

Implementation of Floating Aquatic Vegetative Tilling Technology in the Caloosahatchee River Watershed

Task 20 Deliverable: Final Report

Site 1

Prepared for:

**Florida Department of Agriculture and Consumer Service
(FDACS)**

Contract #021121

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August 18, 2015

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Executive summary

Water & Soil Solutions, LLC (WSSLLC) has deployed an approximately 523-acre Floating Aquatic Vegetative Tilling (FAVT) wetland treatment facility in the Hendry-Hilliard Water Control District (HHWCD) in the East Caloosahatchee River Sub-Watershed southwest of Lake Okeechobee. The purpose of the project is to cost effectively remove phosphorus (P) and nitrogen (N) from regional canals, including surface waters of the HHWCD and the Caloosahatchee River (C-43 Canal), using the patented FAVT technology in a man-made flow-through treatment marsh.

FAVT systems utilize a novel approach to enhance N and P removal from surface waters. The technology uses the direct assimilation of nutrients from the water column through the use of floating plant roots (as compared to plants rooted in the soil) and, rather than periodically harvesting the plants (which is costly and inefficient due to the high water content of the vegetation), all of the biomass is rapidly incorporated directly into the soil via tilling during the dry season. FAVT systems therefore operate similarly to a conventional treatment wetland by storing P in the soil, but they accomplish P removal more efficiently and at a significantly faster rate. At this site, FAV species common to the adjacent canals, namely *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce), are utilized in the front two cells, while *Najas guadalupensis*, *Utricularia* spp., and other species of submerged aquatic vegetation (SAV) dominate the back end (Cell 3) as a final, “polishing”, component of the FAVT system.

The system became fully operational in September 2014, receiving regional source water and discharging through the outflow culverts beginning 9/15/14. Subsequent monitoring of system inflow and outflow water chemistry was conducted on a weekly basis. Monitoring results through June 2015 show that system outflow TP concentrations were consistently lower than inflow TP concentrations, despite highly variable inflow TP concentrations ranging as low as 35 µg/L, during the dry season, and as high as 325 µg/L, during the wet season. Outflow TP concentrations ranged from 22 to 62 µg/L, with the highest concentrations occurring during the first two months of system discharge (September-October 2014). During the remainder of the monitoring period outflow TP

concentrations became increasingly stable, averaging 29 µg/L and ranging from 22 to 38 µg/L. Overall mean TP concentrations in the inflow and outflow streams were 74 and 33 µg/L, respectively. Soluble reactive P (SRP) concentrations were considerably reduced in the outflow stream, from an average of 24 µg/L at the inflow to 2 µg/L at the outflow. On average, SRP accounted for 33 percent of TP in the inflow stream, but only 7 percent of TP in the outflow stream. The reduction in SRP concentration is assumed to be largely attributable to plant uptake. Dissolved organic P (DOP) and particulate P (PP) concentrations were also effectively reduced by the FAVT system.

TP monitoring at the inflow and outflow of each of Cells 1, 2 and 3 beginning in November 2014 indicated that most of the P removal has occurred across Cells 1 and 2. Furthermore, TP concentrations at the Cell 1 and 2 outflows decreased over time, while concentrations at the Cell 3 outflow showed little or no overall change over time. This could be due to a number of factors, including release of soil P to the overlying water in Cell 3, enhanced by decreasing Cell 2 outflow concentrations, and a limited capacity for P removal via plant uptake during establishment of robust SAV communities in Cell 3.

Internal monitoring of TP and SRP at 15 sites within Cells 1 and 2 during June 2015 indicated that P removal within the wetland followed a predictable spatial pattern, with gradual reductions in TP concentrations occurring in Cell 1 as distance increased from the inflow through the cell. TP levels in the back two-thirds of Cell 2 were extremely low, at 15 µg/L or less. The observed spatial trends in TP suggest that much of the pumped inflow water preferentially passes along the eastern side of Cell 1. The bioavailable phosphorous (SRP) results, many of which were below the detection limit of 2 µg/L, also support this hypothesis, with highest SRP levels observed along the eastern portion of the flow path. Plant cover and density also may affect the observed spatial patterns in P removal, and this will be a topic of future assessment at this facility.

Total N (TN) concentrations were not effectively reduced during the 2014-2015 monitoring period. The overall mean outflow TN concentration was slightly higher than mean inflow TN (1.48 vs. 1.39 mg/L, respectively). Nearly all of the TN load to the system was in organic form, representing a substantial pool of N that is not readily bioavailable.

Although some decomposition of organic N, and subsequent removal of inorganic N, is likely occurring in the water column, it is also possible that release of N from the soil is serving to maintain elevated N concentrations in the overlying water during the early stages of operation of this recently-flooded system. Water chemistry monitoring during the upcoming year will likely provide a greater understanding of the short- and long-term N removal capacity of the treatment system.

In order to evaluate vegetation growth and health, visual assessments of speciation and areal coverage (i.e., relative abundance) of FAV (Cells 1 and 2) and SAV (Cell 3) were performed on a routine basis at stations located on a pre-determined grid pattern across Cells 1 (21 stations), 2 (33 stations) and 3 (53 stations). These surveys were conducted monthly from October 2014 through June 2015. Results of the surveys indicated that dense growth of water hyacinth increased in coverage from 56% to 95% in Cell 1 and from 33% to 93% in Cell 2, with a slight decrease in coverage observed at the end of the monitoring period. Dense growth of *Pistia* occurred at 22% of the stations in Cell 1 and 13% of stations in Cell 2 during the October survey, and reached a maximum coverage of only 30% in Cell 1 and 19% in Cell 2, in February and March, respectively, before decreasing slightly during the remainder of the period. Among eight SAV species monitored in Cell 3, *Utricularia* and *Najas* (during later surveys) were by far the most commonly occurring. *Utricularia* maintained a relatively dense growth across the majority of Cell 3 during the entire monitoring period, while *Najas* increased from sparse coverage in October to relatively dense growth in 70% of Cell 3, mostly toward the inflow and outflow regions. *Hydrilla verticillata* appeared in November, increasing in coverage slowly through early spring, and more rapidly thereafter, and attaining an estimated coverage of 45% of the total area of the Cell 3 during the June 2015 survey. Continued monitoring of both SAV and FAV will be performed in FY 2016, in order to enhance system operations and management practices, and to facilitate our understanding of spatial and temporal patterns in TP removal performance.

Introduction

Water & Soil Solutions, LLC (WSSLLC) has completed the first full year of operation of an approximately 523-acre Floating Aquatic Vegetative Tilling (FAVT) wetland treatment facility in the Hendry-Hilliard Water Control District (HHWCD) in the East Caloosahatchee River Sub-Watershed southwest of Lake Okeechobee. The watershed is located in the Northern Everglades west of Lake Okeechobee. The project site is part of a large parcel of private land (Sections 18 & 19/ Township 44 South/ Range 32 East) on the southern side of the Caloosahatchee River (Figure 1). The purpose of the project is to cost effectively remove phosphorus (P) and nitrogen (N) from regional canals, including surface waters of the HHWCD and the Caloosahatchee River (C-43 Canal), using the patented FAVT technology in a man-made flow-through treatment marsh. This document encompasses the Final Report for the project period July 1, 2014 through June 30, 2015.

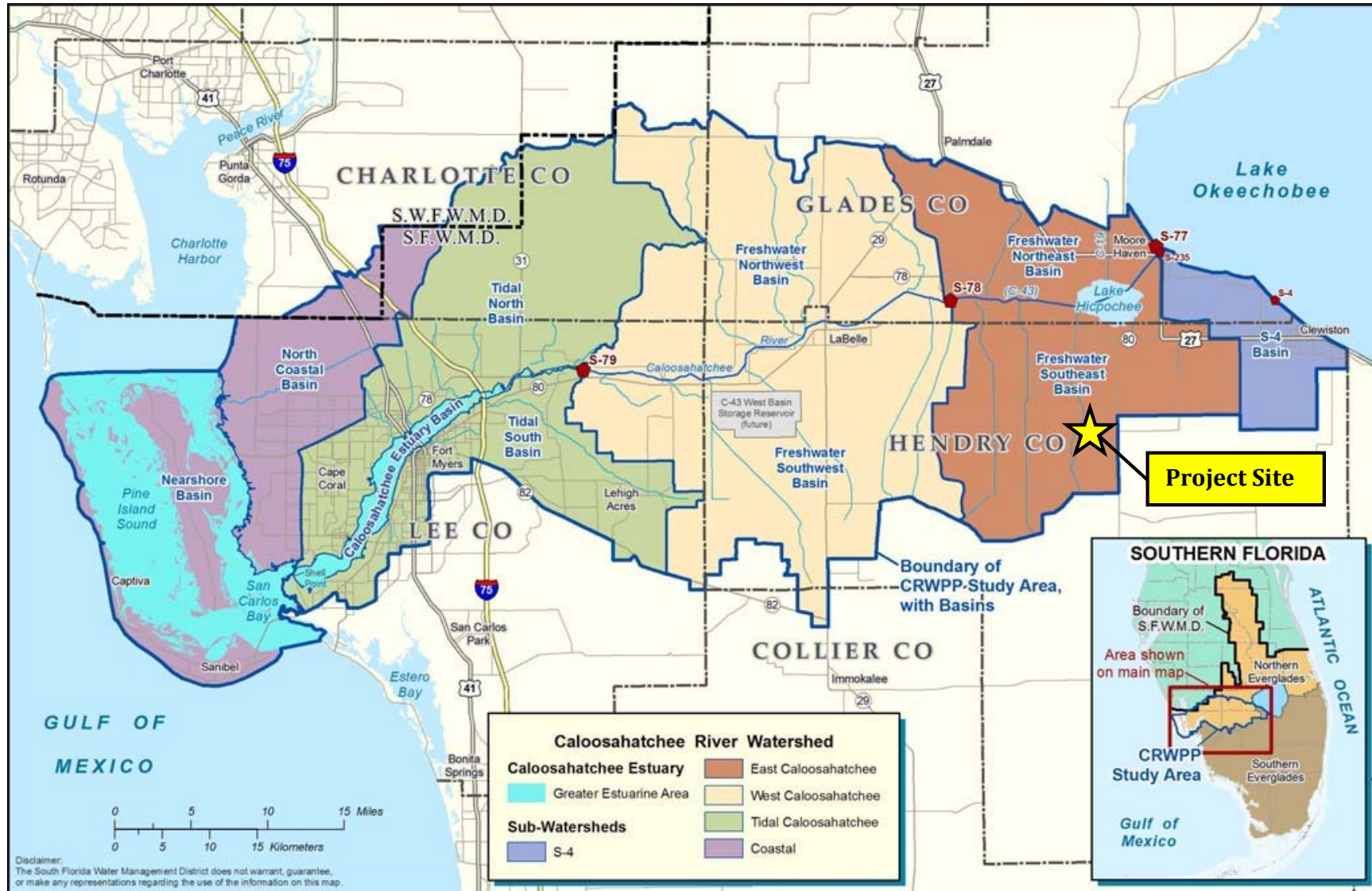


Figure 1. Project location within the watershed (Source - Caloosahatchee River Watershed Protection Plan January 2009).

