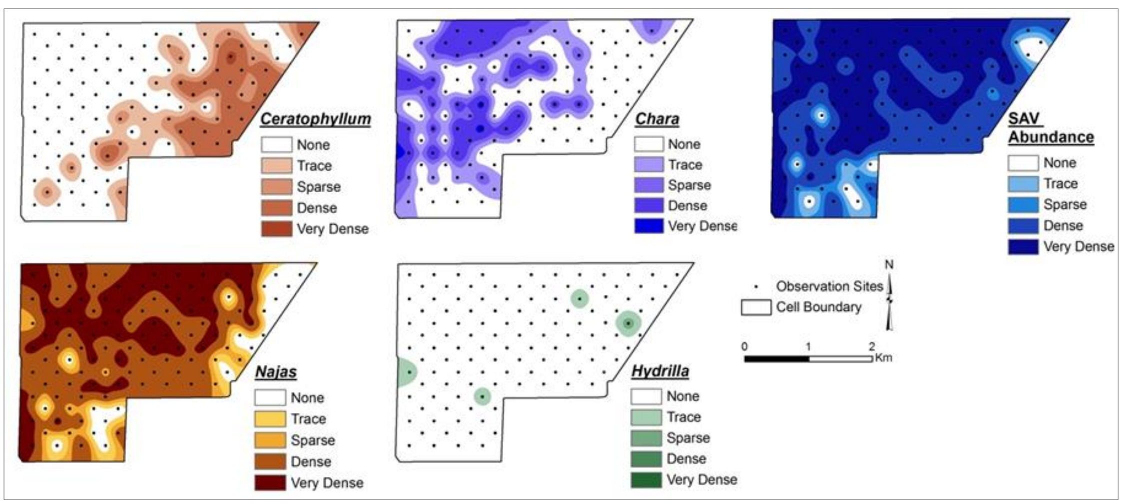


Figure 5B-34. Spatial coverage and relative abundance of coontail (*Ceratophyllum demersum*), muskgrass (*Chara* sp.), southern naiad (*Najas guadalupensis*), hydrilla (*Hydrilla verticillata*), and all SAV species grouped together in STA-1W Cell 5B in July 2013. Dots indicate locations of SAV ground survey points.

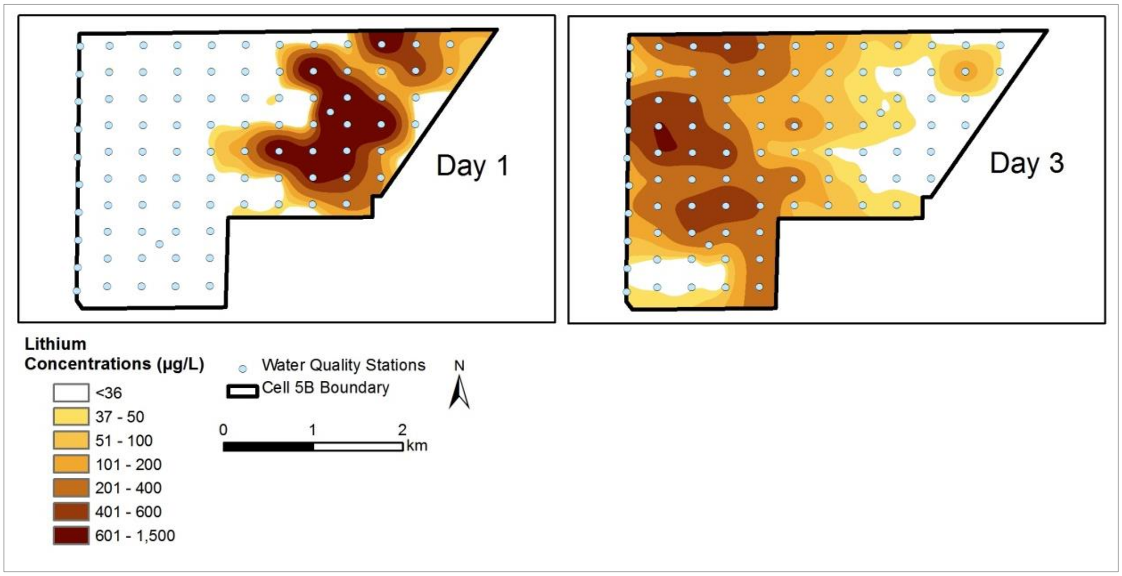


Figure 5B-35. Spatial concentration gradients of a hydraulic tracer (lithium chloride) at one and three days after injection into the STA-1W Cell 5B inflow in 2004.

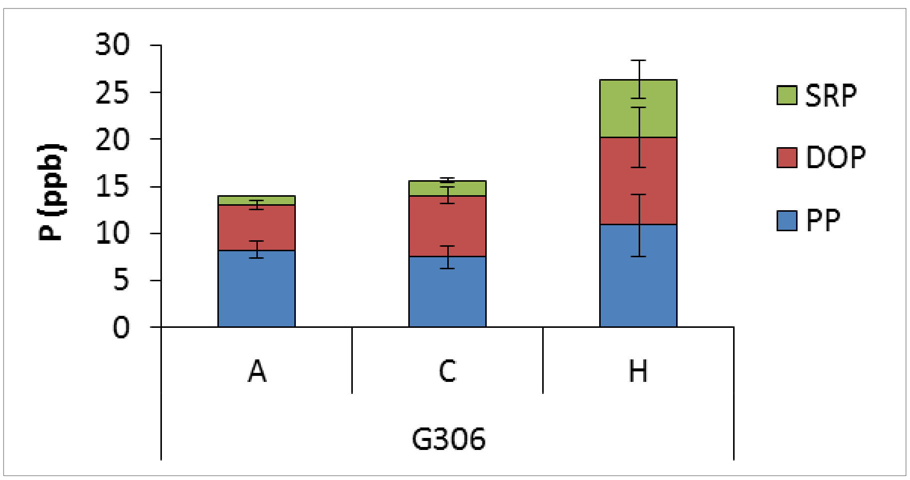


Figure 5B-36. Arithmetic mean (± S.E.) phosphorus (P) concentrations at STA-1W Cell 5 outflow culverts G306-A, C, and H from grab samples collected in July 2012 and March, June, and August 2013. Flow through these three culverts was similar during the sampling events, representing 35, 34, and 31% of the total annual flow through culverts A, C, and H, respectively.

Submerged Aquatic Vegetation Condition in STA-2 and STA-5/6

Delia Ivanoff, Manuel Zamorano and Michael Kirkland

Backgound

Adequate vegetation coverage is critical for effective P removal in the STAs, particularly in SAV-dominated cells. SAV communities in the STAs can experience disturbance due to seasonality, herbivory, high winds/flows during storm events, prolonged drought, and excessive loading of nutrients or highly turbid water. Since aerial photography and satellite remote sensing are not effective for imaging SAV coverage, rapid ground surveys have been utilized to assess spatial distribution and relative abundance of total SAV, as well as the coverage of the various SAV species in the STAs.

Methods

Results of the following SAV surveys are reported in this section: STA-2 Cells 2 and 4, and STA-5/6 Cells 1B, 2B, 3B, 4B, 5B, and 6-2. Surveys were conducted at an established network of geo-referenced stations. The number of survey points and survey dates for each cell are provided in **Table 5B-4**.

Table 5B-4. Vegetation survey information for selected cells in STA-2 and STA-5/6.

STA	Cell	Date of initial cell flooding (calendar year)	Status	# SAV survey points	Survey dates
STA-2	3	1999	Fully established SAV cell	43	09/09/13
	4	2006, then dried for construction; reflooded in 2012	Conversion to SAV is in progress	45	09/19/13 & 04/01/14
STA-5/6	1B	1998	Fully established SAV cell	55	07/17/13 & 01/7-9/14
	2B	1998	Fully established SAV cell	55	07/18/13 & 01/15/14
	3B	2011	Conversion to SAV is in progress	40	10/03/13 & 01/28/14
	4B	2011	Conversion to SAV is in progress	20	07/23/13 & 02/4/14

Results and Discussion

STA-2 Cells 3 and 4 SAV

A survey of Cell 3 in September 2013 found dense SAV coverage throughout the entire cell. This cell continued to have a diverse SAV community with muskgrass and southern naiad as the dominant species (**Figure 5B-37**). Dense beds of hydrilla and coontail were found mainly at the cell's inflow region. Dense beds of pondweed and moderately abundant spiny naiad were observed in the cell's outflow region (**Figure 5B-38**). Spiny naiad has been sparse in STA-2 and 3/4 for the last three years, and there are indications that this species is expanding in both STAs.

Cell 4, which previously had abundant SAV prior to being dewatered for Compartment B construction, has been successfully recolonized with very dense SAV since re-hydration in WY2012 (**Figure 5B-39)**. The diversity of SAV species within this cell is similar to the diversity in adjoining Cell 3. Based on surveys conducted in September 2013 and April 2014, muskgrass and spiny naiad were the two dominant species in Cell 4. Southern naiad has established within the southernmost region and had a lower density near the inflow. Pondweed also was observed at the southern region of the cell. Despite the notable difference in inflow TP concentrations between Cells 3 and 4, means of 98 ±46 (standard deviation) and 70 ±51 ppb, respectively, there was little difference in the mean outflow concentrations between these two cells (~17 ±4 and 19 ±3 ppb, respectively) (**Figure 5B-40**). This was attributed primarily to the relatively dense and stable coverage of SAV in both cells.

STA-5/6 Cells 1B, 2B, 3B, 4B, 5B and 6-2

SAV ground surveys conducted between July and October 2013, and between January and February 2014 found dense SAV coverage in Cells 1B and 2B, which have been in continuous operation since 1999. The dominant species in Cell 1B were hydrilla and southern naiad, with some areas with coontail. In Cell 2B, the SAV community was primarily a mixture of hydrilla and coontail. No southern naiad was observed in Cell 2B (**Figure 5B-41**).

In the newer cells (Cells 3B and 4B), SAV coverage was just beginning to expand. These areas were previously dry and colonized with a mix of woody species, upland grasses, and occasional emergent wetland species. Aerial herbicide applications, which began in October 2011, continued in WY2014 to remove undesirable vegetation and allow for a phased conversion of the plant community into SAV. Surveys performed during WY2014 found sparse coverage of southern naiad (**Figure 5B-41**) and trace amounts of bladderwort and muskgrass in both cells. There was an abundance of periphyton interspersed with SAV and woody species remnants within Cell 4B, although a large portion of this cell still contained woody species, grasses, and cattail (**Figure 5B-42**).

Cell 5B, which was surveyed, but not mapped, continued to have dense coverage of woody species and grasses with only sparse SAV. Similarly, a survey conducted in Cell 6-2 in August 2013 found only sparse muskgrass and bladderwort near their inflow areas. In February 2014, the SAV in Cell 6-2 was lost due to dry conditions throughout most of the cell.

Despite fluctuating inflow TP concentrations into Flow-ways 1, 2, 3, and 4 (annual means of 158–270 ppb), slightly different plant communities, and the sparse SAV establishment in Cells 3B and 4B, the outflow TP concentrations from Cells 1B, 2B, 3B, and 4B had annual means within a narrow concentration range (16 to 34 ppb) throughout WY2014 (**Figure 5B-43**). This suggests that P reduction was through mechanisms other than SAV uptake, e.g., periphyton, microorganisms, and abiotic reactions. A separate study is underway to understand the P cycling mechanisms within the STA cells.

