TECHNICAL PUBLICATION
WR-2015-001

**Restoration Strategies Regional Water Quality Plan –
Science Plan for the Everglades Stormwater Treatment Areas:**

Investigation of STA-3/4 PSTA Technology Performance, Design and Operational Factors

STA-3/4 Periphyton-based Stormwater Treatment Area (PSTA) Cell Water and Total Phosphorus Budget Analyses

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April 2015

Acknowledgments

The authors thank Delia Ivanoff and Richard James for their technical guidance and draft review as well as Wossenu Abtew, Orlando Diaz, Eric Flaig, Lawrence Gerry, Scott Huebner, Kim O'Dell, Ceyda Polatel, Garth Redfield, Larry Schwartz, and Meifang Zhou for reviewing the draft report, Stacey Ollis for detailed editing of this technical report. The PSTA research team is also gratefully acknowledged for technical input and dedicated support in guiding and implementing this study.

INTRODUCTION

In 2012, the State of Florida and the U.S. Environmental Protection Agency reached consensus on new restoration strategies for further improving water quality in the Everglades. Based on months of scientific and technical discussions, these strategies will expand water quality improvement projects to achieve an ultra-low total phosphorus (TP) water quality standard established for the Everglades. Under these strategies, the South Florida Water Management District (SFWMD or District) is implementing a technical plan, as documented in the Restoration Strategies Regional Water Quality Plan (SFWMD, 2012a). Both the National Pollutant Discharge Elimination System (NPDES) permit and state-issued Everglades Forever Act (EFA) watershed permit have established stringent TP limits—a Water Quality Based Effluent Limit, or WQBEL—for water discharged into the Everglades Protection Area (SFWMD, 2012b). The NPDES and EFA watershed permits and associated Consent Orders (FDEP, 2012a,b) also require that the District develops and implements the Science Plan to enhance the understanding of mechanisms and factors that affect phosphorus treatment performance, particularly those that are key drivers to performance at low TP concentrations (SFWMD, 2013). Results from the Science Plan studies may be used to inform the design and operations of water quality projects, which will ultimately improve capabilities to manage achievement of WQBELs. Related data and information gathered from these studies will also be incorporated into the development and refinement of the District's operational guidance tools, as appropriate.

The District's Stormwater Treatment Area 3/4 (STA-3/4) Periphyton-based Stormwater Treatment Area (PSTA) Project has been in operation since Water Year 2008 (WY2008) (May 1, 2007–April 30, 2008). Beginning in Fiscal Year 2012 (FY2012) (October 1, 2011–September 30, 2012), additional research and evaluation efforts were initiated for the PSTA Project, which are continuing as part of the Investigation of STA-3/4 PSTA Technology Performance, Design and Operational Factors Study (PSTA Study) under the Restoration Strategies Science Plan efforts. The purpose of the PSTA Study is to assess the chemical and biological characteristics and the design and operational factors that enable the PSTA Cell to achieve ultra-low outflow TP discharge concentrations. The relatively low TP concentrations that have been observed in PSTA Cell outflows make it a potential option for further implementation in the Everglades STAs to help achieve the WQBELs. However, the uncertainties associated with the PSTA Cell's treatment performance need to be addressed before further application is considered.

Water and TP budgets are an important tool used to characterize and understand TP removal of STA treatment cells. Accurate water budgets are essential to develop accurate TP budgets and TP removal estimates. Water budgets are comprised of structure flows (inflows and outflows), seepage, rainfall, evapotranspiration (ET), and change in storage. Various efforts have been implemented recently to improve structure flow estimates, seepage flow estimates, and seepage water quality estimates associated with the PSTA Cell. This report summarizes annual water and TP budgets developed for the PSTA Cell for the seven-year period from May 1, 2007 to April 30, 2014 (WY2008–WY2014). The annual and long-term average annual TP settling rates (TP removal) for the PSTA Cell are also estimated.

BACKGROUND

The STA-3/4 PSTA facility was constructed to study and implement field-scale periphyton-based treatment wetlands (**Figures 1** and **2**). The PSTA facility consists of a 200-acre Upper Submerged Aquatic Vegetation (SAV) Cell, a 100-acre PSTA Cell, and a 100-acre Lower SAV Cell. The focus of this report is the 100-acre PSTA Cell.

The performance and operational parameters for the PSTA Cell have been reported in the annual South Florida Environmental Report (www.sfwmd.gov/sfer) since its inception. During the first five years (WY2008-WY2012) of operation, the PSTA Cell achieved an average annual total phosphorous (TP) flow-weighted mean concentration (FWMC) in discharge of 10.6 micrograms per liter [µg/L, or parts per billion (ppb)] (Piccone et al., 2012). However, a review of these results indicated the need for improved flow and seepage estimates. First, the low-head differential across the inflow structures (large box culverts) was identified as a major contributor to the uncertainties in the flow estimation. The G-388 PSTA Cell outflow pump station operation was characterized by a high frequency of on/off cycles, which created uncertainties in pump flow estimates. Second, the volume of seepage entering the PSTA Cell from the surrounding water bodies (i.e., Upper SAV Cell, Lower SAV Cell, and Discharge Canal) was not measured but was assumed to be significant, as evidenced by higher PSTA Cell outflow than inflow volumes. This was likely a result of the PSTA Cell topography and operation in relation to adjacent water bodies. The topographical difference between the PSTA Cell and the Upper and Lower SAV Cells exists because the peat substrate in the PSTA Cell was removed down to caprock. As a result, the bottom elevation of the PSTA Cell (8.8 feet National Geodetic Vertical Datum, or ft NGVD) is approximately one foot lower than the adjacent SAV cells (9.7 ft NGVD). In addition, the operating stage for the PSTA Cell (approximately 10.0–10.5 ft NGVD) is lower than that of the Upper and Lower SAV cells (approximately 10.5–11.3 ft NGVD). Third, the phosphorus concentrations of the seepage water were unknown, which increased uncertainty in TP budget analyses for the PSTA Cell. To improve the accuracy of the PSTA Cell's water budgets, TP budgets, and performance estimates, the SFWMD implemented various structural, monitoring, and operational improvements in WY2012–WY2014, as summarized in the following section.

PSTA CELL STRUCTURAL, MONITORING AND OPERATIONAL IMPROVEMENTS

G-388 OUTFLOW PUMP STATION FLOW ESTIMATES

The G-388 pump station was originally constructed with two 100 cubic feet per second (cfs) pumps (referred to as Pump #1 and Pump #2). These pumps, which were salvaged from another SFWMD pump station, were used as a cost-saving measure, with the understanding that they were relatively oversized in comparison to the approximate 20–30 cfs design flow for the PSTA Cell. For the first six years of operation, the Pump #2 on/off settings were set to maintain a PSTA Cell target stage of 10.0 ft NGVD. As a result, the pump would typically cycle on and off approximately eight times a day with a run time of about 20 minutes, and the first 3 to 5 minutes of run time were generally a transient period during which the pumping rate was typically less than rated capacity but could not be accurately determined. For this reason, modification of Pump #2 was proposed as a way to reduce the on/off cycling and provide conditions more favorable for developing accurate flow estimates. In August 2011, the pump speed of Pump #2 was reduced from 350 to 224 revolutions per minute (rpm) (100 to 60 cfs). Following the pump modifications, stream gauging was conducted and the flow rating equation for Pump #2 was subsequently updated to reflect the decrease in speed and capacity. With the new rating, the average absolute difference between measured and calculated flow was 6.2 percent, reduced from 8.8 percent for the previous rating (E. Damisse, SFWMD, pers. comm.).