FAVT System Unit Processes

FAVT systems utilize a novel approach to enhance N and P removal from surface waters. Many species of FAV, such as water hyacinth, are known to rapidly assimilate N and P, but their high nutrient uptake rate can only be sustained if the plants are maintained at an optimal density. The ideal coverage is usually achieved by periodic harvesting; however, since FAV are predominantly water, mechanical removal of the biomass is costly and inefficient. FAVT overcomes these constraints by using the following operational approach: (1) the FAV wetland is operated for an initial growing season, during which time the FAV assimilate nutrients and grow to a high density; (2) the wetland is drained during the dry season, thereby stranding the FAV on the soil; (3) after a natural drying process, the plant material is tilled into the soil together with its associated nutrients; (4) the wetland is reflooded; and (5) FAV that are stored in deeper zones are used to repopulate the wetland for the subsequent growth period. During this post-tilling process, water is held in the wetland without discharge for several weeks to provide time for the vegetation and water column nutrient levels to equilibrate. It is anticipated that tilling will be performed on a yearly basis (approximately) at the Project site.

FAVT systems therefore operate similarly to a conventional treatment wetland by storing P in the soil, but they accomplish P removal more efficiently and at a significantly faster rate. The technology uses the direct assimilation of nutrients from the water column through the use of floating plant roots (as compared to plants rooted in the soil), and all of the biomass is rapidly incorporated directly into the soil through tilling. The process thereby results in a reduction of up to 80% of land needed for treatment as compared to traditional wetland treatment systems. It is expected that the FAVT systems will provide P reductions in the range of 3 to 15 g P/m²-yr, depending on the growth rate of the FAV, which will be linked to factors such as the P loading rate, speciation of P in the inflow waters, and availability of inorganic N and other macro- and micro-nutrients in the inflow waters. Similarly, N removal can be extremely high in FAV systems (up to 250 g N/m²-yr) when the supply of inorganic N is high in the inflow waters. An effort to estimate total P and N mass removal by the East Caloosahatchee River Project has not yet been made due to uncertainties of key underlying variables, such as water availability and nutrient levels.

At this site, FAV species common to the adjacent canals are being utilized, for example, *Eichhornia crassipes* (water hyacinth). Maximum growth (and P uptake) rates of this species occur in the summer, which coincides with the periods of highest runoff flows available for treatment.

As noted above, soils are the ultimate storage reservoir for P within all treatment wetlands. In conventional, emergent plant based wetlands such as the front-end cells of the Everglades Stormwater Treatment Areas (STAs), most of the soil P is associated with organic matter with lesser amounts associated with minerals such as calcium, aluminum and iron. An important aspect of the FAVT tilling approach is that it accelerates the rate of transferring not only P, but also organic matter and inorganic P-sorbing compounds into permanent storage.

Optimization & Monitoring Results

The goal of this optimization and monitoring effort is to collect, analyze and report water quality, water flow, vegetation and soil data to facilitate optimization of the East Caloosahatchee FAVT system in an environmentally sound manner and in accordance with established protocols.

Water Chemistry in the FAVT system

The system became fully operational in September 2014, receiving regional source water and discharging through the outflow culverts, beginning 9/15/14. Subsequent monitoring of system inflow and outflow water chemistry was conducted on a weekly basis. Results of ongoing water quality monitoring are presented for the period 9/15/14 – 6/30/15.

Water samples collected during each event were analyzed for the parameters listed in Table 1, using standard methods of analysis. Dissolved organic P (DOP) and particulate P (PP) were calculated from TP, SRP and TSP ($DOP = TSP - SRP$ and $PP = TP - TSP$); total N (TN) was calculated as the sum of TKN and NO_x-N . pH was measured on site during each sampling event.

Additional weekly monitoring, for TP and pH only, was conducted at the outflows of Cells 1 and 2 (equivalent to the inflows of Cells 2 and 3, respectively), starting in November 2014. The objective of this supplemental monitoring is to evaluate water chemistry changes within each of the three system cells. For this purpose, the system inflow and outflow data represent the Cell 1 inflow and Cell 3 outflow, respectively.

During June 2015, internal monitoring of selected water quality constituents (e.g., total phosphorus [TP], soluble reactive P [SRP]) was performed to better characterize the spatial water treatment patterns within the floating aquatic vegetation (FAV) dominated portions of the wetland (i.e., Cells 1 and 2). The internal water sampling grid is shown in Figure 2.

Table 1. Analytical methods used for laboratory analysis of surface water sampled for the Caloosahatchee FAVT project. Method detection limits (MDL) are shown for each chemical parameter analyzed.

Parameter	Method	MDL
Total Phosphorus (TP)	SM4500-P F	3 µg/L
Soluble reactive P (SRP)	SM4500-P F/DBE SOP OPO4	2 µg/L
Total Soluble Phosphorus (TSP)	SM4500-P F	3 µg/L
Alkalinity	EPA 310.1	3 mg CaCO ₃ /L
Nitrate + nitrite (NO _x -N)	EPA/353.2/SM4500 NO ₃ -F	0.003 mg/L
Total ammonia (NH ₃ +NH ₄)	EPA 350.11	0.020 mg/L
Total Kjeldahl Nitrogen (TKN)	EPA 351.2	0.08 mg/L

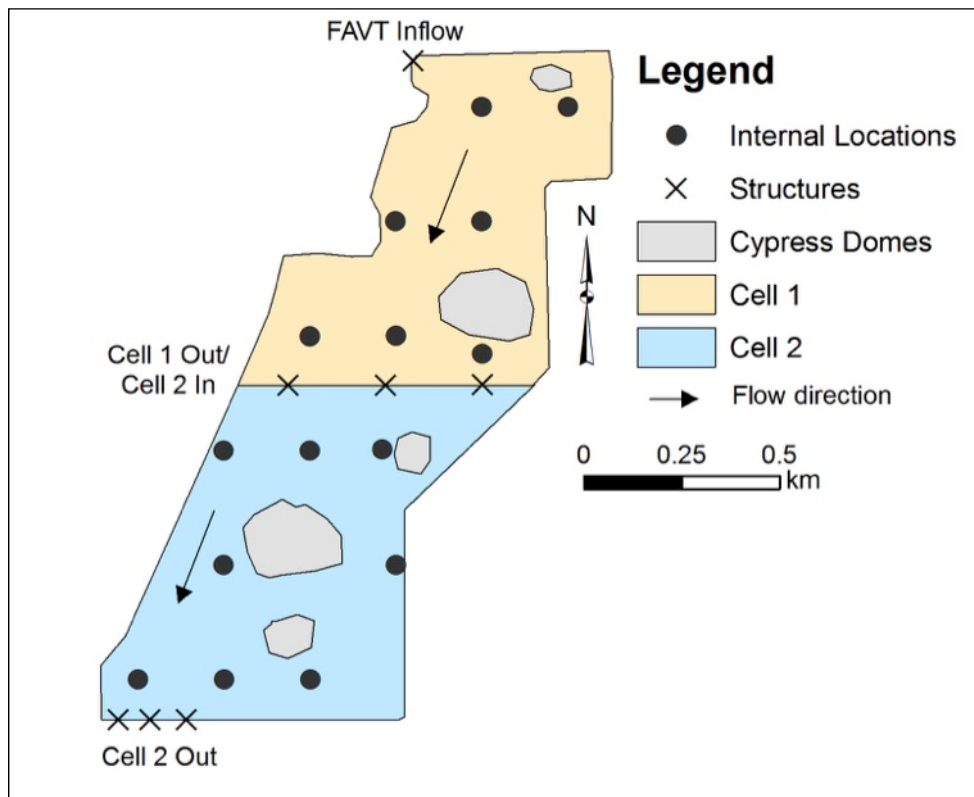


Figure 2. Internal water quality sampling locations in Cells 1 and 2 of the FAVT facility during June 2015.

Characterization of inflow and outflow water chemistry

During the September 2014 – June 2015 monitoring period, system outflow TP concentrations were consistently lower than inflow TP concentrations (Figure 3). Inflow TP concentrations were highly variable, ranging as low as 35 µg/L, during the dry season (February 2015), and as high as 325 µg/L, during the wet season. Outflow TP concentrations ranged from 22 to 62 µg/L, with the highest concentrations occurring during the first two months of system discharge (September-October 2014). During the remainder of the monitoring period outflow TP concentrations became increasingly stable, averaging 29 µg/L and ranging from 22 to 38 µg/L. Overall mean TP concentrations in the inflow and outflow streams were 74 and 33 µg/L, respectively.

Soluble reactive P concentration was considerably reduced in the outflow stream, relative to inflow concentration (Figure 4). Inflow SRP concentrations averaged 24 µg/L, but ranged widely, from 6 to 171 µg/L, during the monitoring period. In contrast, outflow SRP concentrations were consistently below 10 µg/L, ranging from non-detectable (<2 µg/L) to 7 µg/L and averaging 2 µg/L. On average, SRP accounted for 33 percent of TP in the inflow stream, but only 7 percent of TP in the outflow stream. The reduction in SRP concentration is assumed to be largely attributable to plant uptake.

Concentration of DOP, which is not readily available for plant uptake, was slightly lower in the outflow stream than in the inflow stream during most of the monitoring period (Figure 5). The overall mean inflow DOP concentration was 23 µg/L, compared with an outflow mean concentration of 15 µg/L. Inflow DOP concentrations were considerably more variable, ranging from 10 to 66 µg/L, relative to outflow DOP concentrations, which ranged from 8 to 25 µg/L. On average, the proportion of DOP as a fraction of total P increased between the system inflow and outflow, from 32 to 46 percent of TP, reflecting the lower bioavailability of DOP versus SRP.

Particulate P concentrations decreased between the system inflow and outflow during the majority of the monitoring period (Figure 6), with inflow and outflow PP concentrations averaging 26 and 16 µg/L, respectively. Inflow PP concentrations were somewhat more variable, ranging from 8 to 172 µg/L, while outflow PP concentrations ranged from 2 to 40

µg/L. The stability in outflow PP concentration relative to inflow PP is indicative of effective settling of particulates over a wide range of inflow P concentrations.

During the September-June monitoring period, TN concentrations in the inflow and outflow streams were similar (Figure 7), reflecting little or no net removal of N during this period. Inflow TN concentrations ranged from 1.02 to 2.19 mg/L, while outflow TN concentrations were more variable, ranging from 0.93 to 2.30 mg/L. The overall mean TN concentration in the outflow stream was slightly higher than the mean inflow TN concentration (1.48 vs. 1.39 mg/L, respectively). Only a small fraction of the TN load to the system was in inorganic form, either as NO_x-N or ammonia-N (Figure 8 and Figure 9). The large fraction of organic N in the system inflow represents a substantial pool of N that is not readily bioavailable. Although mineralization of this organic N (decomposition of organic N to ammonia-N) is likely occurring within the wetland, it is also possible that a net efflux of soil organic N (including soil organic matter originating from manure) is occurring during the early stages of operation of this recently-flooded system. Within the much smaller inorganic N pool in the system inflow, there is evidence of depletion of NO_x-N either through plant uptake or denitrification, and ammonia-N via plant uptake or nitrification. Thus, it is likely that net removal of TN from the combined soil-water system has occurred, but that surface water TN concentrations have remained elevated due to continued soil N efflux. Water chemistry monitoring during the upcoming year will likely provide a greater understanding of the short- and long-term N removal capacity of the treatment system.