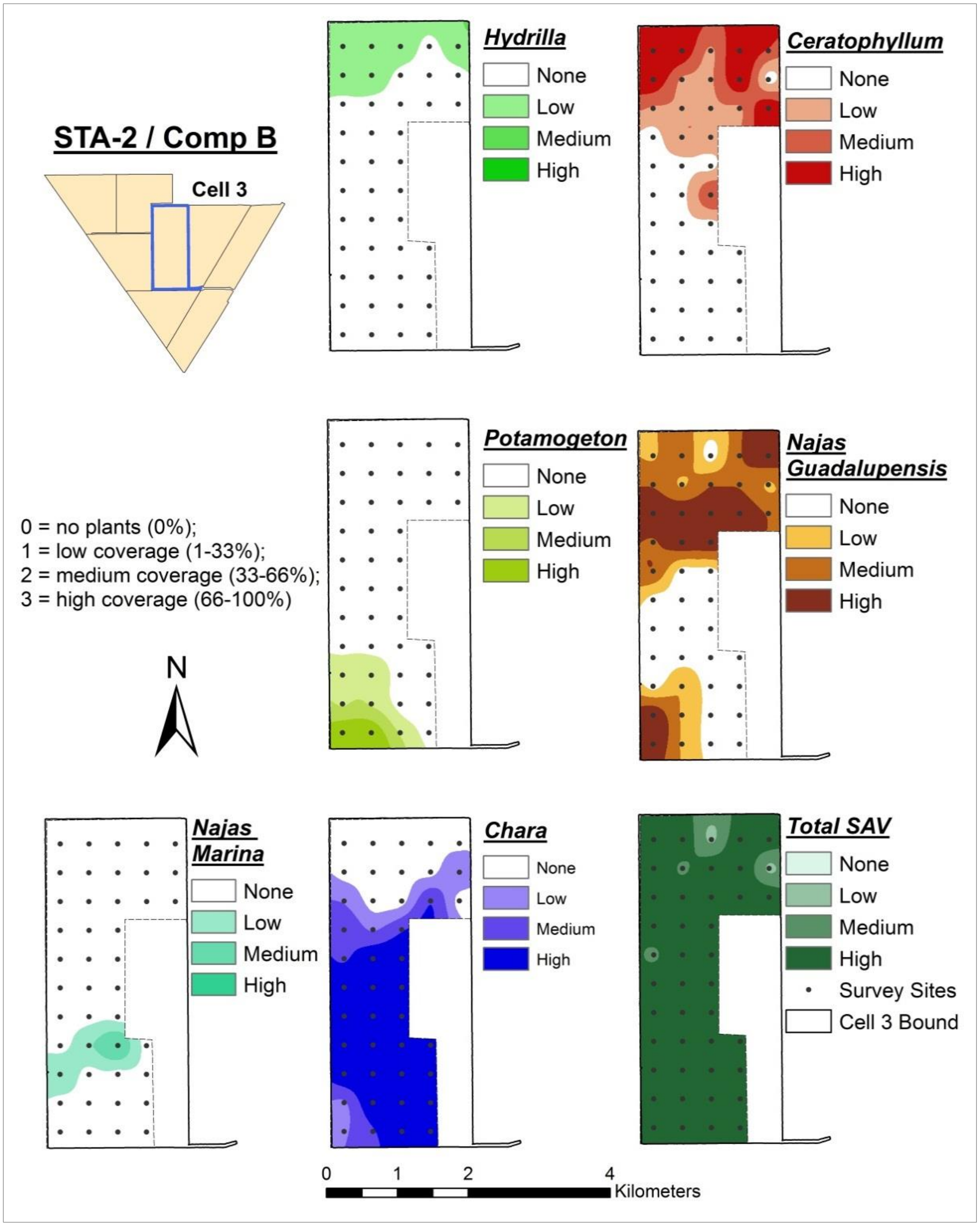


Figure 5B-37. Spatial coverage and relative abundance of hydrilla (*Hydrilla verticillata*), coontail (*Ceratophyllum demersum*), pondweed (*Potamogeten illinoensis*), southern naiad (*Najas guadalupensis*), spiny naiad (*Najas marina)*, muskgrass (*Chara* sp.), and all SAV species grouped together in STA-2 Cell 3 in September 2013. Dots indicate location of SAV ground survey sites.

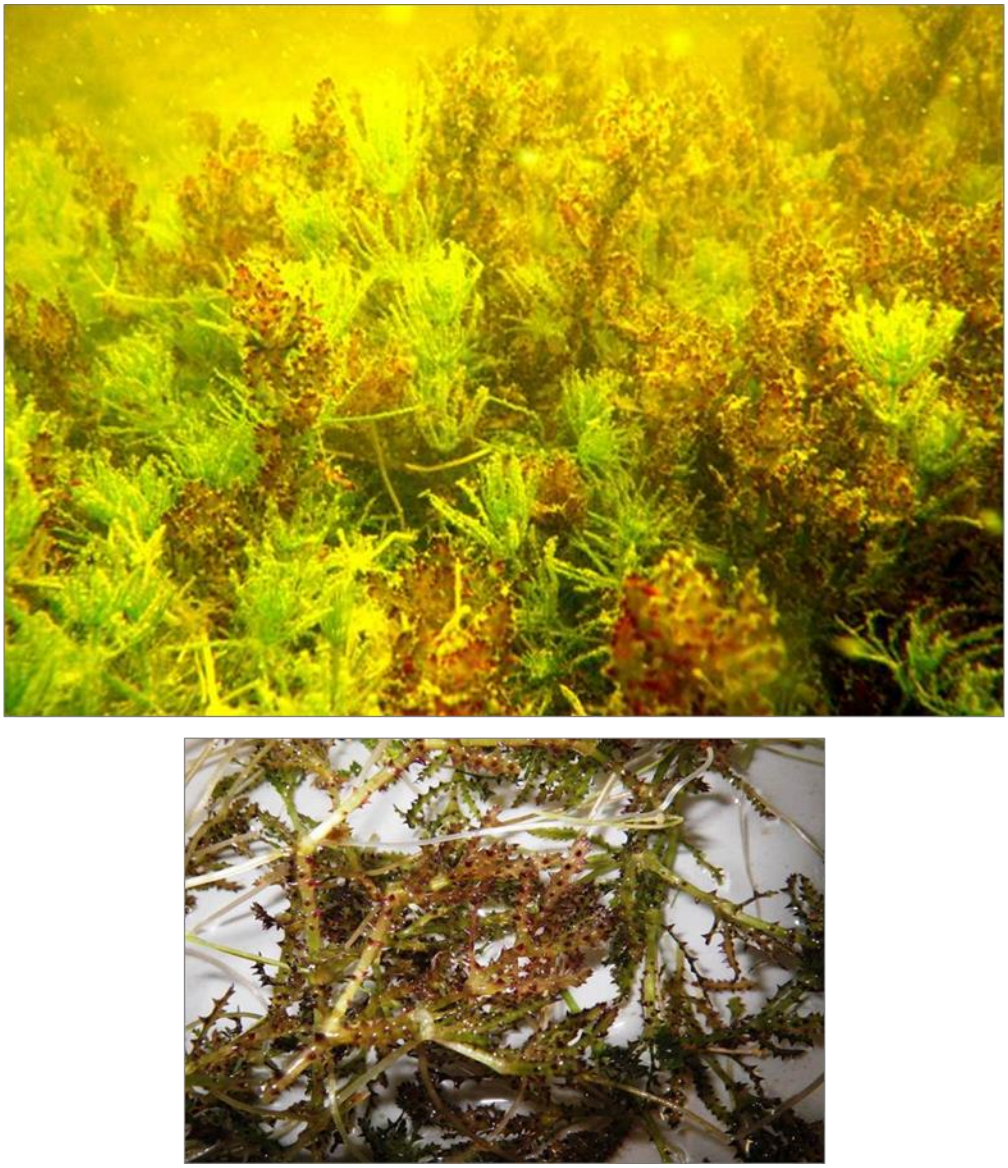


Figure 5B-38. Spiny naiad (*Najas marina*) observed in STA-2 Cells 3 and 4 during vegetation surveys conducted in September 2013 and April 2014 (photos by the SFWMD).

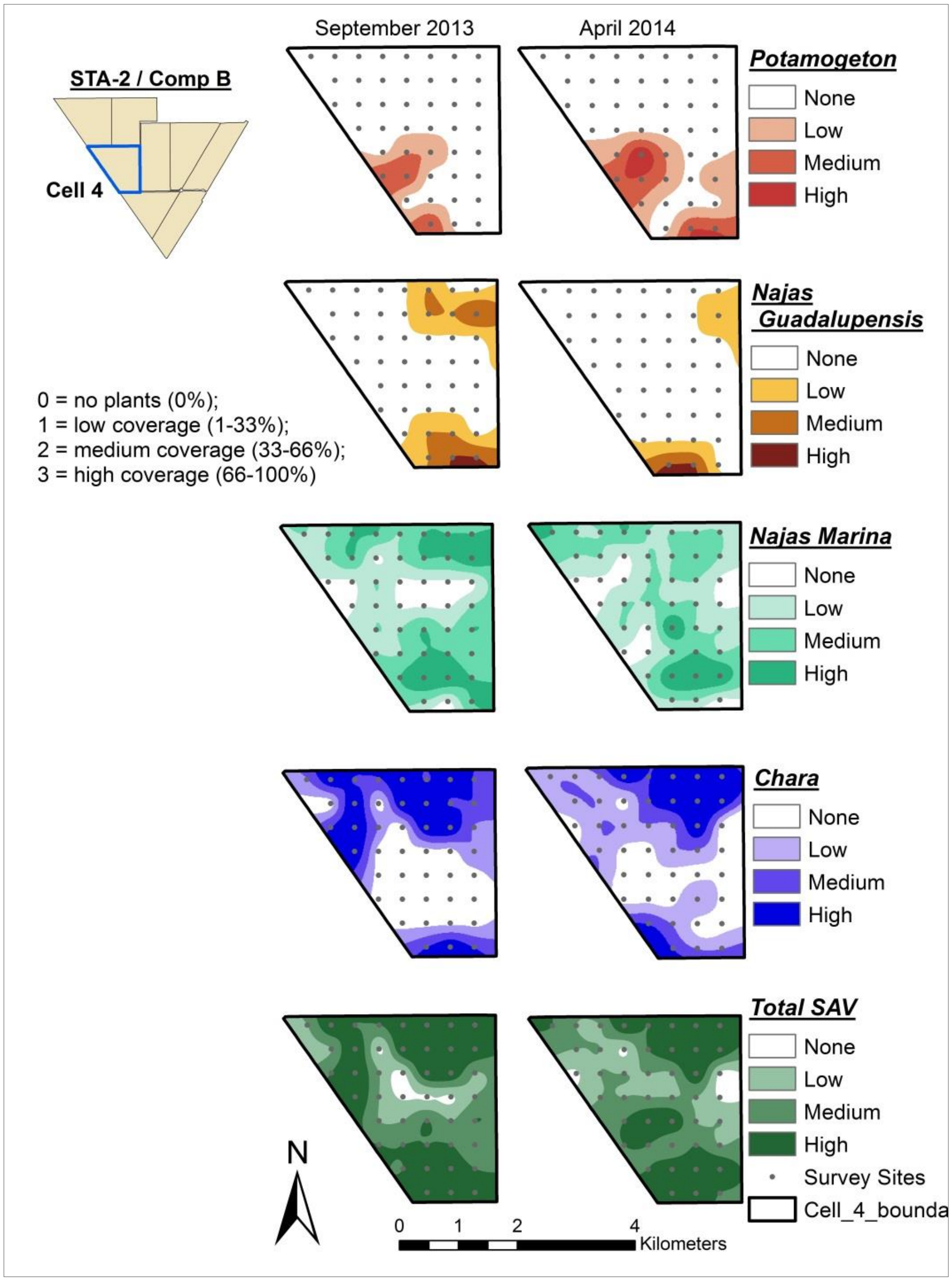


Figure 5B-39. Spatial coverage and relative abundance of pondweed (*Potamogeton illinoensis*), southern naiad (*Najas guadalupensis*), spiny naiad (*Najas marina*), muskgrass (*Chara* sp.), and all SAV species grouped together in STA-2 Cell 4 in September 2013 and April 1, 2014. Dots indicate location of SAV ground survey sites.