G-390A & B INFLOW CULVERT FLOW ESTIMATES

In March 2011, the flow data for the PSTA Cell inflow structures (G-390A & B) for the period from May 1, 2007 to December 31, 2010 were revised by the District[1]. While an improvement over previous flow estimates, the revised flow estimates were considered to have remaining uncertainties that could not be resolved[2]. To improve inflow estimates for the PSTA Cell, a recommendation was made to modify the G-390B culvert and keep the G-390A culvert closed during normal operations, focusing all the inflows through G-390B culvert (Polatel, 2012). In October 2011, the inflow cross-sectional area of the G-390B culvert was reduced by installing a 36" diameter aluminum pipe inside the existing 6-foot by 6-foot concrete box culvert (**Figure 3**) to produce increased velocities that can be more accurately measured. A new rating was developed for the G-390B culvert after the structure modifications were completed. With the new rating, the average absolute difference between measured and calculated flow was 1.58 percent (Zhang and Zhang, 2012).

Following the modification of the G-390B culvert, the G-390A culvert has remained closed during normal operations and was opened only during three pulse tests that occurred in August 2012, October 2012, and June 2014. Improvements in the G-390A culvert flow estimates were facilitated by the collection of field data during the pulse tests, which were generally characterized by higher head differences across the G-390A culvert compared to the normal operations.

SEEPAGE WATER QUANTITY ESTIMATES

In April 2013, the target stage in the PSTA Cell was increased by 0.5 ft (i.e., from 10.0 to 10.5 ft NGVD) to reduce seepage inflows to the PSTA Cell from the surrounding water bodies. The increased target stage was achieved by revising the on/off trigger stages of the pumps in the G-388 outflow pump station. In addition, seepage coefficients for the levees were calibrated using a period when there were no inflow culvert flows, the outflow pump station G-388 was under normal operation to maintain the cell target stage (10.0 ft NGVD), the only other outflow was ET, and the only inflows to the cell were seepage and rainfall.

SEEPAGE WATER QUALITY ESTIMATES

To improve seepage water quality estimates, in February 2012, sampling was initiated in monitoring wells located in the east and west levees of the PSTA Cell (**Figure 4**). A total of 19 wells are configured in 8 clusters. Between February 2012 and June 2013, four of the 8-foot wells and four of the 36-foot wells (marked with WQ in **Figure 4**) were sampled five times on a quarterly basis. The well water quality information was used to estimate the TP load from seepage.

[1] The improved flow data was used to complete the analyses in this report with the understanding that while uncertainties remain, it is the best available data.

[2] In order to achieve the 20-30 cfs design flow for the PSTA Cell, the gate openings for G-390 A&B were generally about 0.2-0.3 ft. This size gate opening for 6-foot by 6-foot box culverts is too small to obtain accurate flow measurements.

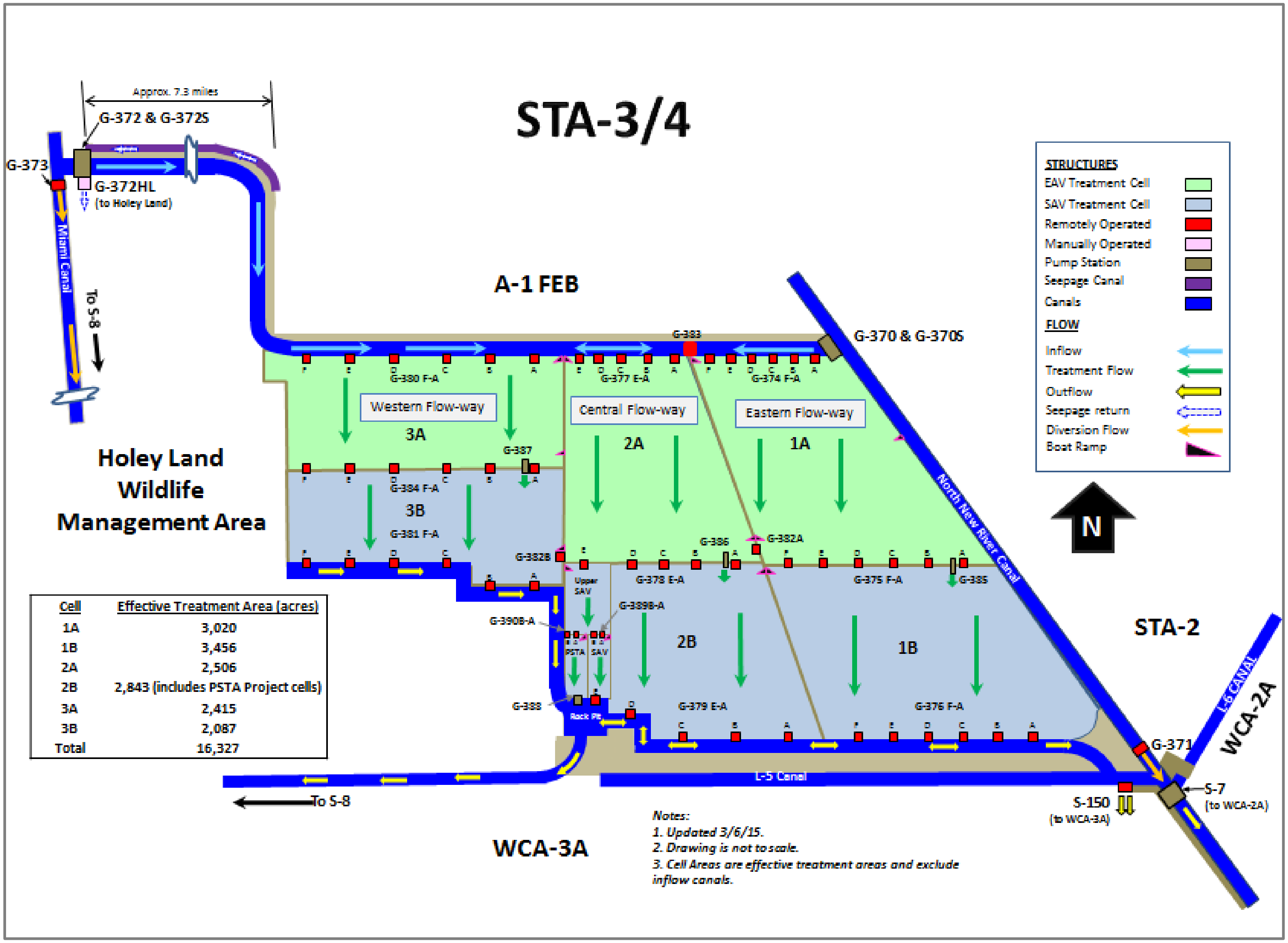

Figure 1. STA-3/4 PSTA Project location map.