Alkalinity levels in the inflow water averaged 146 mg (as CaCO₃)/L and ranged from 114 to 188 mg/L, with no obvious seasonal trend observed over the course of the monitoring period (Figure 10). Outflow alkalinity ranged from 112 to 165 mg/L, and was alternately greater than or less than inflow alkalinity, though the overall mean value (141 mg/L) was similar to mean inflow alkalinity. Outflow pH was consistently higher than inflow pH (Figure 11), likely due in part to the consumption of dissolved CO₂ by submerged vegetation (SAV) in Cell 3 of the treatment system. Inflow pH ranged from 6.8 to 8.1 and averaged 7.3, while outflow pH ranged from 7.2 to 8.3 and averaged 7.7.

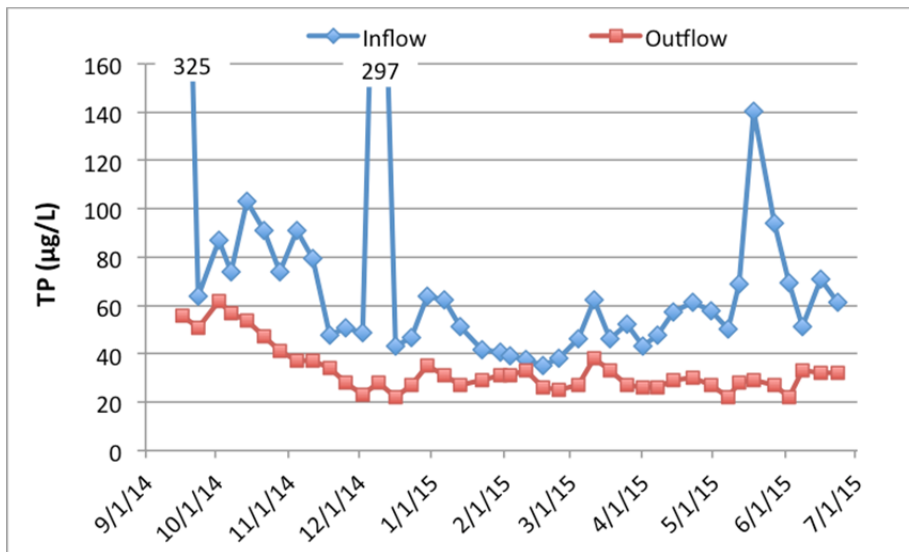


Figure 3. TP concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

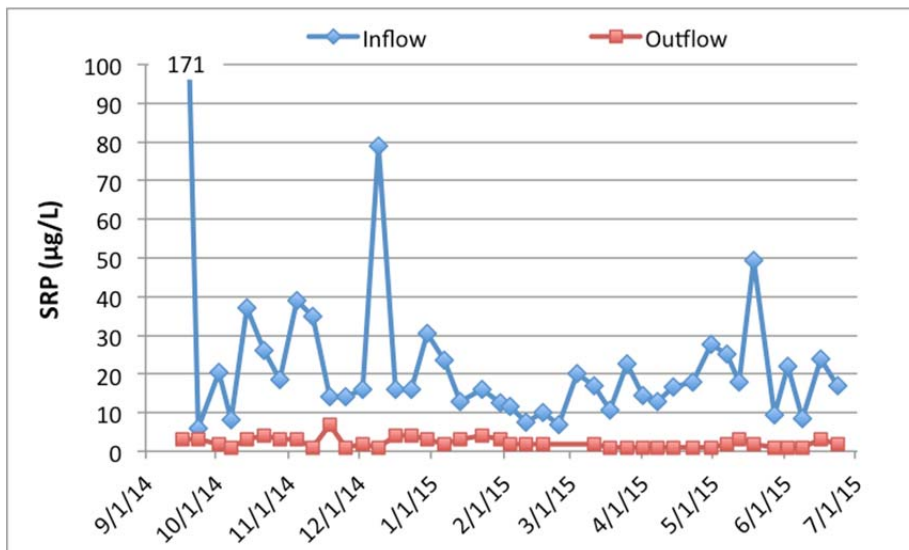


Figure 4. SRP concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

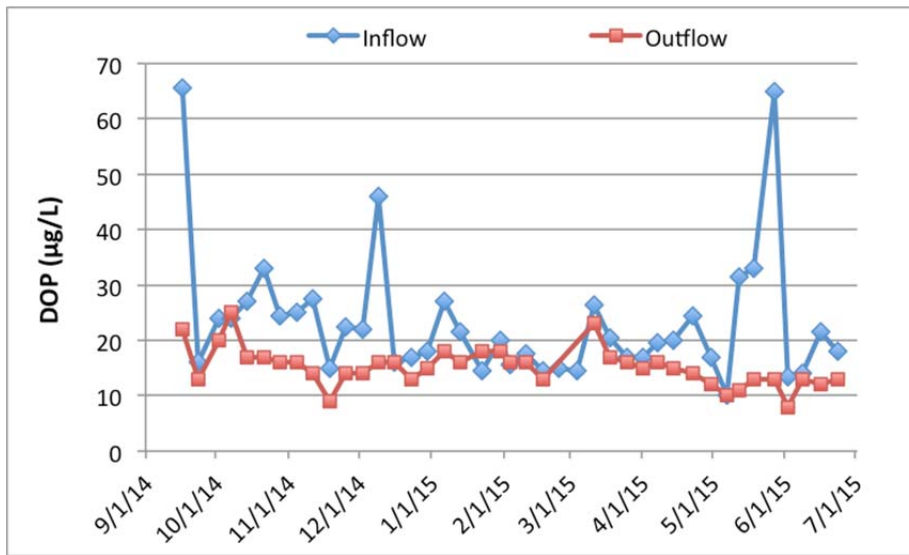


Figure 5. DOP concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

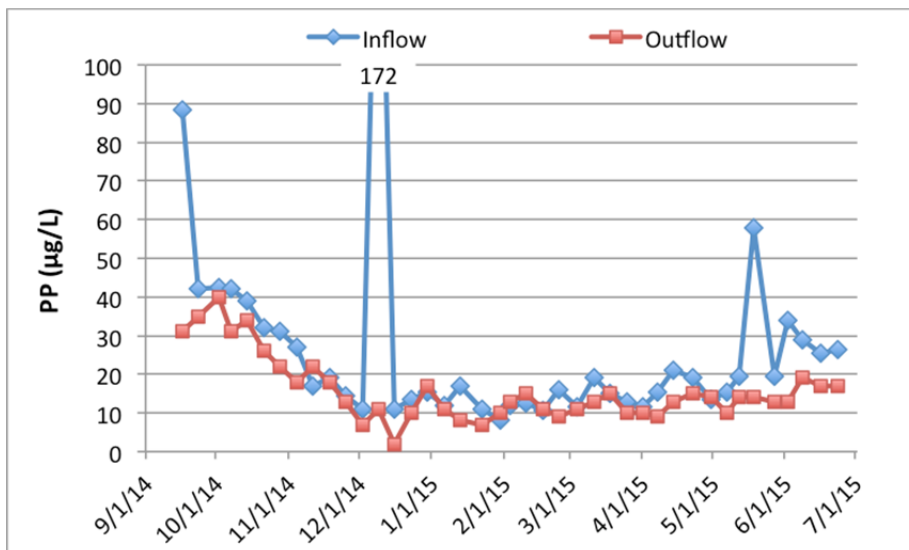


Figure 6. PP concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

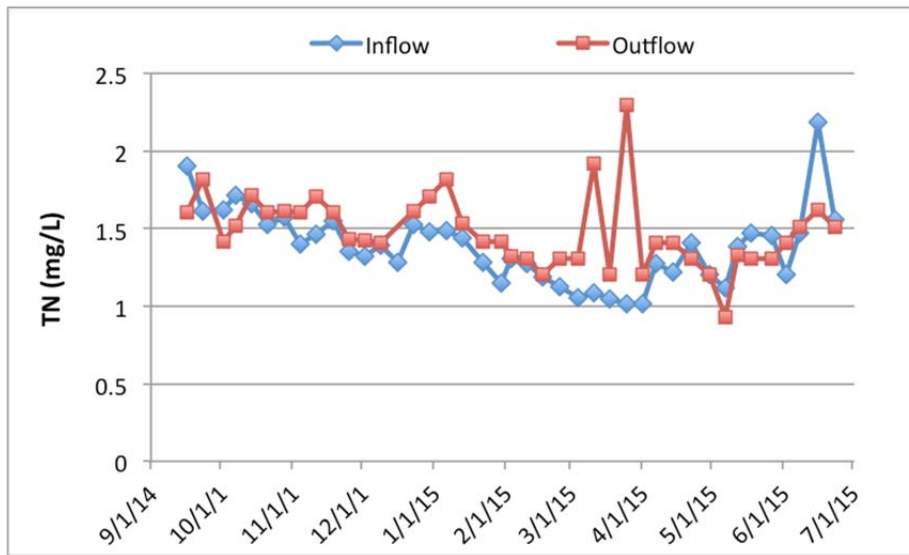


Figure 7. TN concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

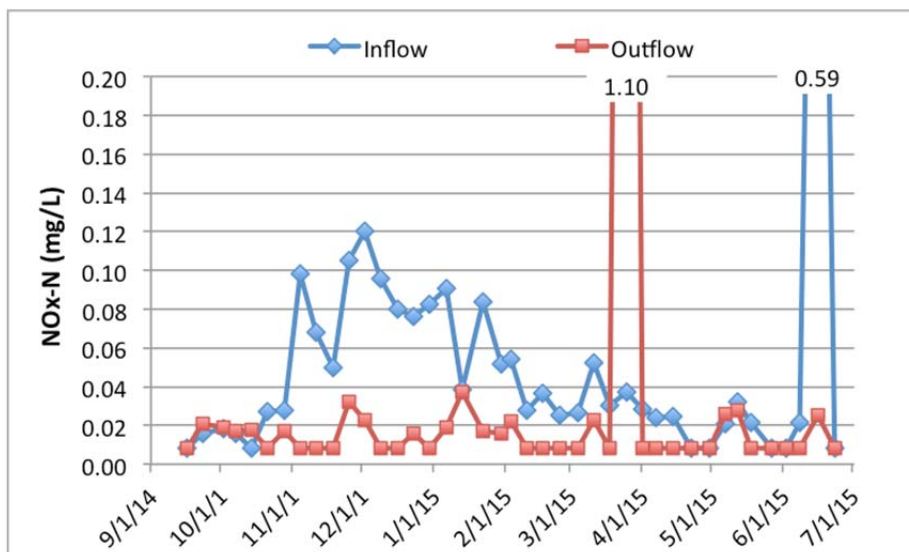


Figure 8. Nitrate+nitrite (NOx) concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

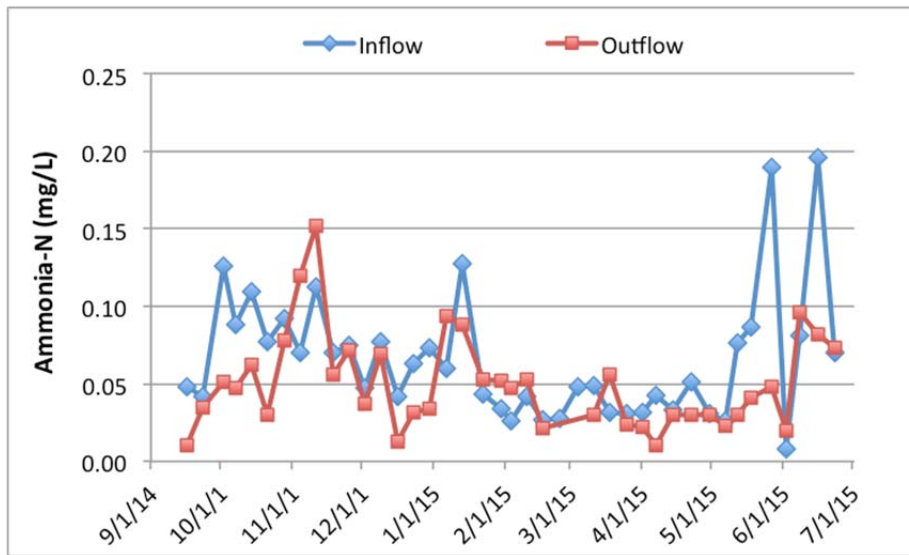


Figure 9. Ammonia-N concentrations in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