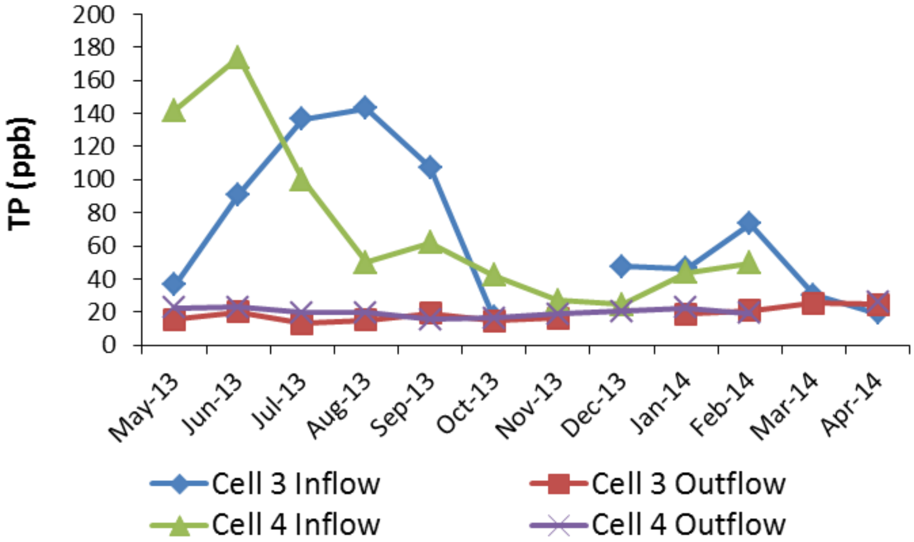


Figure 5B-40. Monthly inflow and outflow flow-weighted mean total phosphorus (TP) concentrations in STA-2 Cells 3 and 4 during WY2014. Submerged aquatic vegetation surveys were conducted in Cell 3 on September 9, 2013 and in Cell 4 on September 19, 2013 and April 1, 2014.

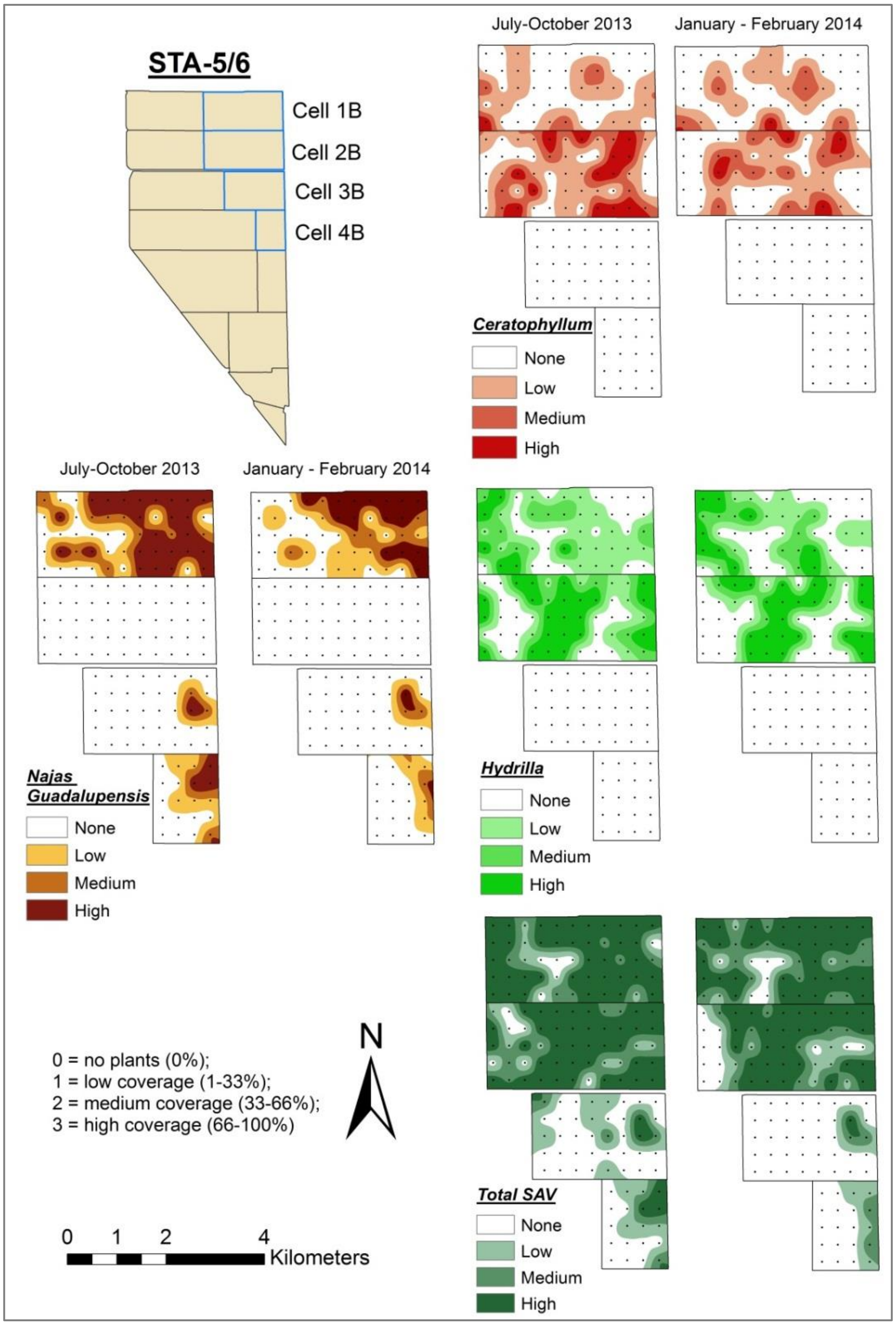


Figure 5B-41. Spatial distribution relative abundance of coontail (*Ceratophyllum demersum*), southern naiad (*Najas guadalupensis*), hydrilla (*Hydrilla verticillata*), and all SAV species grouped together in STA-5/6 Cells 5-1B, 5-2B, 5-3B, and 5-4B between July and October 2013, and between January and February 2014. Dots indicate location of SAV ground survey sites.

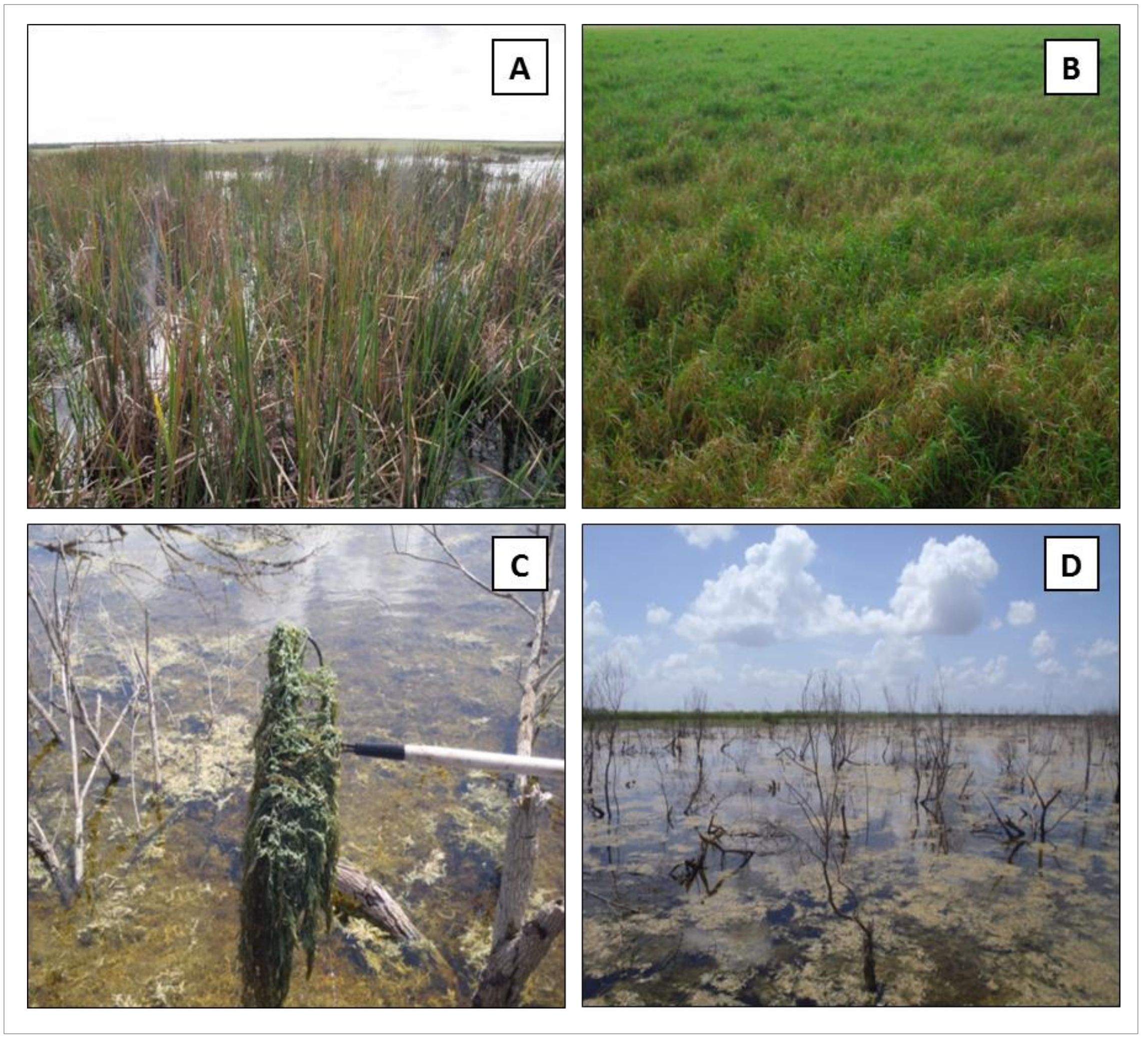


Figure 5B-42. Vegetation conversion in STA-5/6 Cell 4B: A = area colonized with cattail (*Typha* sp.), B = area colonized with mixed upland and facultative wetland grass species, C= southern naiad (*Najas guadalupensis*) beds, and D = periphyton interspersed with SAV and remnant woody species (photos by the SFWMD).

