Appendix 5C-5: Summary Report for Water and Total Phosphorus Budget and Performance Analysis for STA-3/4 Treatment Cells

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INTRODUCTION

The purpose of the Stormwater Treatment Area (STA) Water and Phosphorus Budget Improvements Study is to improve the accuracy of water and total phosphorus (TP) budgets for selected treatment cells in the Everglades STAs. Water budget analysis is used to develop accurate TP budgets and to evaluate treatment performance. Water budgets are comprised of structure flows (inflows and outflows), seepage, rainfall, evapotranspiration (ET), and change in storage. The TP budgets are comprised of TP mass loads associated with structures (inflows and outflows), rainfall, and seepage. Previously reported STA treatment cell annual water budgets contained high residuals (SFWMD 2013), which limited the reliability of the water and TP budgets to characterize and understand treatment performance. Building upon the results of a water budget test case by Polatel et al. (2014), flow data for the structures associated with the STA-3/4 treatment cells were reviewed and updated based on enhanced quality control processes, improvements in flow rating curves, and stage data improvements. Improved seepage volume and TP load estimates were also developed for the STA-3/4 treatment cells. This appendix documents the improved water and TP budgets and the long-term performance evaluation of STA-3/4 Cells 1A, 1B, 2A, 2B, 3A, and 3B, based on improved data (**Figure 1**).

The focus of this current study is to reduce the error in water and phosphorus budgets for individual treatment cells (or single cell flow-ways), not the overall TP removal for flow-ways containing more than one cell. Flow-way TP removal for STA-3/4 will be included in future technical publications. The information presented in this Appendix is intended to be used in concert with the results from other Science Plan studies (in particular the ongoing Data Integration effort) to develop conclusions about the key factors that influence treatment performance and to develop science-based conclusions and potential management recommendations. The results of other STA-3/4 research to date can be found in Chapter 5C (and Appendices) of this year's South Florida Environmental Report (SFER).