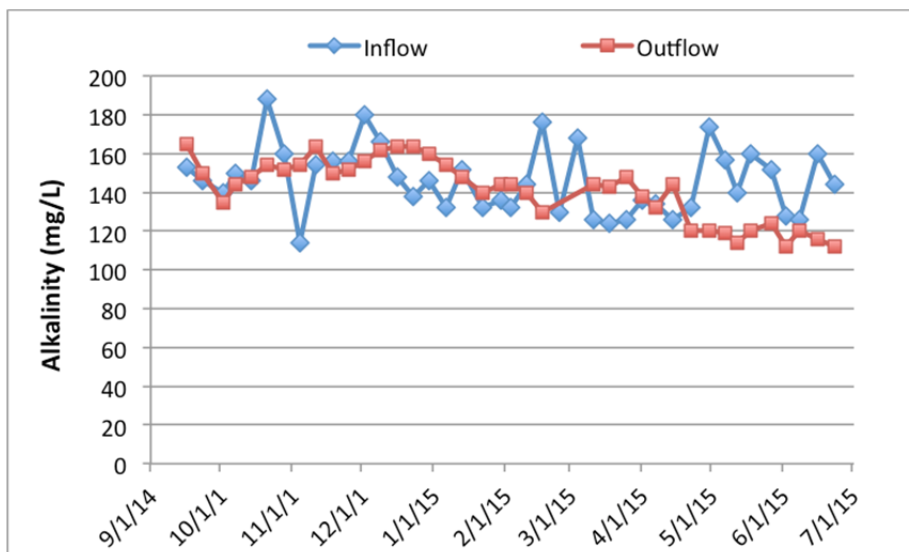


Figure 10. Alkalinity in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

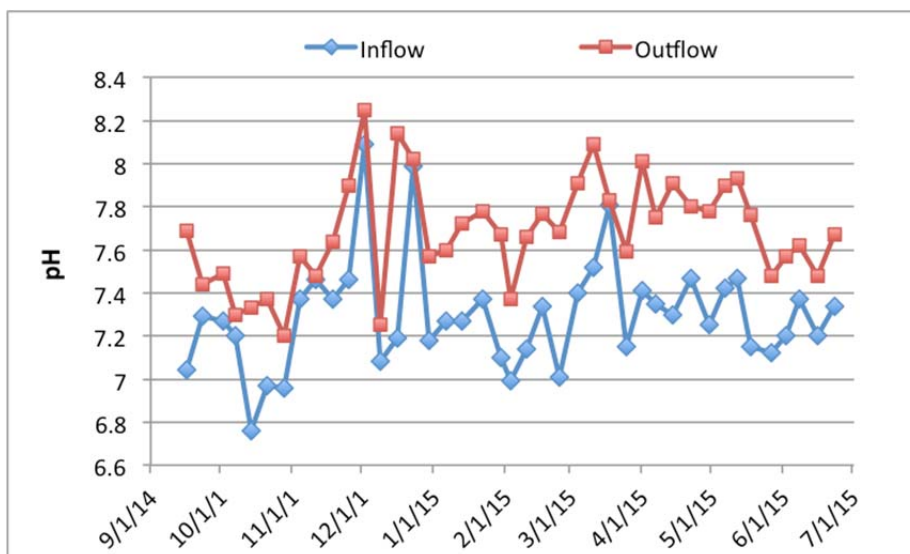


Figure 11. pH in the Caloosahatchee FAVT system inflow and outflow streams, for the POR 9/15/14 (initiation of system discharge) through 6/30/15. Monitoring was conducted on a weekly basis.

TP and pH monitoring at cell inflows and outflows

Water chemistry monitoring at the inflow and outflow of Cells 1 – 3 during November through June revealed somewhat different temporal trends in TP concentrations among cells. TP concentration in the Cell 1 outflow was similar to, or slightly lower than, TP in the Cell 1 inflow (system inflow) during much of the period from November to mid-February (Figure 12). During the remainder of the monitoring period, Cell 1 outflow TP showed a slight overall decrease, even as inflow TP tended to increase, suggestive of an increase in plant uptake of P during the 2015 growing season. The lowest TP concentrations in the Cell 1 outflow stream were measured at the end of the reporting period during June 2015, when concentrations averaged 21 µg/L and ranged from 17 to 27 µg/L.

Cell 2 outflow TP concentration decreased as Cell 2 inflow (same as Cell 1 outflow) TP concentration trended downward, with lower TP levels measured in the outflow during the majority of the monitoring period (Figure 13) reflecting additional P removal in Cell 2. As observed for the Cell 1 outflow, the lowest TP concentrations in the Cell 2 outflow occurred during the latter part of the monitoring period, in May and June. During those months, Cell 2 outflow TP averaged 14 µg/L and ranged from 12 to 18 µg/L.

In contrast to Cells 1 and 2, TP concentrations in the Cell 3 outflow (system outflow) showed no overall trend during the November – June period, as indicated earlier in this report, despite the decreasing trend in TP concentration in the Cell 2 outflow / Cell 3 inflow (Figure 14). This could be due to a number of factors, including diffusive flux of soil P to the overlying water, enhanced by decreasing Cell 2 outflow concentrations, and a limited capacity for P removal via plant uptake during establishment of robust SAV communities in Cell 3.

Monitoring of cell inflows and outflows also shows a minimal change in pH across Cell 1 (from inflow to outflow), although during June the Cell 1 outflow pH decreased to approximately 0.3 units lower than inflow pH (Figure 12). Conversely, pH increased across Cell 2, especially during the 2015 growing season, while both inflow and outflow pH trended downward over time (Figure 13). A further increase in pH was observed between the inflow and outflow of SAV-dominated Cell 3 throughout most of the monitoring period, contributing to the overall net increase in pH between the system inflow and outflow (Figure 14). Unlike Cells 1 and 2, the Cell 3 outflow pH did not exhibit a detectable temporal trend during the November-June monitoring period.

Figure 15 summarizes the overall linear trend in TP concentration along the system flow path during the November 2014 – June 2015 period, for which inflow-outflow TP was monitored simultaneously for Cells 1, 2 and 3. The mean system inflow TP concentration of 65 µg/L during that period decreased to a mean value of 38 µg/L at the Cell 1 outflow and further decreased to 27 µg/L at the Cell 2 outflow. The simultaneous decrease over time in Cell 2 outflow TP concentration and lack of change in Cell 3 outflow TP concentration (Figure 14) is reflected in Figure 15 as a slight increase in the overall mean outflow TP concentration (29 µg/L) as compared to mean Cell 2 outflow TP. Standard deviations of mean TP concentrations at the cell inflow and outflow points reflect a substantial decrease in temporal variability in TP concentrations along the system flow path, and are indicative of substantial attenuation within the system of highly fluctuating inflow TP concentrations observed during the monitoring period.

Changes in pH across sequential treatment cells are summarized in Figure 16. Mean pH values for the November-June period indicate the small decrease in pH observed between the system inflow and Cell 1 outflow, and subsequent increases in pH across Cells 2 and 3. The mean pH of 7.34 at the system inflow decreased slightly to a mean pH of 7.31 at the Cell 1 outflow, while the mean pH values for the Cell 2 and Cell 3 outflows were 7.53 and 7.74, respectively.

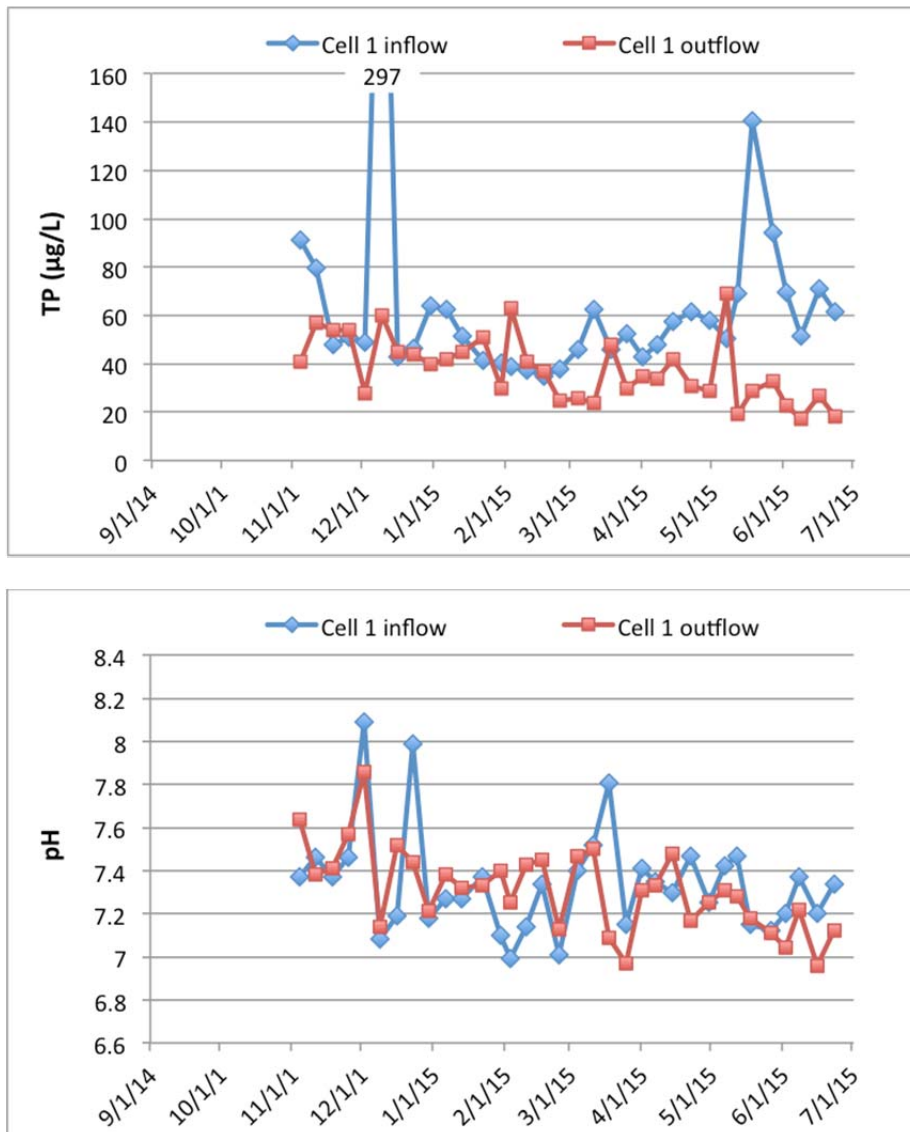


Figure 12. Surface water TP concentration and pH at the inflow and outflow of Cell 1 of the Caloosahatchee FAVT system. Monitoring was conducted on a weekly basis from November 2014 through June 2015.