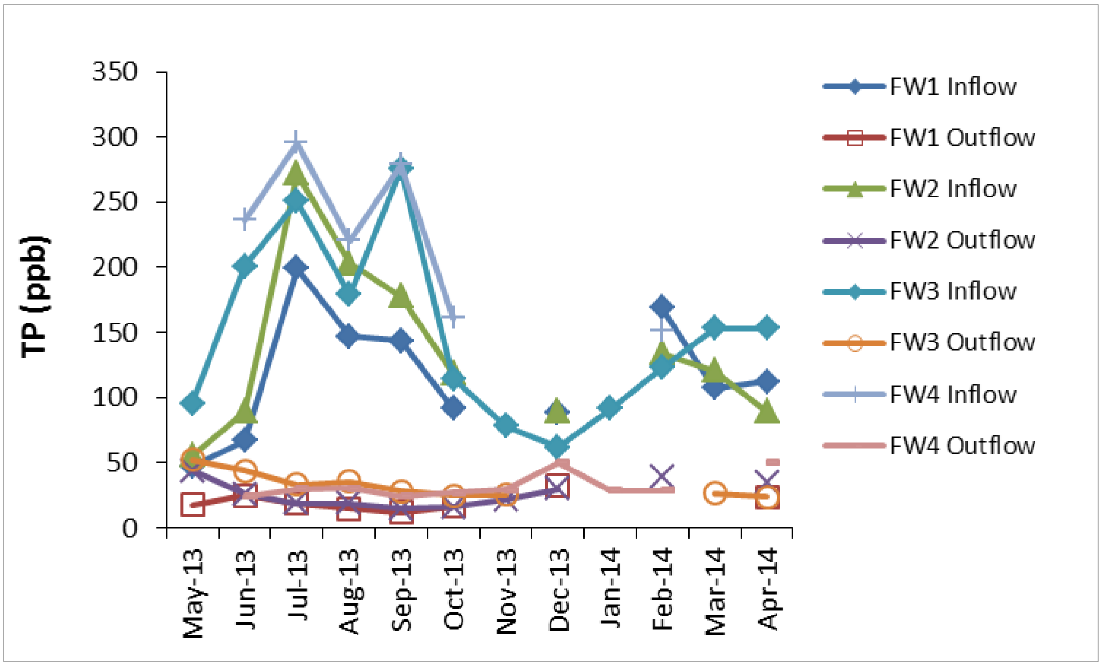


Figure 5B-43. Monthly inflow and outflow flow-weighted mean total phosphorus (TP) concentrations in STA-5/6 Flow-ways 1, 2, 3, and 4 during WY2014. Submerged aquatic vegetation (SAV) surveys were conducted in Cell 1B on July 17, 2013 and January 7 to 9, 2014; in Cell 2B on July 18, 2013 and January 15, 2014; in Cell 3B on October 3, 2013 and January 28, 2014; and in Cell 4B on July 23, 2013 and February 4, 2014. Mean annual TP concentrations at the flow-way mid-levees (i.e., inflow to the SAV cells) ranged from 20 to 100 ppb.

Submerged Aquatic Vegetation Coverage and Abundance in STA-3/4

Delia Ivanoff, Tom DeBusk[9], Mike Jerauld[9],
Michelle Kharbanda[9] and Lou Toth

Background

Sequenced wetland plant communities of EAV-dominated cells followed by SAV-dominated cells have provided effective P removal in many of the STA flow-ways. However, experience in the STAs has shown that SAV communities can be unstable and subject to sudden loss of plants due to uprooting during tropical storms and high flow events, high levels of herbivory, and plant senescence under high nutrient or suspended solids loading. Additionally, there is concern that the easily resuspended fine marl sediments that are deposited in SAV cells can adversely affect vegetation health after years of STA operation, as observed in STA-1W after vegetation loss in 2004-2005. The superior P removal by SAV communities, however, is a compelling reason to encourage and maintain SAV beds at the outflow regions of STA flow-ways.

STA-3/4 began operation in WY2005 and SAV inoculation was performed in August 2004 to aid in the establishment of desired species. Phased conversion of Cell 2B from EAV to SAV began in WY2004. This STA's SAV cells have been negatively impacted by tropical storms, herbivory, cell dryout during drought in WY2011, and other unexplained declines in vegetation.

Objectives

The long-term objectives of this monitoring effort were to document SAV relative abundance in STA-3/4 Cells 1B, 2B, and 3B, and evaluate the role of SAV in P removal by these cells. Observations of SAV growth and decline were used to facilitate our understanding of factors that potentially influence coverage and speciation of submerged plants in the STAs, and their influence on P removal performance.

Methods

SAV ground surveys were performed in STA-3/4 Cell 1B in September 2013 and February 2014; in Cell 2B in May, July, and September 2013; and in Cell 3B in May, July, and September 2013, at a network of fixed geo-referenced stations in each cell (**Figure 5B-44**).

Internal water quality samples were collected in Cell 2B in July 2013 at stations located along transects oriented perpendicular to the direction of flow (**Figure 5B-44**). Samples collected along each transect were composited in the field to provide one sample per transect for analysis.

Results and Discussion

Cells 1B continued to recover from the widespread loss of SAV after the WY2011 drought. In the first half of WY2014, SAV coverage and relative abundance increased during the first half of the water year and then declined in the later part of the year (**Figure 5B-45**). Ground surveys conducted in September 2013 found dense to very dense coverage of primarily muskgrass throughout the cell, with good coverage of southern naiad in the cell's western region. Spiny naiad continued to expand its coverage and relative abundance within the northwest portion of the cell. Sawgrass also was observed growing in the south end of the cell. In January 2014, an aerial (helicopter) survey noted the loss of muskgrass from most of the cell. A ground survey in February 2014 confirmed this observation and noted the loss of southern naiad.

Ground surveys of SAV in Cell 2B during May, July, and September 2013 found increased overall coverage of SAV (**Figure 5B-46**), primarily from the expansion of southern naiad, spiny naiad, and muskgrass. There also was sparse to dense coverage of bladderwort in much of the cell, which declined in coverage between May and September 2013. Based on observations made from a helicopter (data not presented), this cell also had an extensive loss of muskgrass between February and March 2014. Toward the end of WY2014, it was estimated that 80 percent of all the SAV cells in STA-3/4 had little or no SAV. In early 2014, water level was lowered in Cells 2A and 2B to allow for vegetation rehabilitation (regrowth and planting) in Cell 2A. Decreased water depth could have contributed to the loss of muskgrass in Cell 2B, although the adjacent SAV cells (1B and 3B) also experienced a loss of muskgrass; however, their water levels were maintained at target depth. As a result of the loss of SAV in Cell 2B, outflow TP concentrations from the Central Flow-way in WY2014 were almost twice as high (22 ppb annual FWM) as from the adjacent Eastern and Western Flow-ways, which had annual FWM outflow TP concentrations of 13 ppb.

Ground surveys of SAV in Cell 3B during May, July, and September 2013 found dense to very dense plant coverage, which was predominantly muskgrass intermixed with patches of southern naiad and bladderwort (**Figure 5B-47**). There also was evidence of increased coverage of spiny naiad, similar to the trend observed in Cells 1B and 2B. Cell 3B also experienced an extensive loss of muskgrass in April 2014.

The loss of SAV from Cells 1B, 2B, and 3B resulted in spikes in outflow TP concentrations in WY2014 (**Figure 5B-48**). In the Eastern Flow-way, where SAV loss from Cell 1B was first noted in January 2014, outflow TP concentrations (G376-B & D) started rising in November 2013, suggesting that the decline in SAV biomass likely started around that time. In the Central Flow-way, outflow (G379-B & D) TP concentrations were consistently greater than at the mid-levee (G378-B & D), indicating that there was net TP exported from Cell 2B. This P may have been released from the cell's floc, underlying soil, or decomposing SAV and periphyton. The Western Flow-way had the highest TP removal, with monthly outflow TP FWM concentrations of 10 to 30 ppb during the water year. The spike in TP concentration at Cell 3B's outflow was not as large as from Cells 1B and 2B, suggesting that there were other P removal mechanisms in Cell 3B. A separate study is under way to determine the different key P reduction mechanisms in the Western Flow-way.

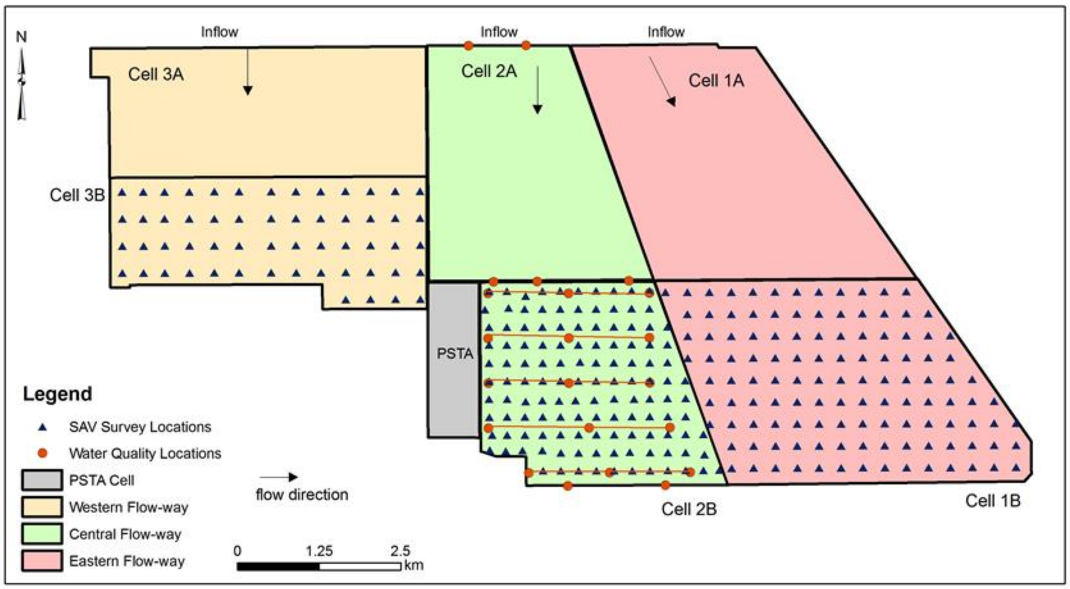


Figure 5B-44. Internal stations used for submerged aquatic vegetation (SAV) ground surveys in STA-3/4 Cells 1B, 2B, and 3B. Note that some stations were inaccessible during these surveys.

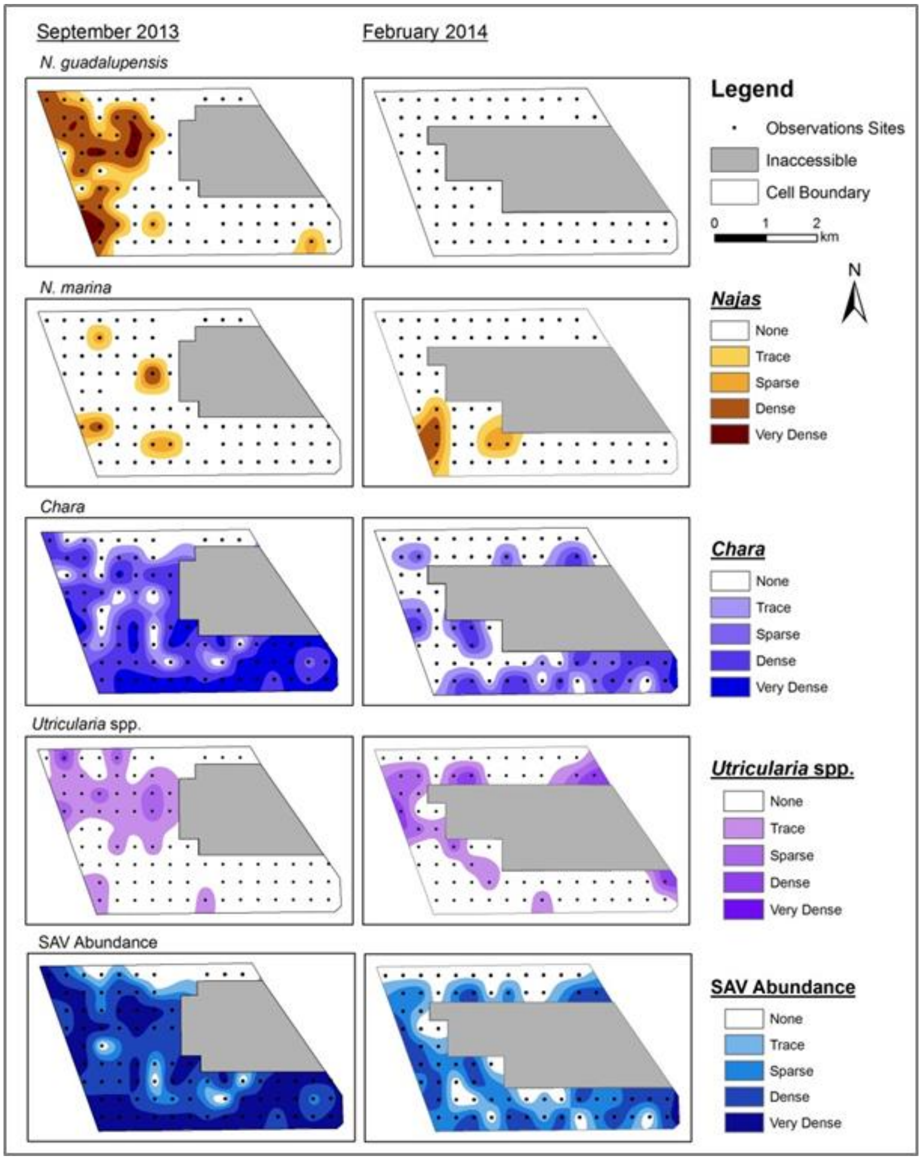


Figure 5B-45. Spatial coverage and relative abundance of muskgrass (*Chara* sp.), southern naiad (*Najas guadalupensis*), spiny naiad (*Najas marina*), bladderwort (*Utricularia* sp.), and all SAV species grouped together in STA-3/4 Cell 1B in September 2013 and February 2014. Dots indicate location of SAV ground survey sites.