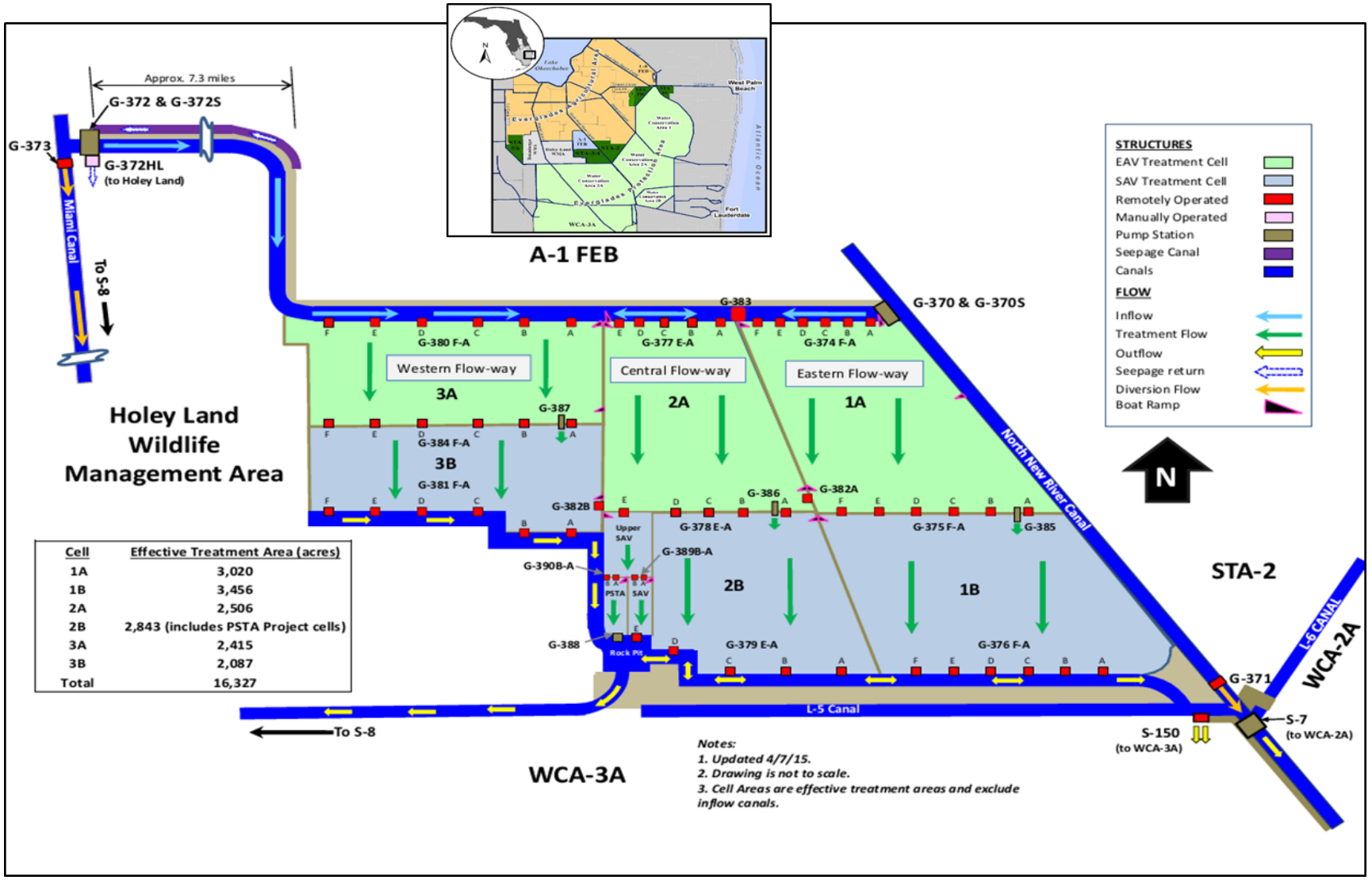

Figure 1. STA-3/4 schematic showing configurations of the treatment cells, flow direction, dominant vegetation type, and locations of flow structures. (Note: Approx. – Approximately, FEB – Flow Equalization Basin, and PSTA – Periphyton-based Stormwater Treatment Area, WCA – Water Conservation Area.)

SUMMARY FOR STA-3/4 TREATMENT CELLS

STA-3/4 contains three parallel flow-ways (FWs) consisting of two treatment cells arranged in series (upstream cell and downstream cell) separated by an interior levee. These are the Eastern FW (Cells 1A and 1B), Central FW (Cells 2A and 2B), and Western FW (Cells 3A and 3B). The vegetation varies among the STA-3/4 treatment cells. The upstream Cells 1A, 2A, and 3A are dominated by dense emergent aquatic vegetation (EAV) consisting mainly of cattail (Pietro and Ivanoff 2015). The downstream Cells 1B, 2B, and 3B have been managed predominantly as submerged aquatic vegetation (SAV) interspersed with large patches of emergent vegetation, which is commonly referred to as a "mixed-marsh" configuration. The EAV-SAV sequence is a result of research that was conducted by SFWMD during the Advanced Treatment Technologies (ATT) program which was conducted over a ten-year period (1994-2003) as a requirement of the 1994 Everglades Forever Act. The general concept is that EAV (i.e. large macrophytes such as cattail) in the upstream cells reduce P in the water column via particulate settling, plant uptake, and microbial uptake, and SAV in the downstream polishing cells further reduce P via plant and microbial uptake.

Annual water and TP budgets were developed for the STA-3/4 treatment cells for the period of record (POR) (Zhao and Piccone in prep). Flow and surface water TP data were available for Cells 1A, 1B, 2A, and 2B for the 12-year period from Water Year 2006 (WY2006; May 1, 2005–April 30, 2006) to WY2017. For Cells 3A and 3B, water and TP budgets were derived for the 9-year period from WY2009 to WY2017 because the internal levee was completed after the construction of the rest of the STA. Following completion of the internal levee in June 2005, the Western FW remained offline through May 2006 to allow for vegetation establishment (SFWMD 2007).

Improved structure flow estimates and the addition of seepage estimates resulted in more accurate annual water budgets for all the treatment cells as measured by significantly smaller annual residuals compared to previously reported results (**Table 1**). The POR flow and TP budgets were used to estimate the annual and average annual TP load, TP load percent reduction, TP flow-weighted mean (FWM) concentration, TP concentration reduction, TP retention rate, hydraulic residence time (HRT), hydraulic loading rate (HLR), and phosphorus loading rate (PLR) for each of the six treatment cells (Zhao and Piccone in prep).