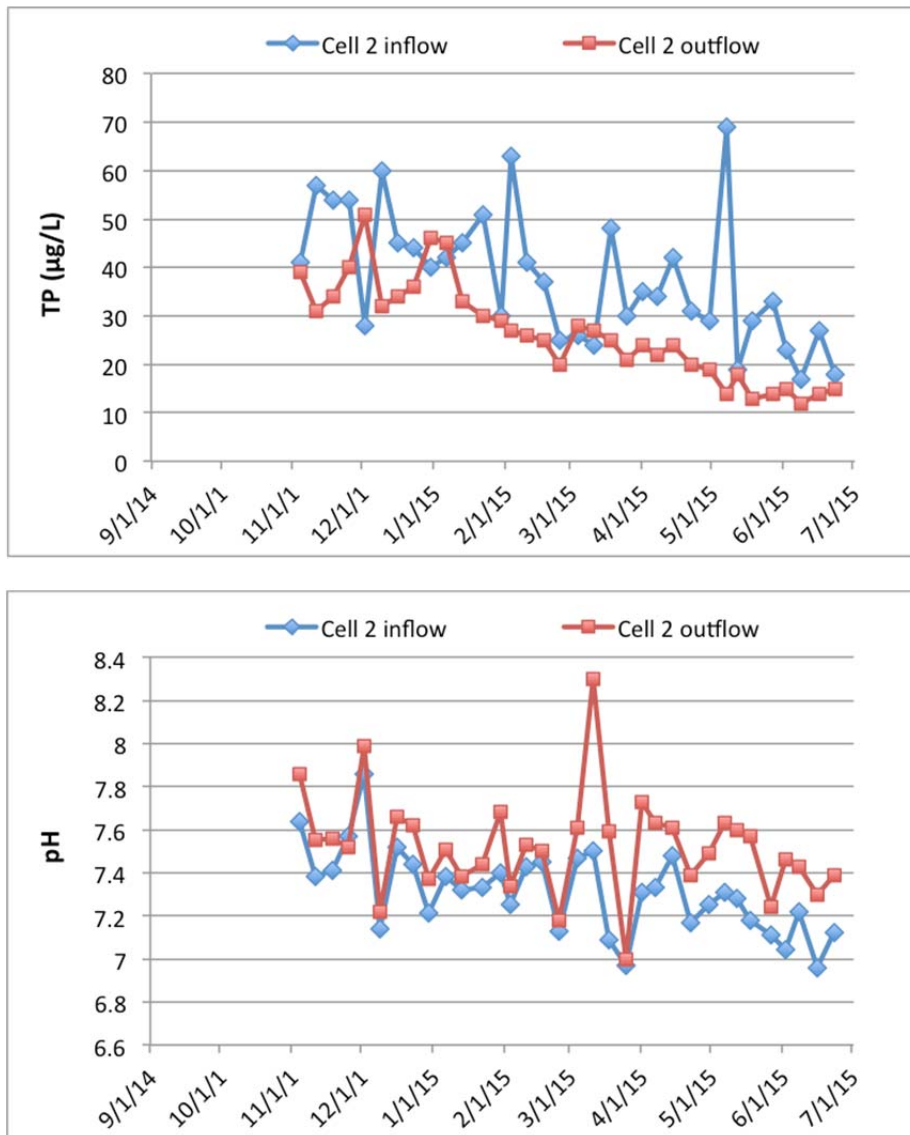


Figure 13. Surface water TP concentration and pH at the inflow and outflow of Cell 2 of the Caloosahatchee FAVT system. Monitoring was conducted on a weekly basis from November 2014 through June 2015.

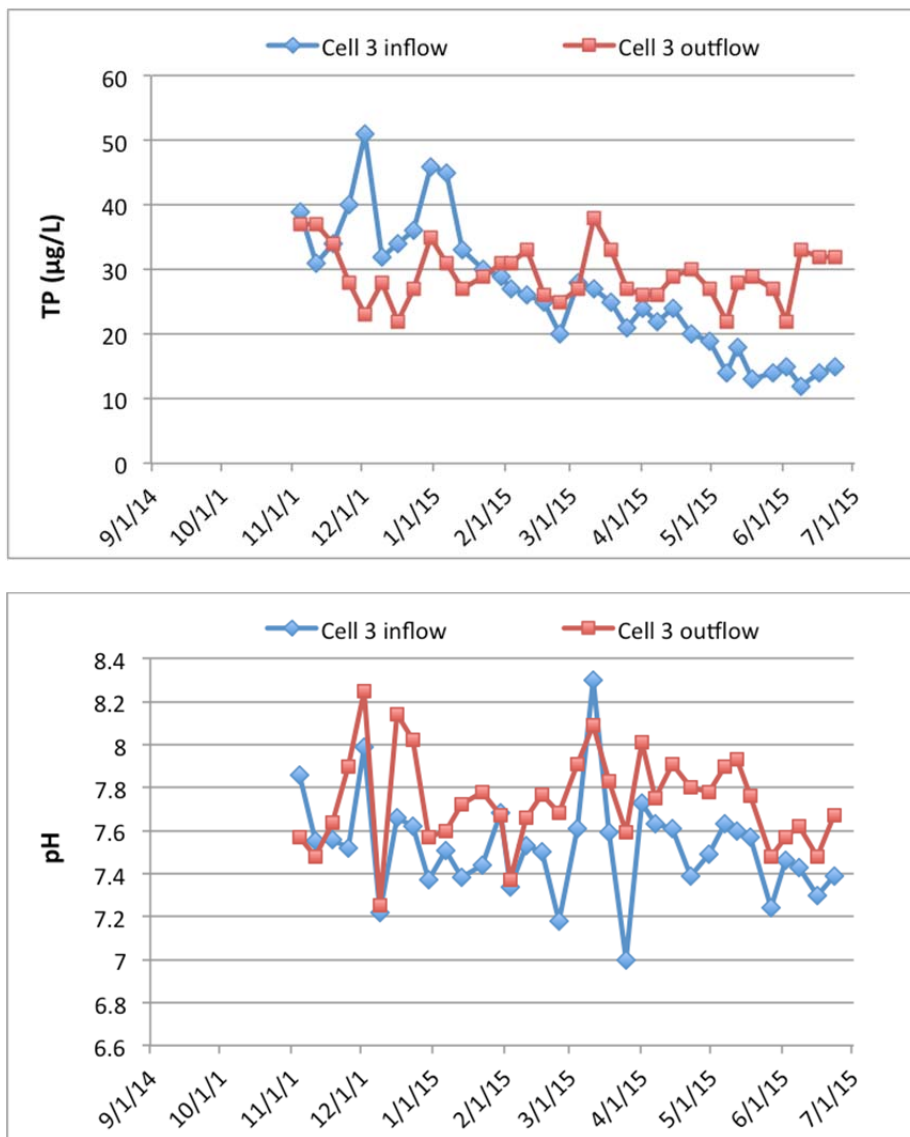


Figure 14. Surface water TP concentration and pH at the inflow and outflow of Cell 3 of the Caloosahatchee FAVT system. Monitoring was conducted on a weekly basis from November 2014 through June 2015.

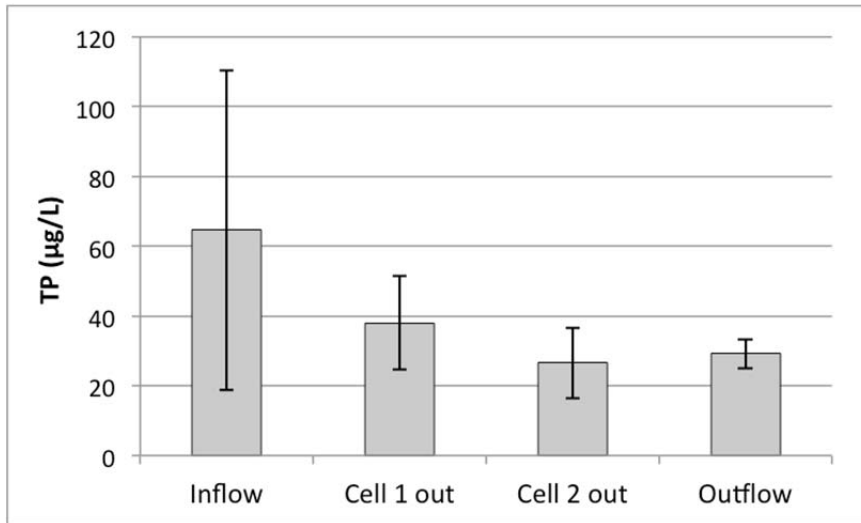


Figure 15. Mean surface water TP concentration (± 1 standard deviation) at the system inflow (=Cell 1 inflow), Cell 1 outflow (=Cell 2 inflow), Cell 2 outflow (=Cell 3 inflow), and system outflow (=Cell 3 outflow) of the Caloosahatchee FAVT system. Values were calculated from data collected during 34 weekly monitoring events from November 2014 through June 2015.

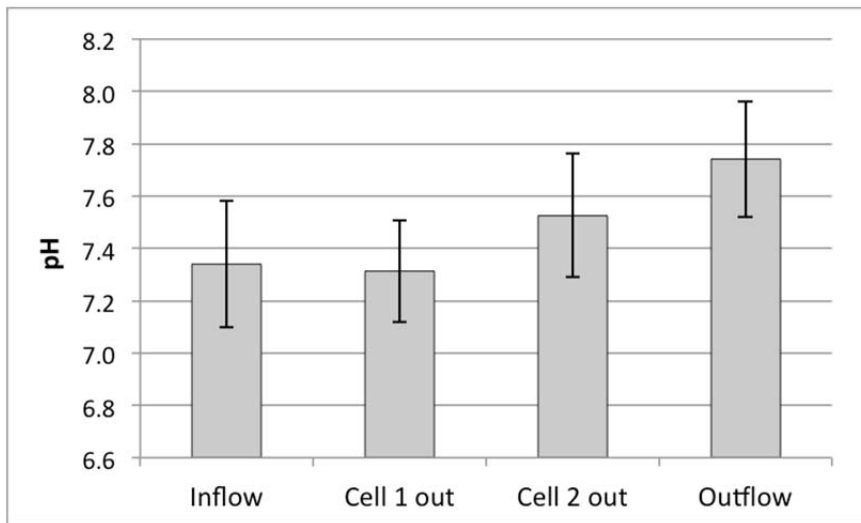


Figure 16. Mean surface water pH (± 1 standard deviation) at the system inflow (=Cell 1 inflow), Cell 1 outflow (=Cell 2 inflow), Cell 2 outflow (=Cell 3 inflow), and system outflow (=Cell 3 outflow) of the Caloosahatchee FAVT system. Values were calculated from data collected during 34 weekly monitoring events from November 2014 through June 2015.

Internal water chemistry monitoring of Cells 1 and 2

Results of internal monitoring of TP and SRP indicated that P removal within the wetland followed a predictable spatial pattern, with gradual reductions in TP concentrations occurring in Cell 1 as distance increased from the inflow through the cell. TP levels in the back two-thirds of Cell 2 were extremely low, at 15 µg/L or less (Figure 17). The observed spatial trends in TP suggest that much of the pumped inflow water preferentially passes along the eastern side of Cell 1. The bioavailable phosphorous (SRP) results, many of which were below the detection limit of 2 µg/L, also support this hypothesis, with highest SRP levels observed along the eastern portion of the flow path (Figure 17). Plant cover and density also may affect the observed spatial patterns in P removal, and this will be a topic of future assessment at this facility.