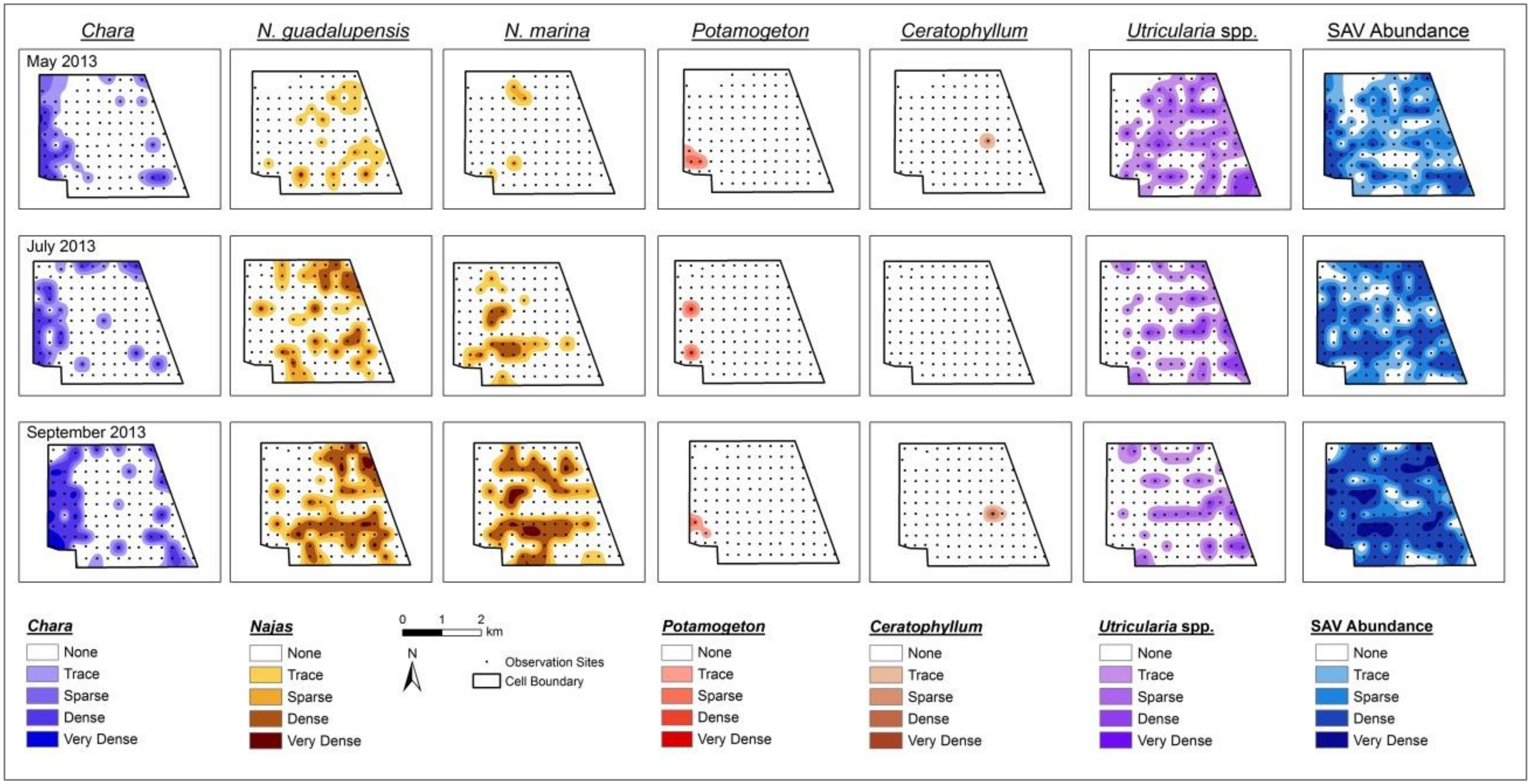


Figure 5B-46. Spatial coverage and relative abundance of muskgrass (*Chara* sp.), southern naiad (*Najas guadalupensis*), spiny naiad (*Najas marina*), pondweed *(Potamogeton illinoensis*), coontail (*Ceratophyllum demersum*), bladderwort (*Utricularia* sp.), and all SAV species grouped together in STA-3/4 Cell 2B in May, July, and September 2013. Dots indicate location of SAV ground survey sites.

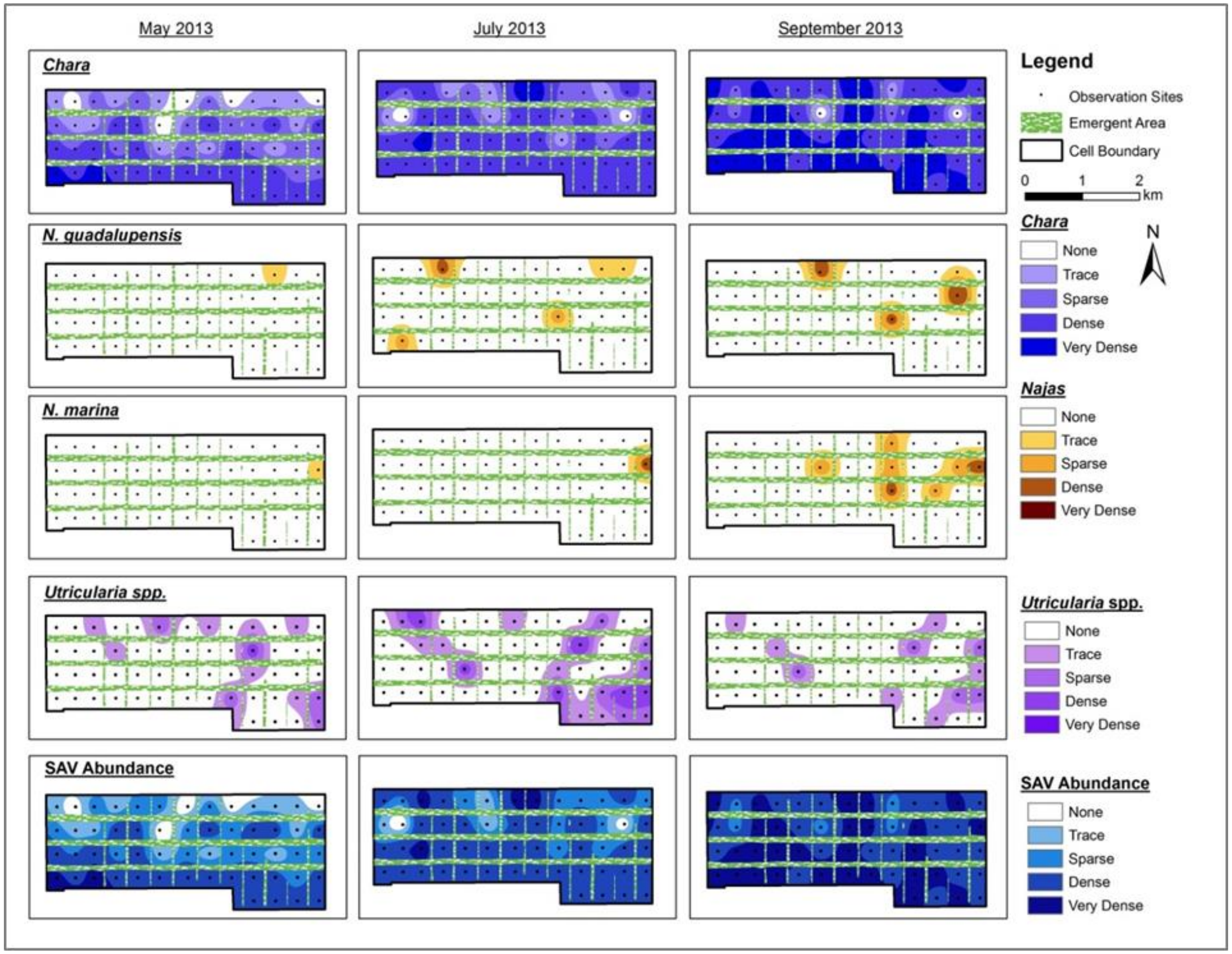


Figure 5B-47. Spatial coverage and relative abundance of muskgrass (*Chara* sp.), southern naiad (*Najas guadalupensis*), spiny naiad *(Najas marina),* bladderwort (*Utricularia* sp.), and all SAV species grouped together in STA-3/4 Cell 3B in May, July, and September 10, 2013. Dots indicate location of SAV ground survey sites.