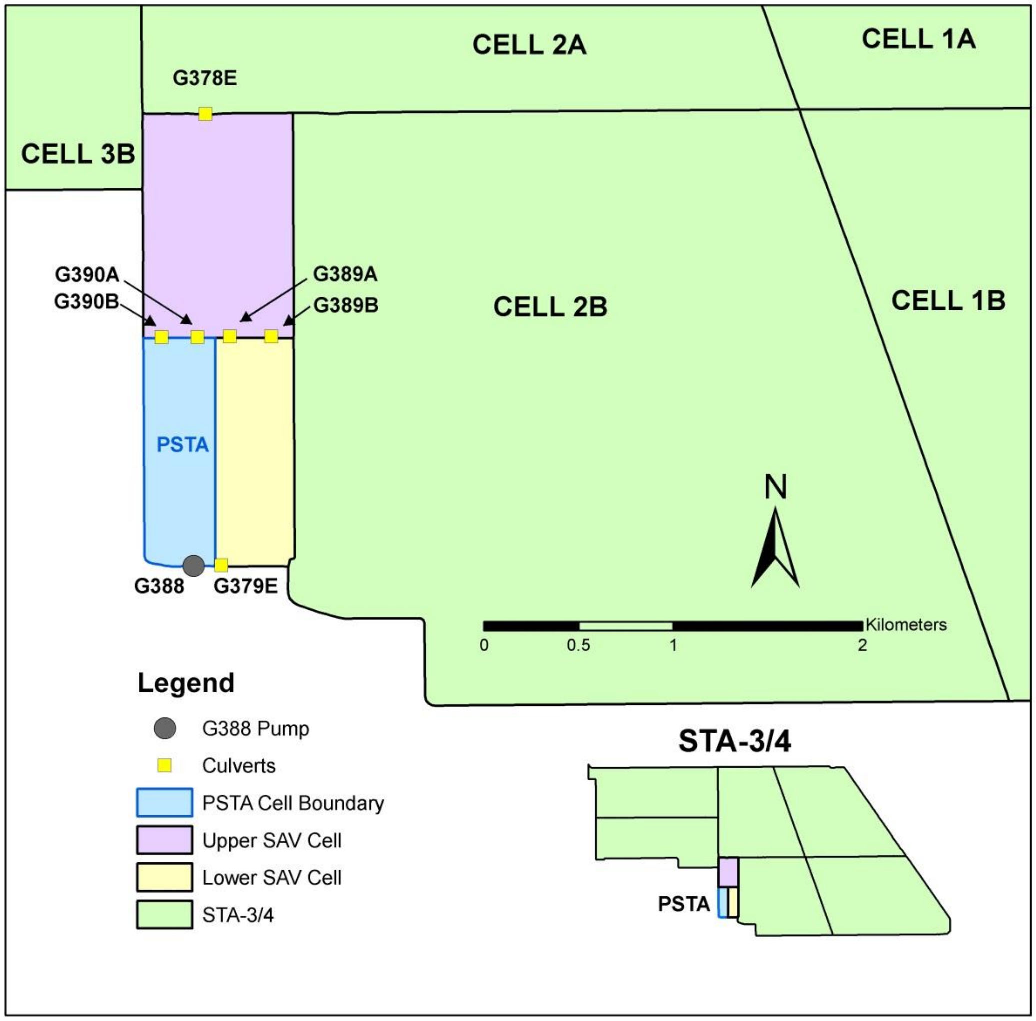

Figure 2. STA-3/4 PSTA Project schematic.

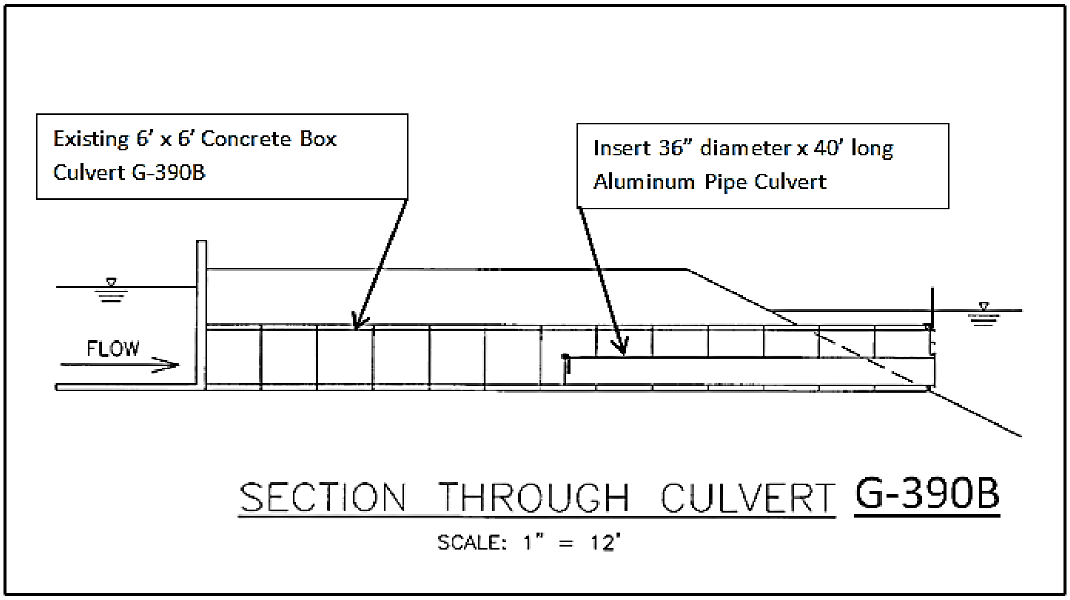

Figure 3. G-390B modification design.

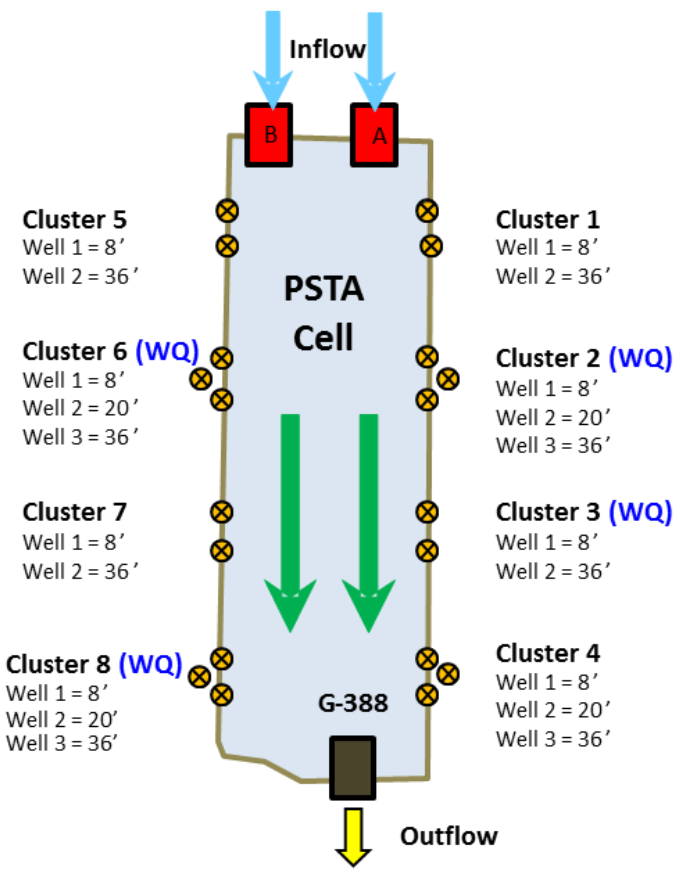

Figure 4. Well sampling and monitoring locations.