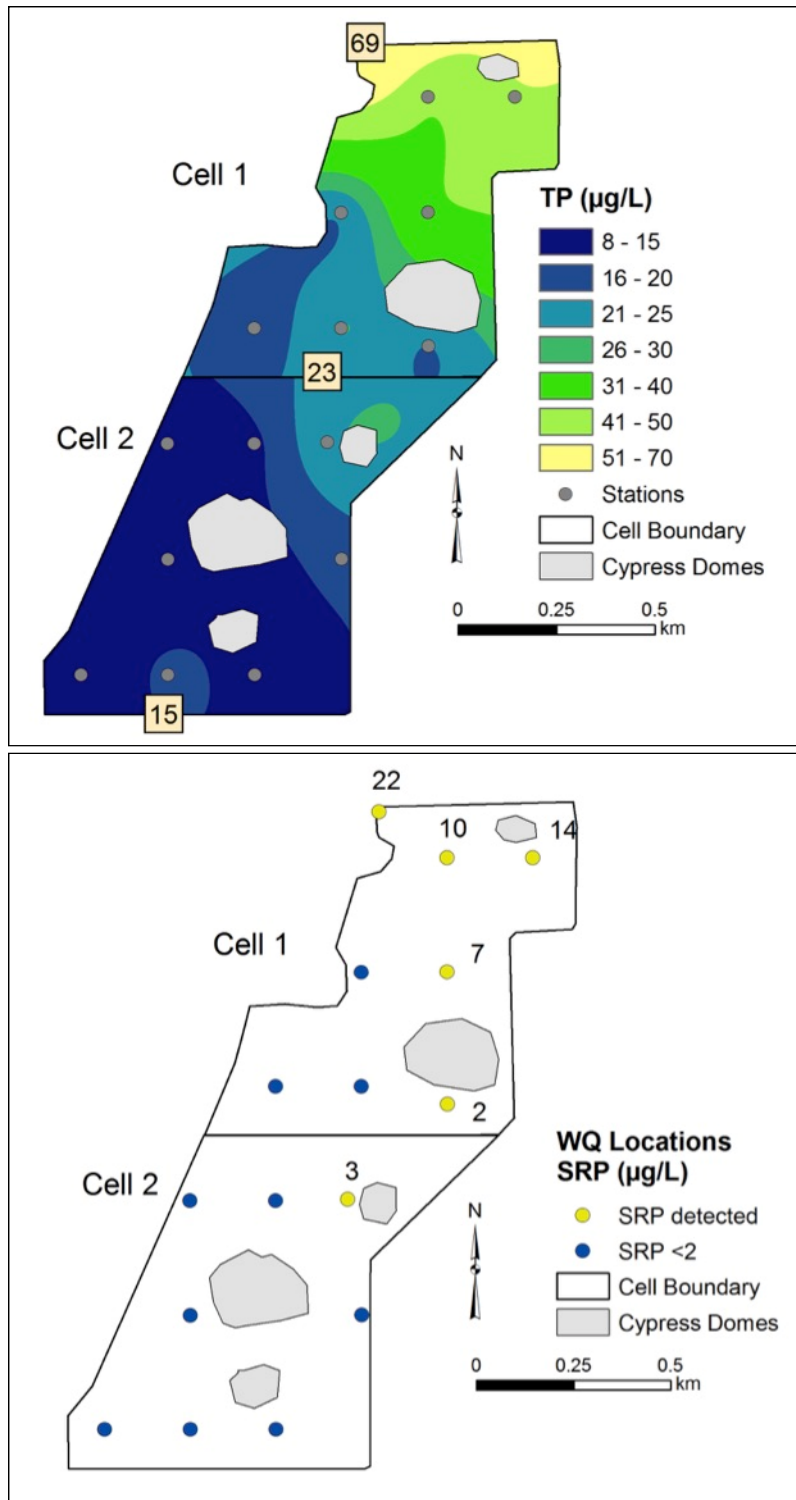


Figure 17. Interpolated spatial TP profiles in Cells 1 and 2 (top), and individual data points for SRP (not interpolated) for Cells 1 and 2 (bottom), for the internal water quality monitoring event in Jun 2015. Note that most SRP values in Cells 1 and 2 were below the detection limit, so no interpolation of these data was performed.

Floating and Submerged Aquatic Vegetation Surveys

Visual assessment of speciation and areal coverage (i.e., relative abundance) of FAV (Cells 1 and 2) and SAV (Cell 3) was performed on a routine basis at stations located on a pre-determined grid pattern across Cells 1 (21 stations), 2 (33 stations) and 3 (53 stations). These surveys were conducted monthly from October 2014 through June 2015. Survey dates were 10/28/14, 11/30/14, 12/30/14, 1/30/15, 2/24/15, 3/30/15, 4/30/15, 5/27/15, and 6/23/15.

During turbid water conditions or when SAV was not visible in the water column, the SAV assessment in Cell 3 was performed using a systematic collection method, whereby a garden rake was dragged three times along the bottom (~1 m distance) to collect the vegetation. Note that this rake method was not used if dense SAV was present. The coverage of each species was scored based on the five-point scale below. For SAV, each of these coverage categories included vegetation observed within the water column as well as any vegetation collected with the rake.

Vegetation coverage (relative abundance) categories were reported as follows:

- None
- Sparse: 0–10 percent
- Moderately Dense: 10–40 percent
- Dense: 40–80 percent
- Very dense: > 80 percent

Results of the FAV surveys reflect a monthly increase in moderately-dense to very-dense (hereafter referred to as “dense”) coverage of water hyacinth (Figure 18) in Cells 1 and 2 between late October 2014 and mid-February 2015 (Figure 19). In Cell 1, the extent of “dense” hyacinth coverage increased from 56 to 95 percent of stations during this time period, then remained relatively constant, at ca. 90 percent of stations, during the subsequent months, through June 2015. During the same time periods, the extent of “dense” hyacinth coverage in Cell 2 increased from 33 percent to 81 percent, then varied between 67 and 93 percent. During all but one monitoring event “dense” hyacinth coverage was greater in Cell 1 than in Cell 2, presumably due to the higher concentrations of plant-available nutrients in Cell 1. Hyacinth was present at all stations in Cell 1 during every

monitoring event, while in Cell 2 hyacinth was found at all stations during all but two events (Figure 20).

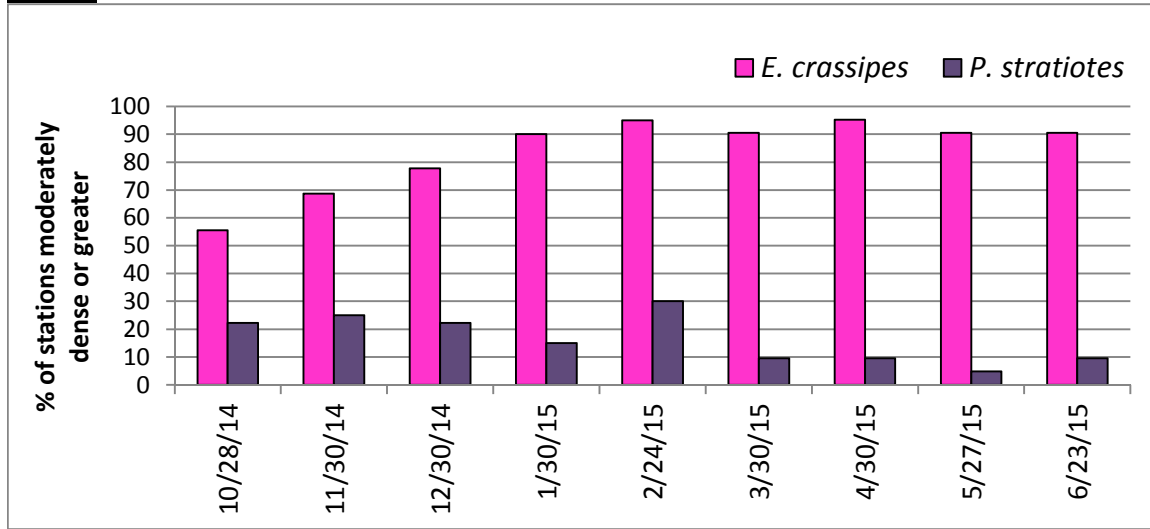
Coverage of *Pistia stratiotes* (water lettuce) was consistently lower than hyacinth coverage, in both cells (Figure 21). In Cell 1, “dense” coverage of *Pistia* was found at less than 30 percent of stations during the course of the monitoring period (Figure 19). The extent of “dense” coverage decreased to less than 10 percent during March through June in Cell 1. Initial “dense” coverage of *Pistia* was lower in Cell 2 than in Cell 1, but the extent of this coverage slowly increased to 19 percent by the end of March. During the subsequent monitoring events (April – June), “dense” *Pistia* coverage decreased to less than 15 percent. Presence of *Pistia*, at all densities, was initially high in Cell 1 (94 percent of stations), but the frequency of occurrence decreased steadily through March to 24 percent (Figure 20). *Pistia* was more frequently observed in Cell 2 than in Cell 1, primarily at very low densities, during all but the first monitoring event in late October, when it was found at only 20 percent of stations. During the last survey in the monitoring period (June 23), *Pistia* was present at 19 percent of stations in Cell 1 and 43 percent of stations in Cell 2.

The spatial distributions of hyacinth and *Pistia* are shown for bi-monthly intervals, from October 2014 through June 2015, in Figure 22. The time series of coverage maps at the top of the figure show the spread of moderate to very dense hyacinth toward the Cell 1 inflow and Cell 2 outflow during the October – April period. A slight decrease in coverage was observed in the western portion of Cell 2 during June, likely due to wind-induced movement of the plants. Relatively dense stands of *Pistia* filled in considerably from October through December toward the Cell 2 inflow and outflow regions (bottom of Figure 22), and during subsequent months the coverage varied in location and total extent. In contrast, *Pistia* coverage tended to recede toward the south in Cell 1, downstream from the system inflow.