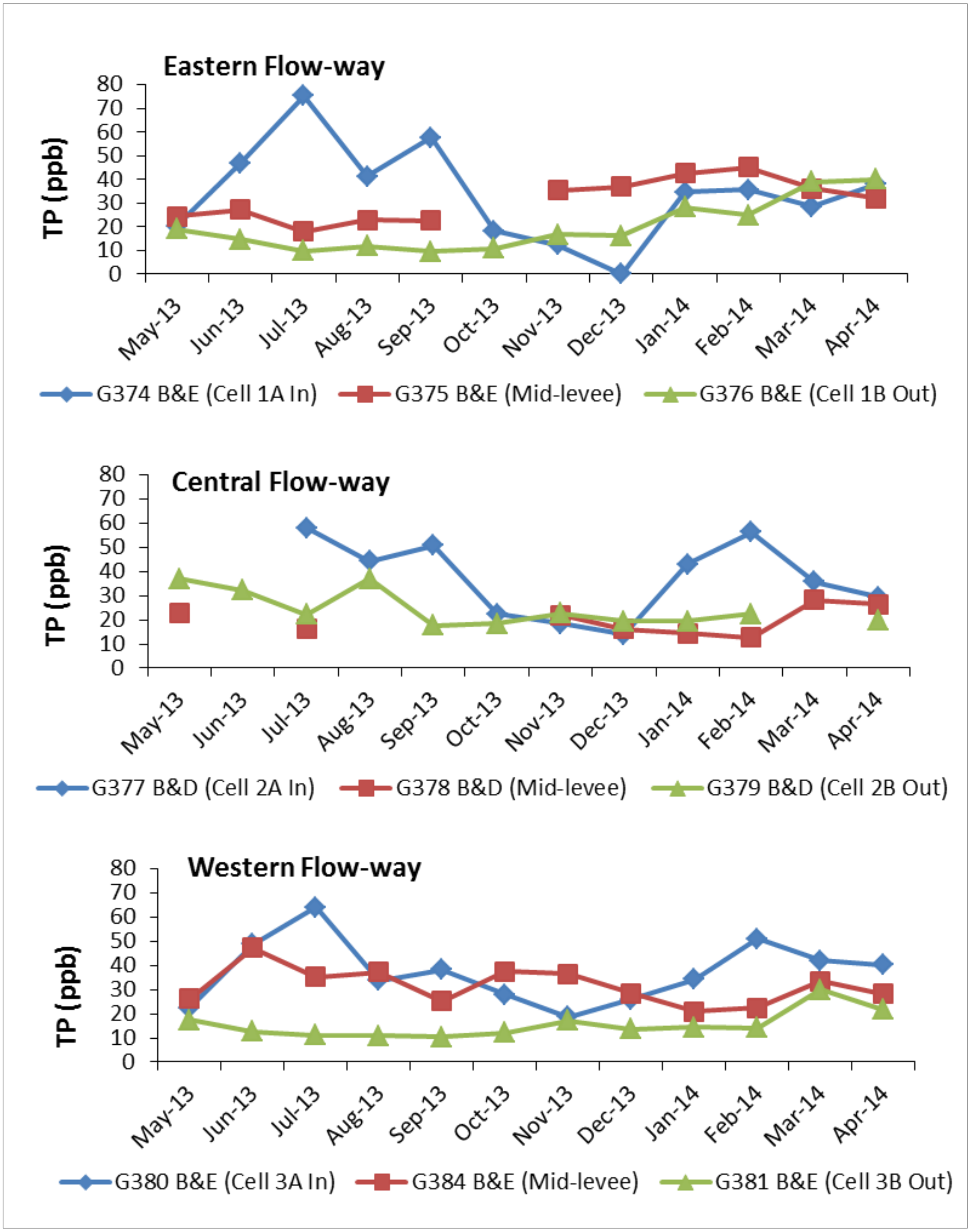


Figure 5B-48. Monthly inflow and outflow flow-weighted mean total phosphorus (TP) concentrations for cells in the Eastern, Central, and Western Flow-ways of STA-3/4. Submerged aquatic vegetation (SAV) surveys were conducted on September 9, 2013 and February 19, 2014 in Cell 1B; on May 9, July 17, and September 9, 2013 in Cell 2B; and on May 16, July 16, and October 10, 2013 in Cell 3B. Die-off of SAV in Cell 1B was first observed in January 2014 and February 2014 in Cell 2B.

STA-1W Mesocosm Study: Evaluation of Phosphorus Removal Efficacies of Several Native Everglades Vegetation Communities in a Low-Phosphorus Environment

Shili Miao

Edited by Larry Schwartz and Garth Redfield

Introduction

There is a need to further improve P removal performance in the STAs. One area of interest is whether there are alternative vegetation communities other than existing SAV communities in the STAs that can grow in a low-P environment and remove additional water-column P. Pristine areas of the remaining Everglades that are oligotrophic are dominated by sawgrass ridges and white water lily (*Nymphaea odorata*) sloughs. The survival mechanisms of these native species, particularly their adaptation to a low P environment, may provide information vital for developing new management approaches to enhance P reduction performance in the STAs. A three year proof-of-concept mesocosm study was conducted comparing the P reduction performance of native plant communities that grow in pristine areas of the remaining Everglades to those that grow in the STAs and to evaluate their P cycling adaptation strategies.

The objective of this study was to assess nutrient removal efficacy of six wetland vegetation communities native to south Florida in surface waters with very low P, using the discharge water from an existing STA as the inflow to mesocosms with these communities. More specifically, the goal of the study was to evaluate surface-water P removal performance of several native vegetation communities to determine if they can be used to further enhance the P reduction performance of the SAV cells in the STAs. Additionally, the study also aimed to identify major processes underlying P cycling in the vegetation communities examined.

Experimental Design

This study was conducted in mesocosms located at the STA-1W Research Site starting in April 2010. The study ended in August 2013. Data were collected for a total of 37 months (August 2010 to August 2013). The experimental treatments were assigned to mesocosms with one factor (vegetation type) initially representing five native-plant communities and a soil treatment (non-vegetated) to evaluate soil P flux without vegetation. The initial five vegetation treatments that were planted included: (1) white water lily monoculture (Water Lily), (2) mixed white water lily and spikerush (*E. cellulosa*) (Water Lily/Spikerush), (3) sawgrass monoculture (Sawgrass), (4) cattail (*T. domengensis*) monoculture (Cattail), and (5) SAV (**Figure 5B-49**, panel A). The first three treatments represented plant communities native to pristine areas of the Everglades, whereas the remaining two are found in the STAs.

The Water Lily, Sawgrass, and Cattail treatments were planted exclusively with white water lily, sawgrass, and cattail, respectively. The Water Lily/Spikerush treatment was started with predominantly white water lily mixed with small amounts of spikerush. The SAV treatment included muskgrass and southern naiad. Therefore, with the soil treatment (non-vegetated) to examine soil P flux without vegetation included, there were six treatments. There were three replicates for each of the six treatments, for a total of 18 mesocosms.

During the course of the study, there were substantive shifts in the dominant species in three treatments (**Figure 5B-49**, panel B) as attempts to remove invasive, non-target species and maintain each of the treatments became too labor intensive. The implications of these species shifts to interpreting results cannot be overstated. First, the Water Lily treatment was colonized with SAV, and this treatment was then referred to as the Mixed Water Lily/SAV treatment. Second, the Water Lily/Spikerush treatment became dominated by spikerush and this treatment was then referred to as the Spikerush treatment. Third, the soil treatment (non-vegetated) was colonized by SAV species and this treatment was then referred as the Soil-SAV treatment to distinguish it from the original SAV treatment. As a result of these changes, the six treatments of the study were then re-labeled as: 1) Mixed Water Lily/SAV, 2) Spikerush, 3) Sawgrass, 4) Cattail, 5) SAV, and 6) Soil-SAV. **Figure 5B-49**, panel C, shows the six treatments in the third year before the study was completed. The loss of treatment fidelity must be fully considered when evaluating the data presented in **Figure 5B-50,** in particular with regard to the results from the final three to four months of data from this study and any extrapolation of the results to the STAs (**Figure 5B-51**).

Water, vegetation, and soil (vegetation and soil data are not presented herein) parameters were measured with a focus on P removal, storage, and cycling in the mesocosms. Water samples were analyzed for nutrients, including TP, SRP, dissolved organic carbon (DOC), total organic carbon (TOC), total dissolved Kjeldahl nitrogen (TDKN), total Kjeldahl nitrogen (TKN), dissolved calcium (Ca^{2+}) and dissolved magnesium (Mg^{2+}). Dissolved organic P (DOP) and particulate P (PP) were calculated values. Aboveground plant biomass and litter were analyzed for TOC, total nitrogen (TN) and TP content. Litter decomposition was evaluated with litterbags before and after deployment. Live plant material collected at STA-2 Cell 1 was used to evaluate decomposition.

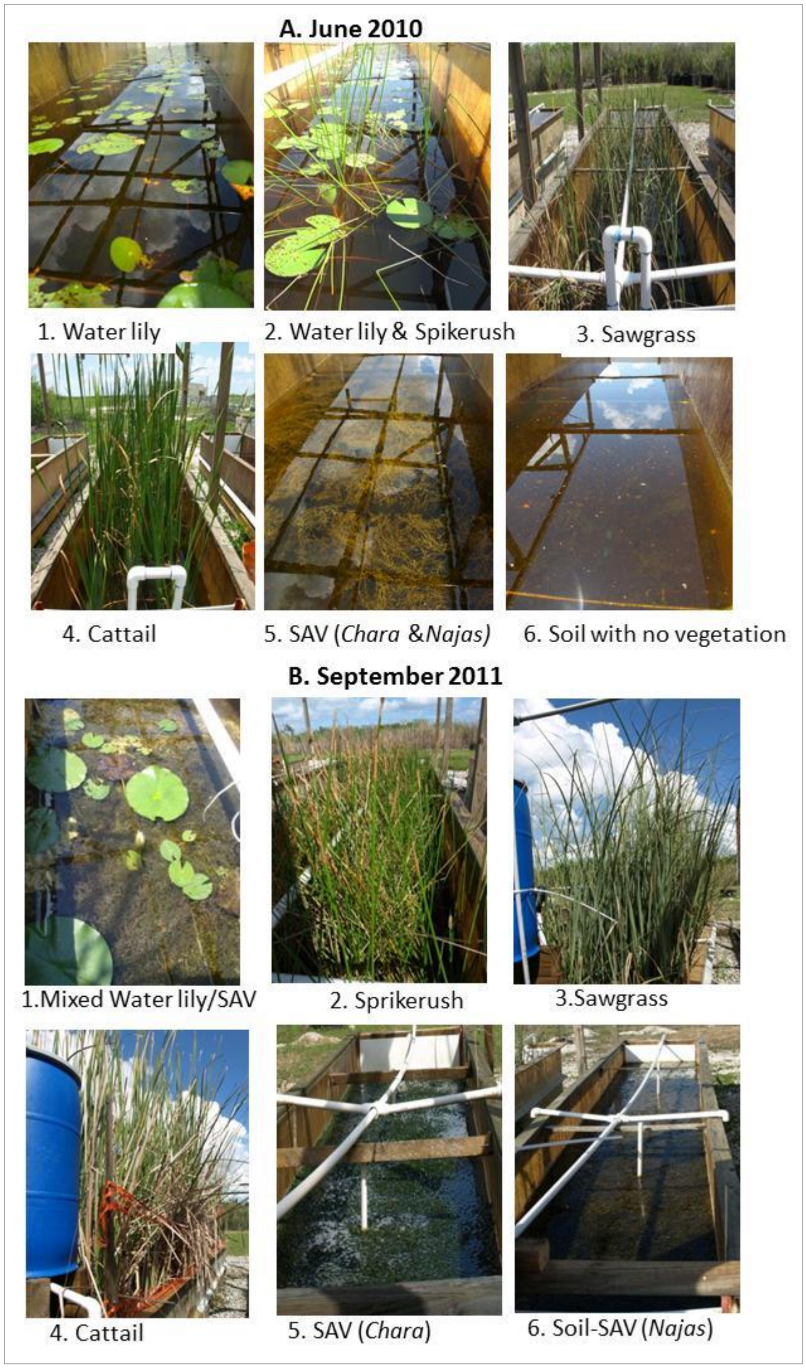


Figure 5B-49. Vegetation development of the six treatments employed in this study between May 2010 and August 2013. (A) Two months after transplantation. [Note that only white water lily was transplanted into Treatment #1, main white water lily with minor spikerush into Treatment #2, and no transplanting into Treatment #6.] (B) Approximately 17 months after transplantation. [Note that Treatment #1 became mixed Water Lily/SAV, Treatment #2 was taken over by spikerush, and Treatment #6 was invaded by SAV (mainly southern naiad); also, the two SAV treatments (#5 and #6) were dominated by muskgrass and southern naiad, respectively.] (C) Approximately 37 months after transplantation. [Note that the two SAV treatments had become muskgrass dominated.] All photos by the SFWMD.

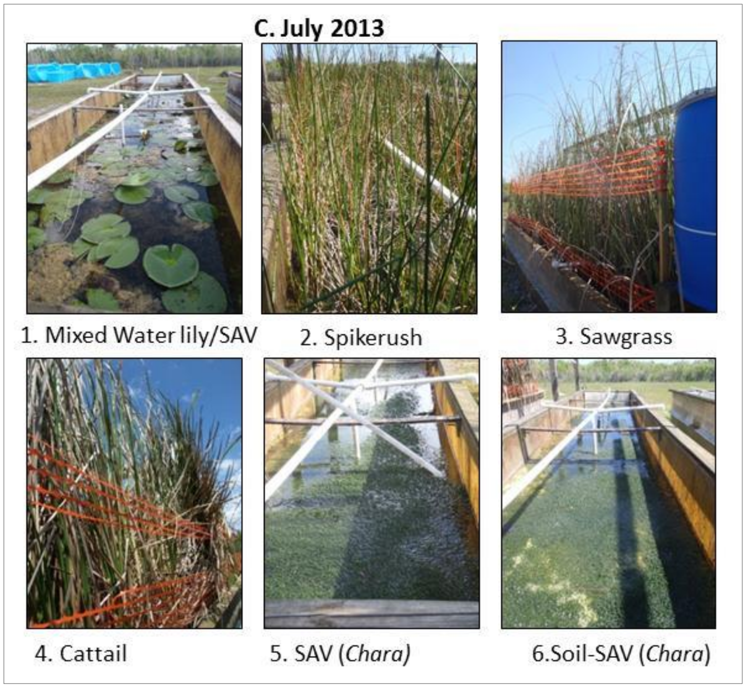


Figure 5B-49. Continued.