PSTA CELL WATER BUDGET MODEL

Various hydrological and hydraulic data such as flow, stage, rainfall, evapotranspiration (ET), and seepage are used to conduct water budget analyses (equation 1). The District's Water Budget Tool, a web-based application, was used to estimate the water budget for the PSTA Cell. The Water Budget Tool retrieves data from the District's DBHYDRO database (www.sfwmd.gov/dbhydro) in order to develop daily volume estimates for each of the water budget components.

$$\text{G-390A} + \text{G-390B} + R - \text{G-388} + \text{seepage} - ET - \Delta S = \varepsilon \qquad (1)$$

Where:

G-390A and G-390B: structure inflow (ac-ft)

R: rainfall (ac-ft)

G-388: pump station outflow (ac-ft)

ET: evapotranspiration losses (ac-ft)

ΔS: change in storage in the cell (ac-ft)ε: error (ac-ft)

PSTA CELL HYDROLOGIC AND HYDRAULIC DATA

Average rainfall data over the PSTA Cell area were retrieved using the nearest rain gauge EEA5 (DBKEY VN030) (Polatel et al., 2014), approximately 5 miles northeast of the PSTA Cell. For comparison, NEXRAD-based rainfall data were also retrieved to calculate the rainfall over the PSTA Cell. Based on seven years of data, the annual average rainfall from NEXRAD data was approximately 2.2 inches higher than the rain gauge based data (54.2 inches versus 52.0 inches). For this evaluation, the rainfall gauge-based data were used for further analysis, consistent with the recommendations by Polatel et al. (2014). The daily ET data were retrieved from weather station ROTNWX (DBKEY RW486,) (Abtew, 1996; Polatel et al., 2014), approximately 15 miles northwest of the PSTA Cell.

Observed data were obtained for structure flows and water levels at various locations within and around the PSTA Cell. These are primarily defined by DBKEY (**Table 1**). The structure inflow and outflow volumes from WY2008–WY2014 are summarized in **Table 2**. For all seven years, the structure outflow volumes were higher than the structure inflow volumes and, in many years, the differences are considerable, suggesting that seepage was a major source of inflow to the PSTA Cell.

Table 1. Summary of flow and stage data DBKEYS.

Locations & Components	Expressions	DBKEYS
G-390A	N/A	• 87621 (05/01/2007 to 2/31/2010) • V8861 (01/01/2011 to 04/30/2012)
G-390B	N/A	• 87622 (05/01/2007 to 2/31/2010) • V8862 (01/01/2011 to 4/30/2011) • 90405 (05/01/2012 to 4/30/2014)
G-388	N/A	W3981
HW for North Levee	G390BHW	
TW for North Levee	G390BTW	
HW for South Levee	G388HW	
TW for South Levee	G379DTW	
HW for West Levee	Average of 390BTW and G388HW	TZ219 and UA609
TW for West Levee	Average of 381BTW and G379DTW	T1056 and T1063
HW for East Levee	Average of 390BTW and G388HW	TZ219 and UA609
TW for East Levee	Average of 389BTW and G379EHW	TZ226 and UA604

DBKEYS: HW - headwater; TW - tailwater

PSTA CELL SEEPAGE VOLUME ESTIMATES

Reliable estimates of seepage quantity and quality are critical for accurate water and TP budget analyses and TP removal evaluation. As suggested by consistently higher outflow volumes (G-388 outflow pump station) than inflow volumes (G-390A&B), seepage is assumed to be a major source of inflow to the PSTA Cell. Because no direct measurement of seepage for the PSTA Cell is available, daily seepage volume estimates were estimated as:

$$G = 1.983 * K_{sp} * L * \Delta H \qquad (2)$$

Where:

G = estimated seepage (ac-ft/d)

K_{sp} = coefficient of seepage (cfs/ft/mi)

L = length along the seepage boundary (mi)

ΔH = hydraulic head difference between water bodies across a levee (ft)

1.983 = constant to convert from cfs to ac-ft/d

Typically, the seepage coefficient, K_{sp}, is adjusted to minimize the annual water budget errors. Because seepage data were not available, historical no-inflow periods were evaluated to develop seepage estimates and calibrate the seepage coefficients for the PSTA Cell levees. Between April 6, 2012 and July 2, 2012, the PSTA Cell inflow structures were closed for vegetation strip modifications. The inflow structures to the PSTA Cell remained closed due to the presence of nesting black-necked stilts (*Himantopus mexicanus*) until July 3, 2012. During the period of April 6, 2012 to July 3, 2012, the outflow pump station G-388 was operated normally to maintain the cell target stage (10.0 ft NGVD), the only other outflow was ET, and the only inflows to the cell were seepage and rainfall.

The east and the north levees of the PSTA Cell were constructed as part of the PSTA Project using muck scraped from the PSTA Cell footprint. The west and south levees of the PSTA Cell were constructed as part of the overall STA-3/4 Project and, therefore, it is assumed that these levees were constructed according to a higher standard. It is also reasonable to assume that the seepage coefficient for the west and south PSTA levees is lower than the seepage coefficient for the east and north levees.

A Seep2D model was developed to analyze STA-3/4 levee seepage (Sangoyomi et al., 2011). The three cross-sections for the STA-3/4 Northern Levee were calibrated using the flow data recorded at G370S and G372S. The resulting calibrated seepage coefficients were 1.3, 2.2, and 2.0 cfs/ft/mi for the three cross sections, A-A (Cell 3A Northern Levee), B-B (Cell 2A Northern Levee), and C-C (Cell 1A Northern Levee), respectively, with an average value of 1.8 cfs/ft/mi. During the calibration process, with a goal of minimizing the remainder, K_2 was set as 1.8 cfs/ft/mi, and K_1 for the west and south levees was varied between 4 to 6.6 cfs/ft/mi with an interval of 0.2. The optimized K_1 value was 6.0 cfs/ft/mi. During the calibration period, the daily average remainder was 0.04 acre-feet (ac-ft) (**Figure 5**). Visual observation and a near-zero daily remainder suggests that K_1 and K_2 values of 6.0 and 1.8 cfs/ft/mi provide a satisfactory seepage estimate. Consequently, these two values are recommended for the PSTA cell long-term mass balance analysis.