Table 1. STA-3/4 water budget residuals (previous reported values versus this study).

	Annual Residual Range		Annual Average Residual	
	Previous Report	This Study	Previous Report	This Study
Cell 1A	-133–48%	-10%–15%	12%	5%
Cell 1B	-30–131%	-14%–2%	-1%	-4%
Cell 2A	-457–41%	-23%–10%	-7%	-8%
Cell 2B	-39–443%	-5%–15%	11%	4%
Cell 3A	-2–101%	-8%–1%	60%	-4%
Cell 3B	-96–23%	-7%–10%	-62%	<1%

EASTERN FLOW-WAY

Cell 1A

Cell 1A structure inflow averaged 218 million cubic meters per year (m^3/yr) for the 12-year period (**Table 2**), which was 93% of the total inflow volume. Rainfall averaged 17 million m^3/yr or 7% of the total inflow volume. The structure outflow averaged 226 million m^3/yr or 91% of the total outflow volume. Evapotranspiration (ET) averaged 16 million m^3/yr or 7% of the total outflow volume. Estimated net seepage averaged 2% of the total outflow volume, indicating a net loss of approximately 5 million m^3/yr. The change in storage averaged 0.5 million m^3/yr.

The inflow and outflow TP FWM concentrations for Cell 1A were 82 and 32 micrograms per liter (µg/L), respectively, over the 12-year period (**Table 3**). The cell retained an annual average of 56% of the total inflow TP load. The average TP concentration reduction in the cell was 61%. The average annual HLR was 4.9 centimeters per day (cm/day) and the average annual PLR was 1.61 grams per square meter per year (g/m^2/yr; **Table 4**). The average annual HRT was 14 days. Over the 12-year period, Cell 1A retained 131.3 metric tons (t) of TP or 10.74 grams per square meter (g/m^2; **Table 5**). The average annual TP load retention rate was 0.90 g/m^2/yr**.**

Cell 1B

Cell 1B structure inflow averaged 226 million m^3/yr over the 12-year period (**Table 2**), which was 92% of the total inflow volume. Rainfall averaged 19 million m^3/yr or 9% of the total inflow volume. The structure outflow averaged 215 million m^3/yr or 91% of the total outflow volume. ET averaged 18 million m^3/yr or 8% of the total outflow volume. Estimated net seepage averaged 1% of the total outflow volume, indicating a net loss of approximately 2 million m^3/yr. The change in storage averaged 0.4 million m^3/yr.

The inflow and outflow TP FWM concentrations for Cell 1B were 32 and 16 µg/L, respectively, over the 12-year period (**Table 3**). The cell retained an annual average of 58% of the total inflow TP load. The average TP concentration reduction in the cell was 50%. The average annual HLR was 4.4 cm/day and the average annual PLR was 0.61 g/m^2/yr (**Table 4**). The average annual HRT was 14 days**.** Over the 12-year period, Cell 1B retained 58.9 t of TP or 4.21 g/m^2. The average annual TP load retention rate was approximately 0.35 g/m^2/yr (**Table 5**).

CENTRAL FLOW-WAY

Cell 2A

Cell 2A structure inflow averaged 177 million m^3/yr over the 12-year period (**Table 2**), which was 92% of the total inflow volume. Rainfall averaged 14 million m^3/yr or 8% of the total inflow volume. The structure outflow averaged 162 million m^3/yr or 91% of the total outflow volume. ET averaged 13 million m^3/yr or 8% of the total outflow volume. Estimated net seepage averaged less than 1% of the total outflow volume, indicating a net loss of approximately 0.6 million m^3/yr. The change in storage averaged 0.3 million m^3/yr.

The inflow and outflow TP FWM concentrations for Cell 2A were 65 and 22 µg/L, respectively, over the 12-year period (**Table 3**). The cell retained an annual average of 68% of the total inflow TP load. The average TP concentration reduction in the cell was 66%. The average annual HLR was 4.8 cm/day and the average annual PLR was 1.31 g/m^2/yr (**Table 4**). The average annual HRT was 15 days. Over the 12-year period, Cell 2A retained 108.4 t of TP or 10.69 g/m^2 (**Table 5**). The average annual TP load retention rate was approximately 0.89 g/m^2/yr**.**

Cell 2B

Cell 2B structure inflow averaged 161 million m^3/yr over the 12-year period (**Table 2**), which was 91% of the total inflow volume. Rainfall averaged 16 million m^3/yr or 9% of the total inflow volume. The structure outflow averaged 167 million m^3/yr or 91% of the total outflow volume. ET averaged 15 million m^3/yr or 8% of the total outflow volume. Estimated net seepage averaged 1% of the total outflow volume, indicating a net loss of approximately 2 million m^3/yr. The change in storage averaged less than 1 million m^3/yr.