Figure 18. Very dense mat of *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) in Cell 1

Cell 1:



Cell 2:

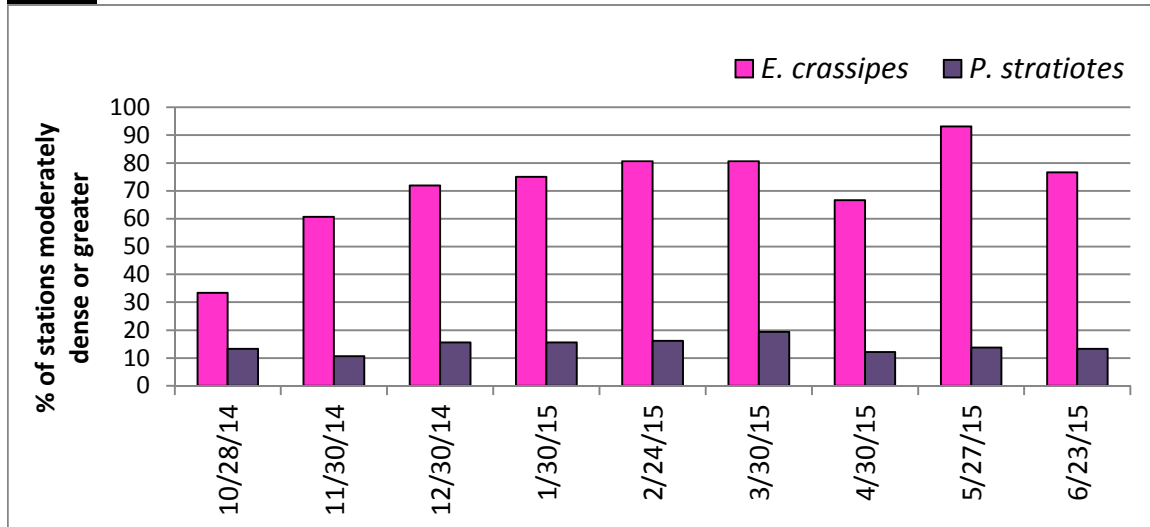
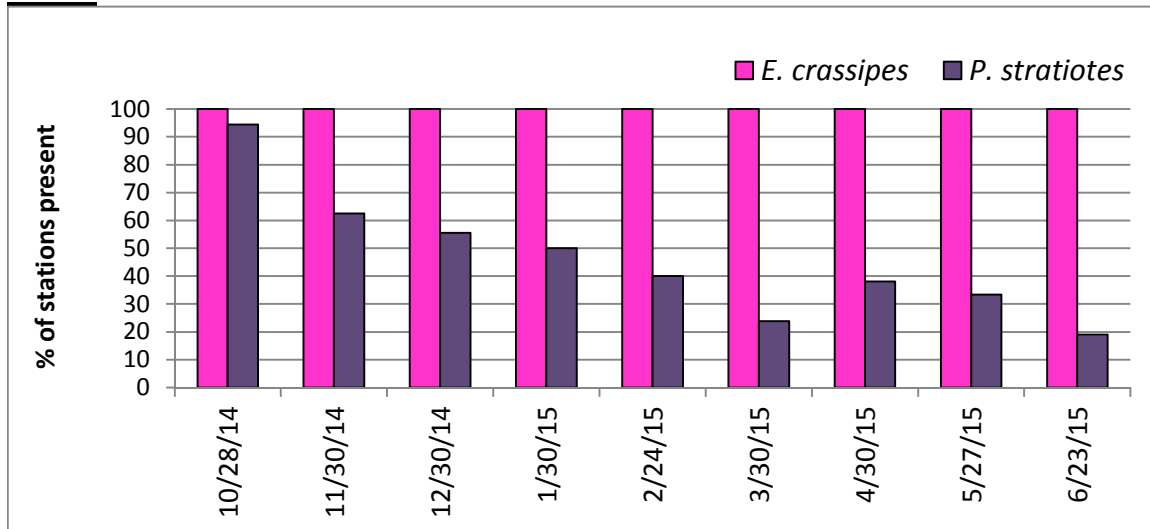


Figure 19. Time-series for FAV species within Cells 1 and 2 depicting the percent of stations that was moderately dense or greater for each species.

Cell 1:



Cell 2:

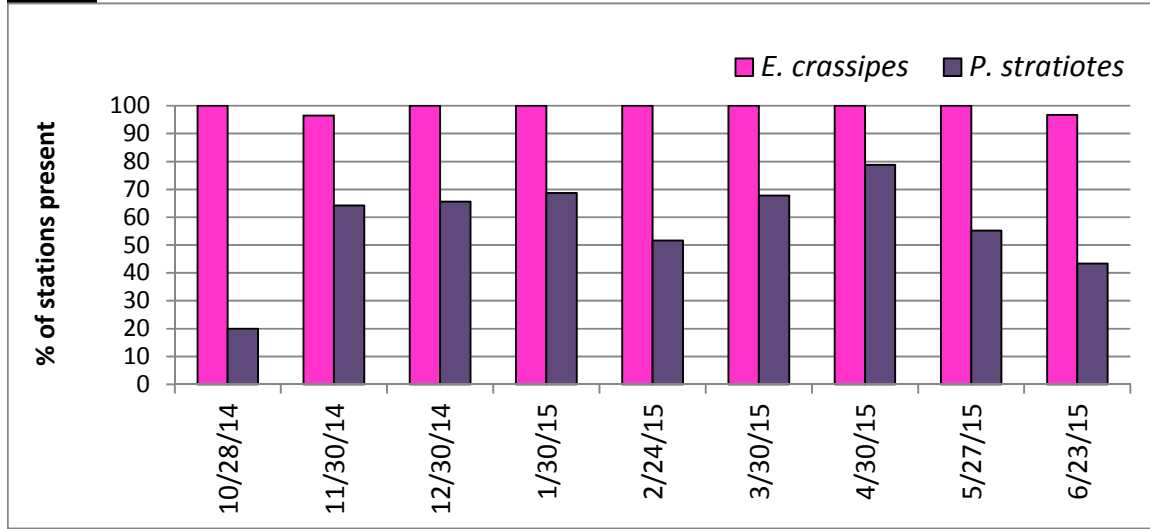


Figure 20. Time-series for FAV species within Cells 1 and 2 depicting the percent of stations that each species present.



Figure 21. Mixed species mat with *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) in Cell 1.

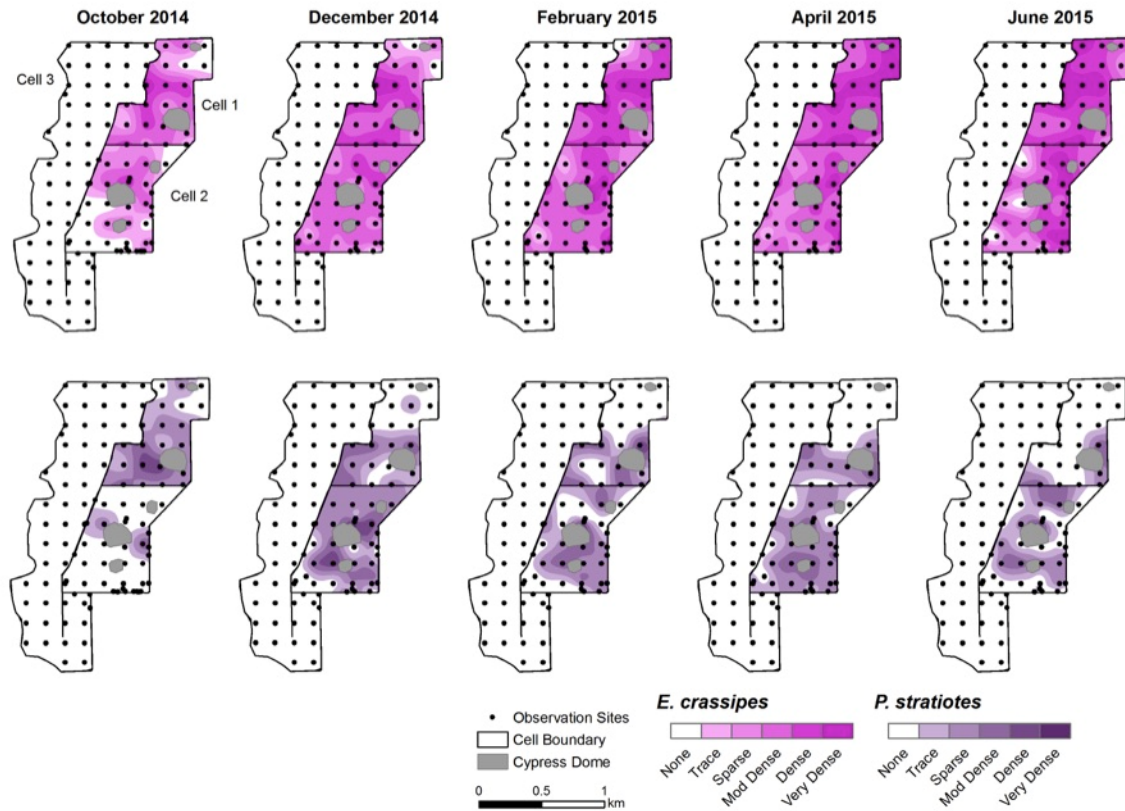


Figure 22. Relative cover of the FAV species *Eichhornia crassipes* and *Pistia stratiotes* in Cells 1 and 2 of the Caloosahatchee wetland during October and December 2014 and February, April, and June 2015. The black dots represent the observation locations, and the six semi-quantitative density categories are shown in the legend.

SAV survey results for Cell 3 revealed that, out of eight species reported during the monitoring period, only two species, *Najas* (Figure 23) and *Utricularia* (Figure 24), were commonly found (greater than 50 percent of stations) at a moderate or greater density, while a third species, *Hydrilla*, increased dramatically in coverage by the end of the period after being passively introduced (not inoculated) (Figure 25). Coverage of “dense” *Utricularia* varied between 42 and 70 percent, with no apparent temporal trend, during the period, while coverage of “dense” *Najas* showed an overall increase throughout the period, from 9 to 70 percent (Figure 26). “Dense” *Hydrilla* occurred at only a few stations during the first six monitoring events, but steadily increased in extent through June to ≥ 30 percent of stations. “Dense” *Bacopa* was observed within Cell 3 during all monitoring events, but at less than 15 percent of stations, on a consistent basis. Similarly, “dense” *Chara* was observed during all surveys, but at only a few stations. *Ceratophyllum*, *Ludwigia repens* and *Potamogeton* were found at higher densities at only a few stations and only during a subset of monitoring events.

Utricularia and *Najas* (during later surveys) were by far the most common SAV species in Cell 3, occurring at the majority of monitoring stations (Figure 27). *Bacopa* was consistently present in Cell 3 during all monitoring events, with a more limited extent of about 10 to 30 percent of stations. *Chara* was also present during all events, but at an even lower spatial extent of less than 10 percent. Overall presence of *Ludwigia* decreased, while *Ceratophyllum* and *Potamogeton* were relatively scarce throughout the monitoring period. In contrast, the occurrence of *Hydrilla* was extremely limited during October-February, the extent of coverage rapidly increased during the period April-June 2015, to 45 percent of stations.

The spatial extent of the most prevalent SAV species, *Najas*, *Utricularia* and *Hydrilla*, exhibited unique spatial patterns during the monitoring period (Figure 28). For example, *Najas* tended to colonize the inflow and outflow regions of Cell 3 over time, while *Hydrilla* proliferated primarily in the mid-region of Cell 3, toward the end of the monitoring period. *Utricularia* maintained a relatively consistent density across Cell 3 for the duration of the monitoring period, although the coverage became somewhat “patchy” near the Cell 3

inflow and outflow regions. Changes in density and species composition during the early stages of system operation will likely continue during the short term as water and soil chemistry across the system stabilize. In addition, inter-specific competition will play a large role in the eventual distribution of SAV species in Cell 3.

Continued monitoring of both SAV and FAV will be performed in FY 2016, in order to enhance system operations and management practices, and to facilitate our understanding of spatial and temporal patterns in TP removal performance.



Figure 23. *Najas guadalupensis* (southern naiad) growing near the outflow of Cell 3.



Figure 24. Mixed SAV assemblage containing *Utricularia* sp. (bladderwort) and other species in Cell 3.



Figure 25. *Hydrilla verticillata*, an invasive SAV species, at the Cell 2 culvert.