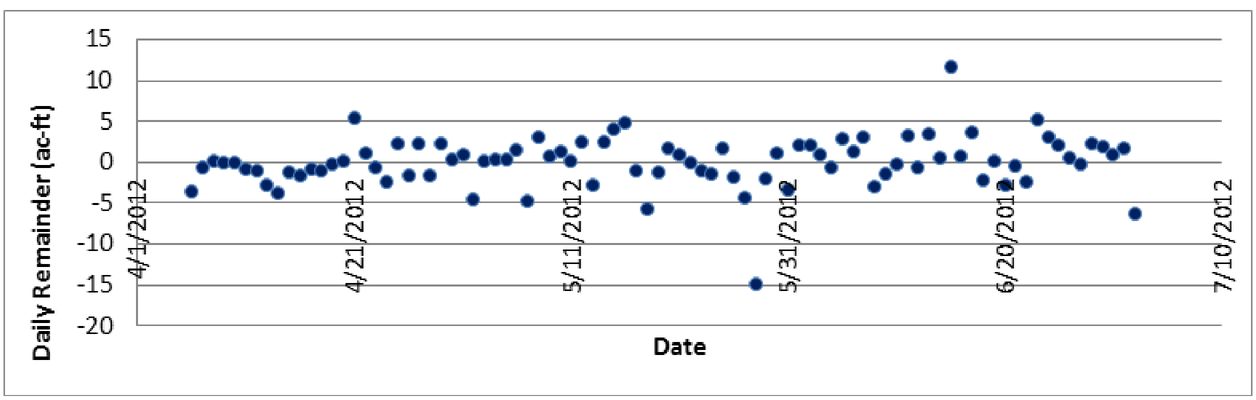

Figure 5. Daily remainder distribution for the calibration period.

PSTA CELL WATER BUDGET SUMMARY

Water budgets were developed for the seven-year period from WY2008–WY2014. Water budget errors were computed daily using equation 1 and summarized by water year (May to April). The annual remainder percentages (defined as the remainder divided by the average of total inflow and total outflow) ranged from -8.0 to 14.9 percent (**Table 2**). As shown in the table, the highest annual error percentage was 14.9% (WY2009). For the remaining six years, the annual water budget errors were less than 10 percent, and the seven-year water budget error was 2.7 percent. Annual net seepage, as percentages of the total PSTA inflow and outflow, ranged from 4 to 34 percent. The amounts of rainfall and ET were relatively small compared to the other water budget components and approximately equivalent in volume, thereby cancelling out each other in the annual water balance. This is consistent with observations from other water bodies in South Florida (Abtew, 2005; Abtew et al., 2007)

In general, visual observations suggest that the daily water budget remainders were distributed evenly around zero (**Figure 6**). Daily remainders had relatively small mean (0.54 ac-ft), median (0.37 ac-ft), and standard error (0.18 ac-ft). For the 2,555 days, 75 percent of the time (2,286 days), the absolute value of the remainder was less than 5 ac-ft, equivalent to 0.05 ft of water depth in the treatment PSTA cell. These statistical analyses suggest that the daily water budget results are satisfactory.

Table 2. Summary of annual water budget (in acre-feet, or ac-ft).

Water Year	Inflow	Seepage in	Rain	Total inflow	Outflow	Seepage out	T	Total outflow	Change in storage	Remainder	Error %
WY2008*	2922	1821	402	5145	4905	31	446	5382	119	355	6.8
WY2009*	3298	2108	448	5854	6405	2	458	6864	-66	945	14.9
WY2010*	7020	2339	504	9864	10080	17	448	10545	-7	675	6.7
WY2011*	3289	885	340	4515	3965	124	464	4554	-9	30	0.7
WY2012	7452	2122	431	10005	9848	29	453	10331	-7	318	3.2
WY2013	9322	2436	516	12275	11219	12	450	11681	32	-561	-4.6
WY2014	4030	432	413	4875	3794	236	449	4479	20	-376	-8
TOTAL	**37334**	**12144**	**3054**	**52533**	**50216**	**450**	**3169**	**53835**	**82**	**1385**	**2.7**

*Flow data for the PSTA Cell inflow structures (G-390A&B) for the period from May 1, 2007–December 31, 2010 were revised by the District. These revised flow estimates were considered to have remaining uncertainties that could not be resolved.

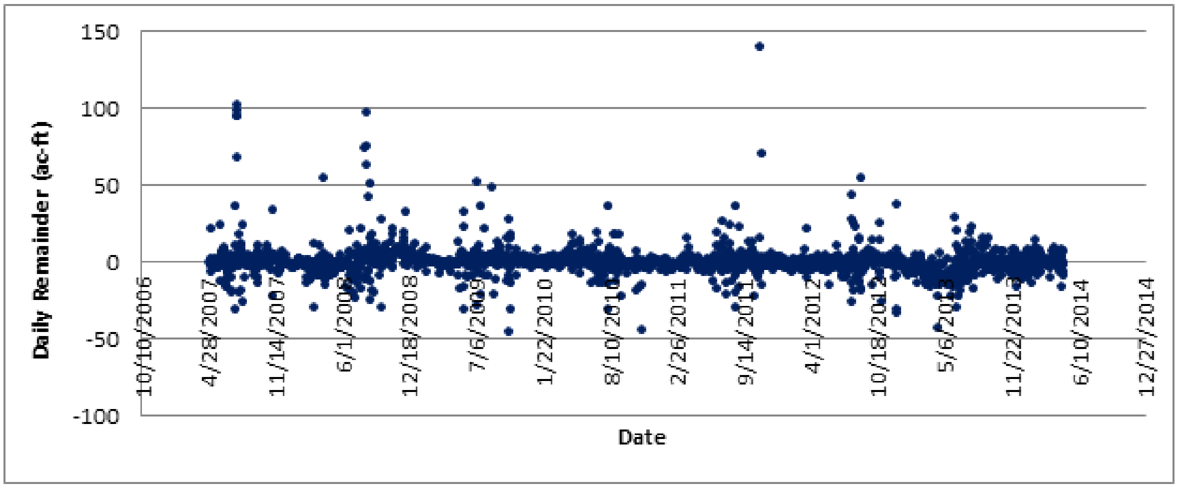

Figure 6. Daily remainder distribution (in ac-ft).

PSTA CELL TOTAL PHOSPHORUS BUDGET

TP mass balance was calculated by equation 3. In this equation, the inflow TP load components include structure inflow TP load (TP $Load_{G390A+G390B}$) rainfall TP load (TP $Load_{Rain}$), and seepage in TP load (TP $Load_{seepage\ in}$). The outflow TP loads include structure outflow TP load (TP $Load_{G388}$) and seepage out TP load (TP $Load_{seepage\ out_t}$). The difference is the TP load reduction, ΔTP.

$$\Delta TP = TP\ Load_{G390A+G390B} + TP\ Load_{Rain} + TP\ Load_{seepage\ in} - TP\ Load_{seepage\ out} - TP\ Load_{G388} \quad (3)$$

Water quality data routinely collected at the inflow and outflow structures were used to develop daily TP load estimates associated with structure flow volumes. Over the seven-year period analyzed, the annual inflow TP FWMC through G-390A and G-390B ranged from 14 to 27 µg/L, with an average of 19 µg/L. To estimate the TP load that left the PSTA Cell due to seepage outflow, the annual average TP FWMC between the PSTA Cell inflow and outflow structures was used. An estimated rainfall TP concentration was used to develop daily rainfall load estimates. Several independent estimates of rainfall TP in South Florida have found median concentrations that range between 5 and 7 µg/L (Brezonik et al., 1982). For this reason, the rainfall TP concentration used for the PSTA Cell TP budget analysis was 6 µg/L.