Results

Concentrations of inflow P species during the entire study are presented in **Figures 5B-50** and **51** and **Table 5B-5**. The average inflow TP concentration to the mesocosms over the 37-month period of record was 24.4 ± 9.3 (SD) ppb, ranging from 13 to 78 ppb. The average inflow PP concentration was 16.7 ± 8.8 ppb and accounted for approximately 69 percent of inflow TP. Inflow PP concentrations had similar temporal variation as inflow TP. The average inflow DOP concentration was 5.6 ± 2.0 ppb, approximately 23 percent of inflow TP. Inflow DOP and SRP were not correlated with inflow TP.

Table 5B-5. Annual average (±SD) concentrations of inflow and outflow phosphorus species in six vegetation treatments between August 2010 and August 2013. The 1st year was from August 2010 to July 2011; the 2nd year was from August 2011 to July 2012; and the 3rd year was from August 2012 to July 2013. N =17 to 25. Outflow values highlighted in red were lower than their corresponding inflow value.

		Outflow					
P species	**Inflow**	**Mixed Water Lily/SAV**	**Spikerush**	**Sawgrass**	**Cattail**	**SAV**	**Soil-SAV**
TP (ppb)							
1st year	26.8±14.5	42.5±7.2	190.8±101.0	69.7±16.7	60.7±13.1	44.5±10.1	42.7±11.5
2nd year	25.0±5.3	32.3±8.2	82.5±39.0	40.1±9.0	32.4±9.3	35.3±12.0	38.6±12.1
3rd year	22.1±7.2	18.5±6.7	31.2±12.2	34.1±8.7	21.8±4.8	33.5±11.1	24.0±9.0
DOP ppb)							
1st year	6.7±2.5	24.0±5.5	48.1±11.6	42.7±9.9	35.0±6.7	30.5±10.2	25.1±6.7
2nd year	5.6±1.7	14.1±2.8	28.5±10.5	19.8±5.0	19.3±5.5	16.5±5.9	16.7±5.4
3rd year	4.9±1.4	6.3±1.4	10.8±2.5	15.8±2.5	11.3±2.3	12.0±2.1	8.0±6.2
PP (ppb)							
1st year	17.9±13.2	15.6±4.2	26.1±41.4	14.3±4.0	10.5±2.5	10.4±6.2	11.7±4.1
2nd year	17.4±5.4	15.1±6.8	26.0±13.2	9.1±2.8	8.9±4.4	15.2±7.3	17.4±8.1
3rd year	15.0±7.5	10.1±5.5	18.2±10.0	7.4±2.0	8.1±3.1	17.8±9.7	14.0±7.1
SRP (ppb)							
1st year	2.2±0.5	2.9±1.4	116.7±75.8	14.1±5.5	15.2±8.5	3.7±1.2	5.9±3.2
2nd year	2.0±0.0	2.4±0.6	26.9±24.5	11.0±5.5	3.7±1.0	3.1±2.4	3.8±1.6
3rd year	2.2±0.7	2.0±0.1	2.1±0.4	10.9±6.3	2.4±0.4	3.4±2.5	2.0±0.1

During the course of the study, three treatments had outflow TP < inflow TP for a short period of time. However, P removal was subsequently reversed (TP export) as indicated clearly in **Figure 5B-51**. The outflow TP concentrations of the Mixed Water Lily/SAV treatment were lower than the inflow TP for approximately seven months between November 2012 and May 2013. During this period, the outflow TP concentrations of the treatment averaged 14.4 ppb and the average inflow TP was 22.6 ppb. In the Cattail treatment there was an approximate four-month period (between late November 2012 and early April 2013) when the outflow TP concentrations were lower than inflow TP concentrations, an average of 17.7 ppb. The outflow TP concentrations of the Soil-SAV treatment were lower than inflow TP for approximately four months (between November 2012 and April 2013), an average of 16.1 ppb. In contrast, the outflow TP concentrations of the remaining three treatments, Spikerush, Sawgrass, and SAV, were never lower than the inflow TP concentrations (**Table 5B-5**). With poor performance in the SAV treatment (unlike in the STAs), and limited performance of Mixed Water lily/SAV, Cattail, and Soil/SAV only after 27 months, these data do not provide any definite patterns or conclusions on the role of these macrophyte species in the TP treatment provided in the STAs.

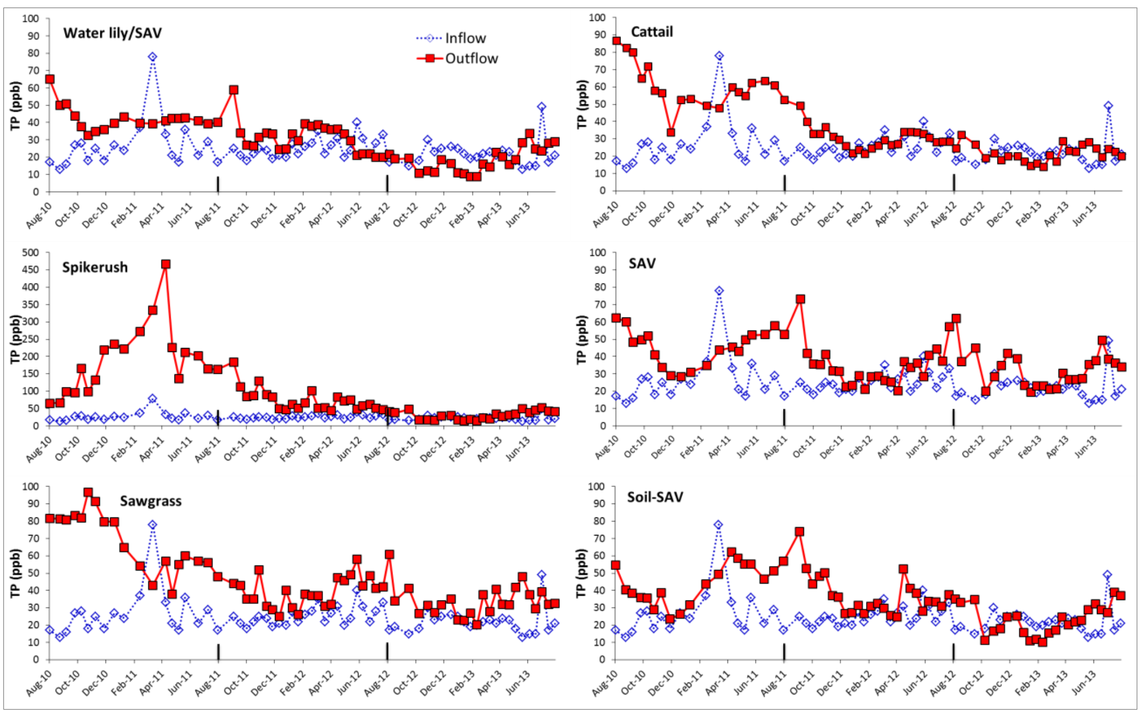


Figure 5B-50. Inflow and outflow total phosphorus (TP) concentrations for the six treatments from August 2010 to August 2013. Each data point represents an average of three replicates. Note that the Y-axis scale for spikerush is different from the other treatments.

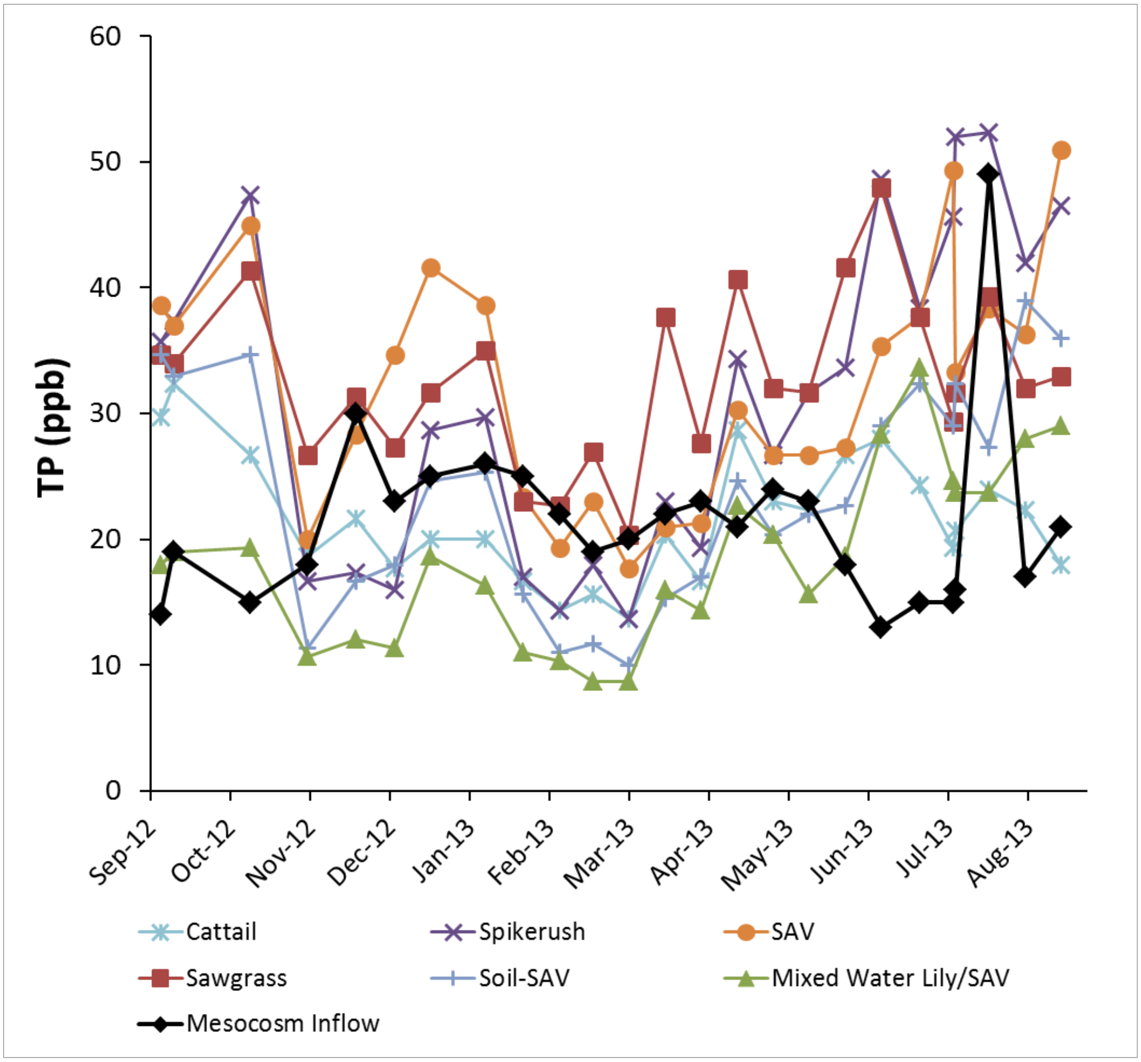


Figure 5B-51. Inflow and outflow TP concentrations for the six treatments over the final 12 months of the study. Each data point represents an average of three replicates.