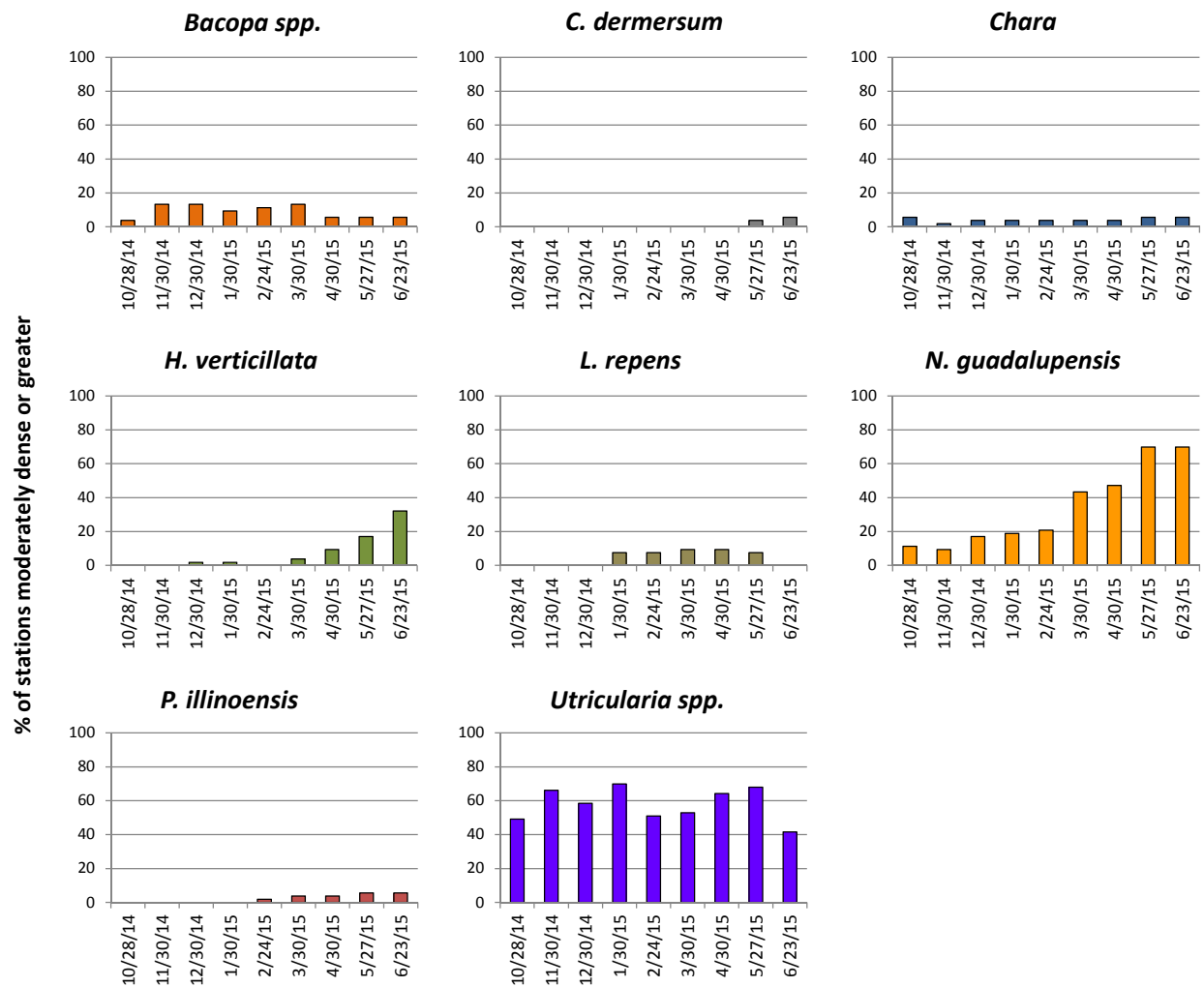


Figure 26. Time-series for SAV species within Cell 3 depicting the percent of stations that stations that was moderately dense or greater for each species.

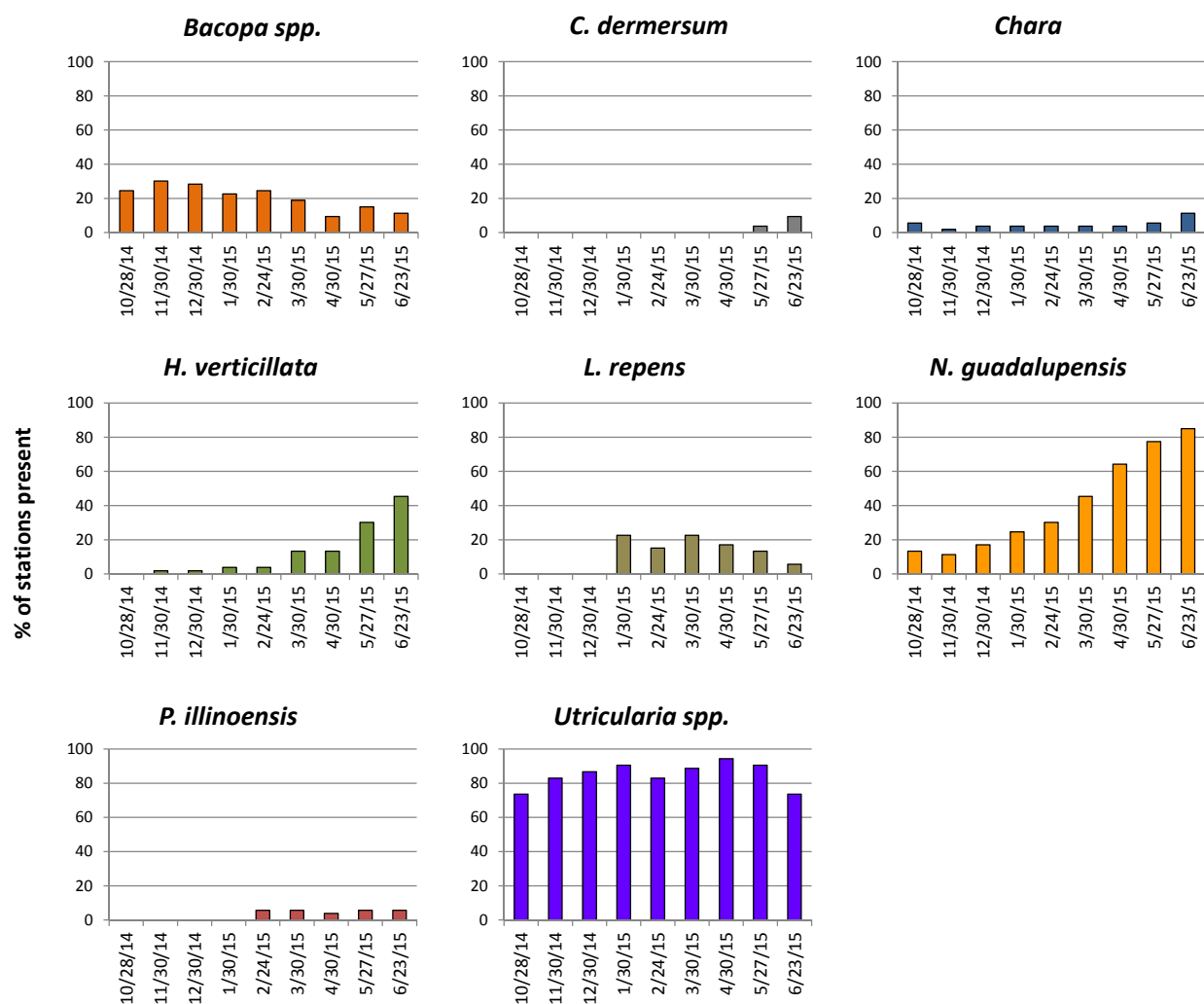


Figure 27. Time-series for SAV species within Cell 3 depicting the percent of stations that each species is present.

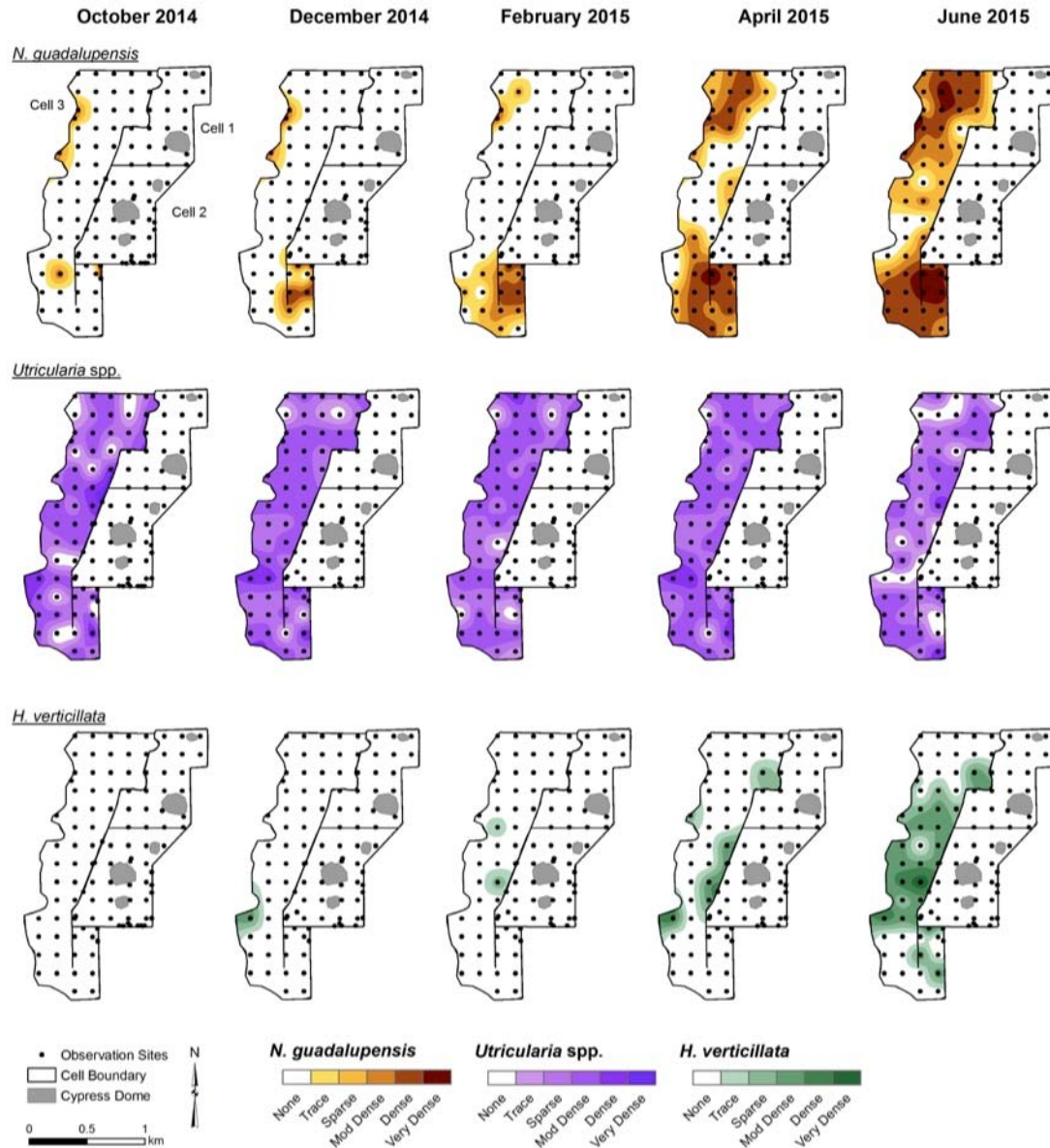


Figure 28. Relative cover of *Najas guadalupensis*, *Utricularia* spp., and *Hydrilla verticillata* in Cell 3 of the Caloosahatchee wetland during October and December 2014, and February, April, and June 2015. The black dots represent the observation locations, and the six semi-quantitative density categories are shown in the legend.