Seepage TP concentrations were measured from samples taken from four clusters of wells during the period from February 2012 to June 2013 (**Figure 4**). Clusters 2 and 3 were located at the east levee and clusters 6 and 8 were located at the west levee. For clusters 6 and 8, samples from the 8-foot wells were not included in the calculation because the measured groundwater tables were constantly significantly higher than the water levels in the surrounding water bodies. This suggests that these wells may have been collecting rainfall along the levee and were not representative of seepage. The sampled TP concentration data from the other six wells also demonstrated high variability. Typically, for a data series, if the lower quartile is Q1 and the upper quartile is Q3, then the difference (Q3 - Q1) is called the interquartile range or IQ. A mild outlier can be defined as a point outside the range of (Q1 – 1.5 IQ, Q3 + 1.5 IQ). An extreme outlier can be defined as a point outside the range of (Q1 – 3 IQ, Q3 + 3 IQ). For this analysis, well sample concentrations higher than 100 µg/L met the definition of extreme outliers and were excluded from further analyses. These values (587, 170, and 106 µg/L) were substantially higher than the TP concentrations from the surrounding water bodies. Field observations indicated that these samples were highly turbid, likely due to disturbance of the well during the well purging and sampling process. For the remaining sample concentrations, the minimum TP concentration was 3 µg/L, the median concentration was 10 µg/L, and the average concentration was 19 µg/L (**Table 3**). Large variations in the well TP concentration data suggest the need for additional groundwater data collection.

To supplement the well TP concentration data, seepage concentration data series collected at the two STA-3/4 seepage return pumps were evaluated. G-370S and G-372S are two pumps located within the STA-3/4 inflow pump stations G-370 and G-372 (**Figure 1**). The function of these two seepage pump stations is to return seepage collected in the seepage canal and return it to the STA-3/4 Supply/Inflow canals. Since 2004, more than 600 water quality samples have been collected at these two sites. Frequency analysis of the TP concentration data from these two sites is summarized in **Table 4**. It is interesting to note that the median TP concentration data for G-370S and G-372S were 11 µg/L for G-370S and 10 µg/L for G-372S, respectively, which closely matches the median TP concentration data from the PSTA well samples. Based on the G-370S and G-372S TP concentration data series, the 5th percentile of both data series is 7 µg/L (**Figure 7**). In other words, 95 percent of the TP concentrations were at or higher than 7 µg/L.

Because of the current uncertainties in the seepage water quality, the following range of seepage TP concentrations was used to develop the TP budget and the corresponding TP load, TP FWMC, and TP settling rates: 7 µg/L (corresponding to the 5 percentile of the G-370S and G-372S water quality data series), 10 µg/L (the median value from the PSTA well sampling data and the G-370S and G-372S data), and 19 µg/L (the average value from the PSTA well sampling data). The results based on a 10 µg/L seepage concentration were used as a baseline scenario, as discussed in this section. The results based on 7 and 19 µg/L seepage concentrations are presented in the sensitivity analysis section.

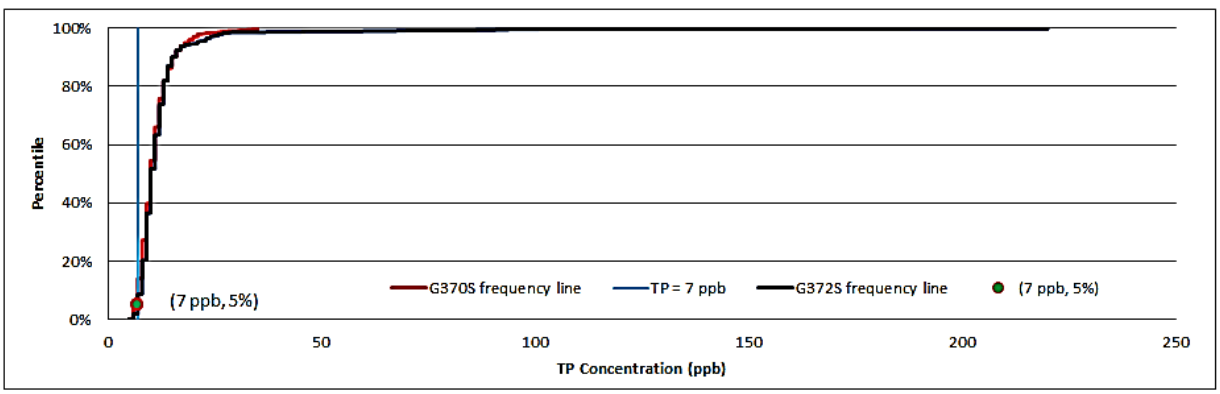

Figure 7. G-370S and G-372S TP concentration data series frequency curve.

Table 3. PSTA well water quality sampling data.

Sampling Date	Well ID	Well depth	TP Concentration (µg/L)
2/15/2012	PSTAWELLS2	8'	57
2/15/2012	PSTAWELLS2	36'	10
6/13/2012	PSTAWELLS2	8'	41
6/13/2012	PSTAWELLS2	36'	7
9/26/2012	PSTAWELLS2	8'	18
9/26/2012	PSTAWELLS2	36'	9
2/5/2013	PSTAWELLS2	8'	64
2/5/2013	PSTAWELLS2	36'	7
6/19/2013	PSTAWELLS2	8'	22
6/19/2013	PSTAWELLS2	36'	9
2/15/2012	PSTAWELLS3	8'	16
6/13/2012	PSTAWELLS3	8'	19
6/13/2012	PSTAWELLS3	36'	24
9/26/2012	PSTAWELLS3	8'	9
2/5/2013	PSTAWELLS3	8'	22
2/5/2013	PSTAWELLS3	36'	63
6/19/2013	PSTAWELLS3	8'	21
6/19/2013	PSTAWELLS3	36'	32
2/15/2012	PSTAWELLS6	36'	5
6/13/2012	PSTAWELLS6	36'	5
9/26/2012	PSTAWELLS6	36'	6
6/19/2013	PSTAWELLS6	36'	4
2/15/2012	PSTAWELLS8	36'	7
6/13/2012	PSTAWELLS8	36'	5
9/26/2012	PSTAWELLS8	36'	7
2/5/2013	PSTAWELLS8	36'	3
6/19/2013	PSTAWELLS8	36'	11
		minimum TP concentration (µg/L)	3
		median TP concentration (µg/L)	10
		average TP concentration (µg/L)	19

Table 4. Frequency analyses for TP concentration data series at G-370S and G-372S.