Outflow TP concentrations decreased annually for all treatments (**Table 5B-5**). However, outflow DOP concentrations were almost never lower than the inflow DOP concentrations regardless of the treatment. Outflow PP concentrations were generally lower than the inflow PP concentrations in all treatments, except for the Spikerush treatment, indicating the PP was removed from the water column. In particular, in the Sawgrass and the Cattail treatments the outflow PP concentrations had lower concentrations than the inflow PP concentrations during almost the entire study period. The outflow SRP concentrations were different from the TP, DOP, and PP concentrations. During about the first 1.5 years, all treatments, except for the Sawgrass treatment, had higher outflow SRP concentrations than inflow SRP concentrations.

Overall, the six treatments differed in TP and P species removal in the third year of the study. The best performing treatment was the Mixed Water Lily/SAV, as it showed approximately 16.3, 32.4, and 8.5 percent removal for TP, PP, and SRP, respectively, although it exported 29.0 percent of the DOP. The next best performing treatment was Cattail, exhibiting 1.3 and 45.8 percent removal of TP and PP, respectively, but exported 12.9 percent of the DOP. The two SAV treatments as well as the Sawgrass and Spikerush treatments did not remove TP in the third year of the study. It should be noted that in the Sawgrass treatment, a very large amount of SRP (-393.9 percent) was exported by the third year of the study. Dissolved Ca concentration in the outflow increased in the SAV and Soil-SAV treatments towards the end of the study during a slow growth and vegetation-loss period, which might indicate a decline in Ca binding activities and increased SRP export.

Litter decomposition was examined exclusively for aboveground plant tissues. The decomposition sub-study continued for 94 days. Mass loss rates were in the order of white water lily > southern naiad > muskgrass > sawgrass and cattail. Cattail and sawgrass had slow decomposition rates with over 80 percent of their litter remaining at the end of the decomposition sub-study, whereas over 90 percent of white water lily material decomposed within 57 days. Muskgrass and southern naiad had the second fastest decomposition with approximately 45 to 55 percent of mass loss in 40 days. Aboveground tissue composition differed among species.

Muskgrass and southern naiad had much lower carbon related parameters (TC and TOC) than EAV and Water lily and this might be associated with their growth form being submerged in the water column and hence lacking supporting tissue structures. Total P and TN of sawgrass and cattail were much lower than those of white water lily. However, muskgrass and southern naiad had similar TP and TN values as white water lily.

The nutrient ratios of live to recently senesced leaves are an indicator of the degree of nutrient re-translocation (i.e., withdrawal) before leaf senescence (Killingbeck 1996, Aerts et al. 1999, Miao 2004). The ratio relative to other plants reflects the plants' ability to store nutrients and release them back to the water column. A higher nutrient ratio of live versus recently senesced leaves suggests a greater amount of leaf nutrients can be re-translocated to belowground components, as less nutrients remain in senesced leaves, and thus less nutrients are released back to water column via decomposition. For the two large EAV species, cattail exhibited the highest N and P re-translocation percentages, whereas sawgrass and water lily showed the lowest N and P ratios.

Discussion

This mesocosm-scale study was conducted in surface waters with very low P for a total of 37 months, one month longer than originally intended. For the first 27 months of the study, TP export presumed to be primarily from soil was observed in all treatments. The soil used in the mesocosms was obtained from previously accreted STA soil, which had oxidized prior to this study. Phosphorus flux and consequently P export was aggravated by the large gradient in P concentration between the soil and the water column (the water column P averaged 24.4 ppb). Later export also included P release from decomposing plant materials.

By the twenty-eighth month of the study, TP reduction was observed in some treatments (Mixed Water Lily/SAV, Cattail, and SAV) but only for a four to seven month period. The TP removal was subsequently reversed (i.e., net TP exported) for the final three to four months of the study that raised critical concerns about the sustainability of the observed short-term TP removal in the study (**Figures 5B-50** & **51**). As a result of the loss of treatment fidelity and lack of data patterns in the results, the study was deemed complete at the end of the three-year (plus one month) proof-of-concept study. The loss of treatment fidelity must be fully considered when evaluating the data, particularly with regard to the results from the final three to four months of the study and any extrapolation of the results to the STAs.

However, qualitatively synthesizing data collected in the study improves our knowledge and understanding of vegetation differences in surface-water P removal performance under very low-P conditions, which may form the basis for potential future STA P performance studies in a low-P environment. The following discussion focuses on what was learned in the study and what uncertainties still exist.

In this study, PP accounted for over 65 percent of the inflow water TP. However, the annual average outflow PP concentrations were generally much lower than that of the inflow PP concentrations for all treatments through most of the study period, indicating PP removal from the water column. Ca-P co-precipitation in this study was indirectly assumed based on a decrease in the outflow dissolved Ca concentrations in some treatments. The increased outflow dissolved Ca concentrations towards the end of the study in the two SAV treatments appeared largely related to poor SAV growth and vegetation die-off that corresponded to increased outflow TP.

In this study, outflow TP concentrations initially increased greatly in all treatments, and outflow DOP concentrations were similar to outflow TP concentrations. DOP was generated internally and was exported during the entire study in all treatments. Transformations related to DOP should be further evaluated to determine if P removal performance in low-P environments can be enhanced. DOP decreased gradually in all treatments, however, outflow DOP concentrations were never below the inflow DOP during the study in all treatments. Due to the absence of a true control, the contribution of soil P flux versus P from litter decomposition on the observed DOP in the outflow cannot be quantified.

Phosphorus storage in vegetation, in general, is regulated by plant characteristics such as biomass allocation, tissue nutrient concentration, and re-translocation prior to tissue (mainly leaves) senescence, and tissue turnover rate. Although rooted EAV and floating-leaved plants mine substantial quantities of P from the soil, they vary greatly in P release back to the water column. It has been well-documented that plants with low above- to belowground biomass allocation, high tissue-nutrient concentration, high nutrient re-translocation, and slow tissue turnover rate have greater nutrient storage (e.g., Chapin III 1980, Howard-Williams 1985, Bazzaz 1986, Killingbeck 1996, Miao 2004, Brix et al. 2010, Miao and Zou 2012). In the present study, the EAV and floating-leaved plants translocated approximately 40 to 80 percent of the plant P into belowground tissue prior to leaf senescence. However, the SAV plants in this study had minimal to no belowground storage component, and hence most of their tissue P was released into the water column via decomposition. Miao and Zou (2012) showed that white water lily had the most efficient nutrient storage (lowest ratio of above-/below-ground biomass and highest tissue P concentration) in comparison with EAV (including sawgrass, cattail, and spikerush) and SAV.

Internal nutrient loading primarily includes P release from soil and litter decomposition. The difference between the inflow and outflow P concentrations in this study suggests that P was released from the soil. The substantial initial soil P release observed in this study might have been largely due to three reasons. First, the extremely low-TP inflow water (collected from the outflow region of STA-1W) might have created a steep concentration gradient between the soil and overlaying water column. Second, the soils added to the mesocosms were loose, not root bound, and therefore were different from the soil of an STA at start-up, which might have allowed for greater release of soil P. Third, although the soils had a low TP concentration, they were stockpiled for one to two years in a dry condition. The oxidized soil might have had enhanced P release upon re-flooding. The soil source should be evaluated for future mesocosm studies.

Rooted and floating-leaved plants and EAV with efficient internal aerenchyma tissues can transport substantial oxygen from the atmosphere down into flooded soil and form an oxidized zone around the roots in an otherwise reduced environment (Dacey 1980, Carco et al 2006, Richards et al. 2011). The oxidized micro-zone can reduce soil P release by affecting redox processes and reducing anaerobic release of P (Al-P and Fe-P) from the sediment (Fisher and Reddy 2001, Mitsch and Gosselink 2007). Wetlands dominated with SAV, on the other hand, lack an oxidized micro-zone to minimize soil P release to the water column due to lack of or very limited belowground roots, although they achieve low TP levels via other mechanisms.

Decomposition is an important process contributing to both organic matter turnover and nutrient cycling in wetlands. The litter decomposition results indicate that SAV and water lily litter had higher mass-loss rates than sawgrass and cattail litters. This was similar to results found by Chimney and Pietro (2006), and Reddy and DeLaune (2008). For the Everglades and STA macrophytes, Newman et al. (2001) and Chimney and Pietro (2006) showed that the rates of litter decomposition and the degree to which litter is decomposed are primarily associated with tissue P, N, and C concentrations. In the present study, although the two SAV species exhibited high P concentrations, they had much lower total carbon and TOC concentrations, and hence the lowest C:P ratios in comparison with EAV and floating-leaved plants. This indicates that SAV may have lower structural carbon, such as lignin, and hence may decompose quicker, which may explain why the SAV litter decomposed much faster than the EAV plants evaluated.

Overall, the available information suggests that vegetation treatments differed in ecosystem processes associated with TP reduction performance. SAV has a lack of or very limited belowground roots that limit nutrient uptake and storage. Limited belowground roots may result in a greater release of P from the soil to the water column, a critical process affecting overall treatment performance in a low-P environment. In addition, SAV have a faster turnover and decomposition rate, which may lead to a greater P release to the water column. On the other hand, EAV-dominated macrophyte communities do not favor Ca-P co-precipitation and have less efficient water-column uptake when the plant canopy is dense. A dense EAV canopy can block light transmission, which greatly limits the growth of SAV, algae, periphyton, and microorganisms in the water column (Smith 1986, McCormick et al. 1997). Dense SAV beds also result in a pH increase that can stimulate Ca-P co-precipitation. Therefore, water-column SRP may not be removed as efficiently by EAV-dominated communities as by SAV-dominated communities. A mixed rooted floating-leaved plant/SAV community (like the Mixed Water Lily/SAV treatment) may have advantages over EAV or SAV monoculture communities such as (1) belowground roots and storage tissues minimizing P release from the soil, and (2) enhancement of chemical co-precipitation to remove SRP from the water column and increase P retention in the soil. In addition, the mixture of rooted floating-leaved plant and SAV community may improve the sustainability of SAV. Finally, some rooted floating-leaved plants may experience greater winter dieback than SAV. Thus, mixed floating-leaved plants and SAV may have a longer P performance period annually than monocultures of these plants.

A mixture of rooted floating-leaved plants and SAV may provide better P treatment than a monoculture of floating-leaved plants or SAV. This hypothesis could be further tested in the field. If the hypothesis is correct, then introducing rooted and floating-leaved macrophytes (including white water lily) into the downstream end of existing SAV cells to establish a mixture of vegetation may be a promising approach to further improve P reduction performance in SAV cells.

Recommendations

The results of this study indicated that the Mixed Water Lily/SAV treatment was the only treatment that sustained a period of good performance with 16 percent TP removal during the third year of the study. However, the duration of good performance was only seven months, after which export of TP was again observed from this treatment. The short period of good performance in this treatment might be due to the combined P removal mechanisms of rooted floating-leaved and SAV plants. In addition, the mixture of rooted floating-leaved plants and SAV exists in several SAV cells in the STAs. Therefore, it may be appropriate to conduct further studies focusing on the P treatment performance of a mixture of white water lily [and other rooted floating-leaved plants, like the American lotus (*Nelumbo lutea*)] and SAV in comparison to monocultures of SAV. A future study might be implemented in the STAs with an existing mixture of these plants or in a better-controlled environment.

Overall, the results suggested that in all treatments initial soil P release elevated the outflow TP. Therefore, the soil characteristics should be carefully evaluated for future mesocosm studies, particularly with surface waters with very low P in order to minimize the interference of high soil P flux in study treatments.

Another recommendation related to SAV communities is their succession and sustainability. A shift in SAV species and SAV turnover was observed during the course of this study, which is similar to what has been observed in full-scale SAV cells. Future studies on population dynamics of major SAV species in the STAs may be warranted, including determining the major reasons that cause healthy SAV communities to crash.

To improve P removal treatment in the STAs with surface waters with very low P, it may be necessary to further determine (1) the magnitude of the dominant P species released from the soil in the major types of macrophyte communities and how these change as litter decomposes, and (2) the sources of P species in outflow of full-scale EAV and SAV cells. These are the subjects of a separate current study in the STAs.

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