	G-370S	G-372S
Sample number	682	636
Average TP concentration (µg/L)	8	12
Median TP concentration (µg/L)	11	10
5th percentile TP concentration (µg/L)	7	7
95th percentile TP concentration (µg/L)	18	21

To evaluate the PSTA Cell's treatment performance, two terms were defined to estimate the TP load reduction rate and TP flow-weighted mean concentration (FWMC) reduction rate (equations 4 and 5). Equation 6 was used to calculate the TP settling rate k.

$$\Delta TP\ \% = \text{TP load reduction rate} = (\text{TP Load}_{in} - \text{TP Load}_{out}) / \text{TP Load}_{in} * 100 \quad (4)$$

$$\Delta TP\ FWMC\ \% = \text{TP concentration reduction rate} = (FWMC_{in} - FWMC_{out}) / FWMC_{in} * 100 \quad (5)$$

$$k = \frac{\frac{(V_{in}+V_{out})\times N}{2}}{A} \times \left(\left(\frac{C_{in}-C^*}{C_{out}-C^*}\right)^{\frac{1}{N}} - 1\right)/3.28 \quad (6)$$

Where:

$\text{TP Load}_{in} = \text{TP Load}_{G390A+G390B} + \text{TP Load}_{Rain} + \text{TP Load}_{seepage\ in} - \text{TP Load}_{seepage\ out}$

$\text{TP Load}_{out} = \text{TP Load}_{G388}$

$FWMC_{in}$ (inflow flow weighted mean concentration) = $\text{TP Load}_{in}/V_{in}$

V_{in} (total inflow volume) = G390A + G390B + Rain + Seepage in – Seepage out

$FWMC_{out}$ (outflow flow weighted mean concentration) = $\text{TP Load}_{G388}/V_{G388}$

k = the TP settling rate (i.e., removal coefficient) (m/yr);

V_{in} = the total inflow volume (ac-ft/yr);

V_{out} = the total outflow volume (ac-ft/yr);

A = the PSTA Cell effective treatment area (ac);

N = the number of continuously stirred tanks-in-series (= 6), (DB Environmental, Inc. 2009);

C^* = the background TP concentration (= 4 µg/L), a concentration of 4 µg/L was typically used for the background TP concentration in STA design;

C_{in} = the annual inflow FWM TP concentration (µg/L); and

C_{out} = the annual outflow FWM TP concentration (µg/L).

Using a seepage concentration of 10 µg/L (**Table 5**), the annual TP load reduction rate varied from 20 to 50 percent, with a seven-year annual average of 34 percent; the annual TP FWMC reduction in the outflow from the PSTA Cell was 19 to 39 percent lower than inflow TP FWMC, with a seven-year annual average of 31 percent; and the annual TP settling rate ranged from 8 to 34 m/yr, with a seven-year annual average of 17 m/yr.

Table 5. Water and TP budget analyses using 10 µg/L as seepage TP concentration.

Parameter	Unit	WY2008	WY2009	WY2010	WY2011	WY2012	WY2013	WY2014	WY2008-
rain	ac-ft	402	448	504	340	431	516	413	3,054
ET	ac-ft	446	458	448	464	453	450	449	3,168
structure inflow (G390A+G390B)	ac-ft	2,922	3,298	7,020	3,289	7,452	9,322	4,029	37,332
structure outflow (G388)	ac-ft	4,905	6,405	10,080	3,965	9,848	11,219	3,794	50,216
seepage in	ac-ft	1,821	2,108	2,339	885	2,122	2,436	432	12,144
seepage out	ac-ft	31	2	17	124	29	12	236	450
total inflow	ac-ft	5,145	5,854	9,863	4,514	10,005	12,274	4,874	52,529
total outflow	ac-ft	5,382	6,865	10,545	4,553	10,330	11,681	4,479	53,835
structure Inflow TP FWMC	µg/L	27	14	20	18	17	16	24	19
structure outflow TP FWMC	µg/L	12	8	10	11	12	11	13	11
inflow TP FWMC (less seepage	µg/L	19	12	17	15	15	14	21	16
TP load from Rain	kg	3	3	4	3	3	4	3	23
TP load in ET	kg	-	-	-	-	-	-	-	-
total structure inflow Load	kg	98	57	170	72	157	183	118	854
total structure outflow TP Load	kg	73	63	123	55	149	150	61	674
seepage in TP Load	kg	22	26	29	11	26	30	5	150
seepage out TP Load	kg	1	0	0	2	1	0	5	9
TP load reduction rate	%	41%	26%	39%	34%	20%	30%	50%	34%
TP FWMC reduction rate	%	38%	32%	41%	27%	19%	24%	39%	31%
TP settling rate k	(m/yr)	14	22	34	8	12	20	12	17

SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to determine the impact of different seepage TP concentrations and rainfall TP concentrations on the TP load reduction rate, TP FWMC reduction rates, TP settling rate, and remainder error percentage. While the sensitivity with respect to one parameter was being evaluated, the other parameters were held constant. The baseline scenario was set as K_1 = 6.0 cfs/ft/mi, K_2 = 1.8 cfs/ft/mi, rainfall TP = 6 µg/L, and seepage TP = 10 µg/L. Rainfall TP concentrations were varied from 3 to 9 µg/L, corresponding to a 50 percent decrease and a 50 percent increase from the baseline value. The seepage TP concentrations tested were 7 µg/L (a 30 percent decrease from the baseline value), corresponding to the 5th percentile seepage concentration from the G-370S and G-372S water quality data series, and 19 µg/L (a 90 percent increase from the baseline value), the average PSTA well concentration. The resulting TP load reduction rate, TP FWMC reduction rate, TP settling rate, and remainder error percentage were compared with the baseline scenario. The results are summarized in **Table 6**.

- Maintain constant seepage TP concentration of 10 µg/L; K_1 = 6.0 cfs/ft/mi, K_2 = 1.8 cfs/ft/mi; and vary the rainfall TP concentration from 3 to 9 µg/L. The seven-year annual average TP load reduction rate and the TP FWMC reduction rate changed by 1 percent, and the TP settling rate varied by 0.5 m/yr. These small differences suggest that the TP reduction and settling rates were not sensitive to the rainfall TP concentrations tested.

- Maintain constant K_1 = 6.0 cfs/ft/mi, K_2 = 1.8 cfs/ft/mi, rainfall TP of 6 µg/L, and vary the seepage TP concentration from 7 to 19 µg/L.

    - For 7 µg/L, the seven-year annual average TP load reduction rate decreased from 34 to 31 percent and the TP FWMC reduction rate decreased from 31to 28 percent. The seven-year annual average TP settling rate decreased from 17 to 15 m/yr.

    - For 19 µg/L, both the seven-year annual average TP load reduction rate and TP FWMC reduction rate increased from 34 to 42 percent and from 31 to 39 percent, respectively. The seven-year annual average TP settling rate increased from 17 to 23 m/yr.

The TP concentration applied to the seepage water has an effect on the TP load reduction, TP FWMC reduction, and TP settling rates.

Table 6. Summary of sensitivity analyses used in this study.

Parameter	Annual Average Values (WY2008–WY2014)				
	Base Value	Scenario II: K_1 = 6.0, K_2 = 1.8, seepage = 10 µg/L		Scenario II: K_1 = 6.0, K_2 = 1.8, rainfall = 6 µg/L	
	K_1 = 6.0 K_2 = 1.8 Rainfall TP=6 µg/L Seep.	Rainfall TP = 3 µg/L	Rainfall TP = 9 µg/L	seepage = 7 µg/L	seepage = 19 µg/L
TP load reduction rate (%)	34%	33%	35%	31%	42%
TP FWMC reduction rate (%)	31%	30%	32%	28%	39%
TP settling rate k (m/yr)	17.4	16.9	17.9	15.3	23.1

SUMMARY AND RECOMMENDATIONS

This report summarizes annual water and TP budgets developed for the STA-3/4 PSTA Cell during the seven-year period from WY2008–WY2014. The annual and long-term average annual TP settling rates (TP removal) for the PSTA Cell are also estimated.

During the study period, the total inflow volume to the PSTA Cell was 52,876 ac-ft. Of this total, 37,332 ac-ft (71 percent) was through inflow structures G-390A and G-390B; 3,054 ac-ft (6 percent) was rainfall; and 13,625 ac-ft (24 percent) was seepage inflow. The total outflow volume from the PSTA Cell was 53,851 ac-ft. Of this total, 50,239 ac-ft (92 percent) was through the outflow structure G-388, 445 ac-ft (1 percent) was seepage outflow; and 3,168 ac-ft (6.0 percent) was ET. The mass balance error percentage was 2.7 percent. This relatively small error percentage suggests that the overall mass balance result is satisfactory. The PSTA Cell had a seven-year annual average outflow FWM TP concentration of 11 µg/L and outflow FWM TP for all years at or below 13 µg/L.

The seepage coefficient calibrated by Sangoyomi et al. (2011) for the STA-3/4 northern levees with an average value of 1.8 cfs/ft/mi was used for the west and south levees. The seepage coefficient for the east and north levees was calibrated using the period from April 6, 2012 to July 3, 2012, when the PSTA Cell inflow structures were closed. This period was selected to calibrate the seepage coefficients because the uncertainty from inflow structures was excluded. The calibrated seepage coefficient was 6.0 cfs/ft/mi for the east and north levees. The calibrated seepage coefficients were used in the water and TP budget analyses presented in this report.

Compared to the total annual inflow to the PSTA Cell, the percentage of net seepage to the PSTA Cell varied from 5 to 37 percent depending on the hydrological conditions. The years with a large percentage of estimated seepage into the PSTA Cell were a result of the stage differences between the PSTA Cell and the surrounding water bodies. The smallest net estimated seepage occurred in WY2014, with an estimate of 213 ac-ft. This small seepage volume compared to other years can be explained by the 0.5 ft increase in the operational stage that was fully implemented in WY2014. As a result of this change, the head difference between the PSTA Cell and the surrounding water bodies was reduced. In addition, greatly reduced inflows to STA-3/4 Central Flow-way due to vegetation enhancements also contributed to the very low inflow volumes to the PSTA Cell.

Overall, the amounts of rainfall and ET were relatively small compared to the other water budget components and were approximately equivalent in volume, thereby cancelling out each other in the annual water balance. This is consistent with observations from other water bodies in South Florida (Abtew, 2005; Abtew et al., 2007). For the seepage water quality component, large variance in the PSTA Cell well sample concentrations resulted in high uncertainties. Due to the uncertainties with the seepage data, a range of seepage TP concentrations was used to develop a range of PSTA Cell performance values. Using the median well TP concentration of 10 µg/L, during the seven-year study period the PSTA Cell had an annual average TP load reduction rate of 34 percent, annual average TP FWMC reduction rate of 31 percent, and annual average settling rate of 17.5 m/yr. The TP concentration applied to the seepage water had a major effect on the TP load, FWMC reduction, and settling rate estimates, as confirmed by the sensitivity analysis.

Additional well sampling is recommended to reduce the uncertainty in the TP budget analyses. Continued operation with the improved flow data and improved estimates of seepage quantity and quality will help improve the assessment of the PSTA Cell's treatment performance. While the flow and water quality measurements at both inflow and outflow structures continue, it is recommended to:

- Continue the water quality sampling at the wells located along the west and east levees (i.e., minimum of two additional sampling events, one in June 2015 and one in September 2015);
- Update the water and TP budget analyses annually; and

- Conduct an additional seepage test with inflow gates closed to reflect conditions under the current target stage (10.5 ft NGVD).

REFERENCES

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

Abtew, W. 2005. Evapotranspiration in the Everglades; comparison of Bowen ratio measurements and model estimations. ASAE Paper No. 052188. St. Joseph, MI: American Society of Civil Engineers.

Abtew, W., R. Huebner and C. Pathak. 2007. Hydrology and hydraulics of South Florida. *ASCE 2007 World Environmental & Water Resources Congress.* Tampa, FL: American Society of Civil Engineers.

Brezonik, P.L., C.D. Hendry, Jr., E.S. Edgerton, R.L. Schulze and T.L. Crisman. 1983. Acidity, nutrients, and minerals in atmospheric precipitation over Florida: Deposition patterns, mechanisms, and ecological effects. EPA/600/3-84/004, U.S. Environmental Protection Agency, Corvallis, OR.

DB Environmental. 2009. Tracer Study: PSTA Cell, STA-3/4. Technical Memorandum submitted to the South Florida Water Management District, West Palm Beach, FL.

FDEP. 2012a. STA National Pollutant Discharge Elimination System (NPDES) Watershed Permit (No. FL0778451) and Associated Consent Order (OGC 12-1148). Florida Department of Environmental Protection, Tallahassee, FL. September 10, 2012.

FDEP. 2012b. STA Everglades Forever Act (EFA) Watershed Permit (No. 0311207) and Associated Consent Order (OGC 12-1149). Florida Department of Environmental Protection, Tallahassee, FL. September 10, 2012.

Polatel, C. 2012. Hydrodata Management Section Recommendations for Data Improvement on PSTA Project of STA-3/4. South Florida Water Management District, West Palm Beach, FL.

Polatel, C., W. Abtew, S. Krupa and T. Piccone. 2014. Stormwater Treatment Area Water and Phosphorus Budget Improvements - Phase I: STA-3/4 Cells 3A and 3B Water Budgets. Technical Publication WR-2014-004. South Florida Water Management District, West Palm Beach, FL.

Piccone, T., H. Zhao, D. Ivanoff, S. Miao, K. Grace and T. DeBusk. 2012. STA-3/4 Periphyton-Based Stormwater Treatment Area Project. In: Chapter 5: Performance and Optimization of the Everglades Stormwater Treatment Areas, *2013 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Sangoyomi, T., A. Nayak, G. Huang and S. Xiao. 2011. Levee Seepage Analysis at Stormwater Treatment Area 3/4. South Florida Water Management District, West Palm Beach, FL. 33pp.

SFWMD. 2012a. Technical Support Document for Derivation of the Water Quality Based Effluent Limit for Total Phosphorus in Discharges from Everglades Stormwater Treatment Areas to the Everglades Protection Area. South Florida Water Management District, West Palm Beach, FL. June 27, 2012.

SFWMD. 2012b. Restoration Strategies Regional Water Quality Plan. South Florida Water Management District, West Palm Beach, FL. April 27, 2012. Available online at www.sfwmd.gov/restorationstrategies.

SFWMD. 2013. Restoration Strategies Regional Water Quality Plan: Science Plan for the Everglades Stormwater Treatment Areas. South Florida Water Management District, West Palm Beach, FL. June 2013. Available online at www.sfwmd.gov/rs_scienceplan.

Yue, S. and E. Damisse. 2012. Flow Rating Analysis for Pump Unit 2 at Pump Station G388. Rating Report. South Florida Water Management District, West Palm Beach, FL.

Zhang, L., and L. Zhang. 2012. G390b Flow Rating After Structure Modification. Technical Note. South Florida Water Management District, West Palm Beach, FL.