The total inflow and outflow TP FWM concentration for Cell 2B was 22 and 19 µg/L, respectively, over the 12-year period (**Table 3**). The cell retained an annual average of 32% of the total inflow TP load. The average TP concentration reduction in the cell was 15%. The average annual HLR was 3.8 cm/day and the average annual PLR was 0.41 g/m^2/yr (**Table 4**). The average annual HRT was 13 days. Over the 12-year period, Cell 2B retained 18.3 t of TP or 1.59 g/m^2 (**Table 5**). The average annual TP load retention rate was approximately 0.13 g/m^2/yr**.**

WESTERN FLOW-WAY

Cell 3A

Cell 3A structure inflow averaged 226 million m^3/yr over the 9-year period (**Table 2**), which was 94% of the total inflow volume. Rainfall averaged 13 million m^3/yr or 6% of the total inflow volume. The structure outflow averaged 214 million m^3/yr or 93% of the total outflow volume. ET was 13 million m^3/yr or 6% of the total outflow volume. Estimated net seepage averaged 1% of the total outflow volume, indicating a net loss of approximately 2 million m^3/yr. The change in storage was less than 1 million m^3/yr.

The total inflow and outflow TP FWM concentration for Cell 3A was 55 and 23 µg/L, respectively, over the 9-year period (**Table 3**). The cell retained an annual average of 60% of the total inflow TP load. The average TP concentration reduction in the cell was a 58%. The average annual HLR was 6.3 cm/day and the average annual PLR was 1.34 g/m^2/yr (**Table 4**). The average annual HRT was 9 days. Over the 9-year period, Cell 3A retained 71.1 t of TP or 7.28 g/m^2 (**Table 5**). The average annual TP load retention rate was approximately 0.81 g/m^2/yr**.**

Cell 3B

Cell 3B structure inflow averaged 214 million m^3/yr over the 9-year period (**Table 2**), which was 95% of the total inflow volume. Rainfall averaged 11 million m^3/yr or 5% of the total inflow volume. The structure outflow averaged 212 million m^3/yr or 94% of the total outflow volume. ET averaged 11 million m^3/yr or 5% of the total outflow volume. Estimated net seepage averaged 1% of the total outflow volume, indicating a net loss of approximately 2 million m^3/yr. The change in storage averaged less than 1 million m^3/yr.

The total inflow and outflow TP FWM concentration for Cell 3B was 23 and 13 µg/L, respectively, over the 9-year period (**Table 3**). The cell retained an annual average of 51% of the total inflow TP load. The average TP concentration reduction in the cell was a 45%. The average annual HLR was 6.9 cm/day and the average annual PLR was 0.66 g/m^2/yr (**Table 4**). The average annual HRT was 7 days. Over the 9-year period, Cell 3B retained 25.3 t of TP or 3.00 g/m^2 (**Table 5**). The average annual TP load retention rate was approximately 0.33 g/m^2/yr**.**

Treatment Cell Performance Comparison and Summary

- Of the three EAV cells, the annual average inflow TP FWM for Cell 1A was the highest (82 µg/L) followed by 2A (65 µg/L) and 3A (55 µg/L). Cell 1A had the highest annual PLR of 1.61 $g/m^2/yr$ compared to Cells 2A and 3A which were 1.31 and 1.34 $g/m^2/yr$.
- Cell 3A had the highest HLR (6.3 cm/yr) compared to Cells 1A (4.9 cm/yr) and 2A (4.8 cm/yr). The relatively short flow path of Cell 3A compared to Cells 1A and 2A, i.e., approximately 2/3 of the length, is one of the contributing factors to the higher HLR.
- Of the three EAV cells, Cell 2A provided the best performance. The annual average outflow TP FWM concentration of 22 µg/L from Cell 2A was lower than the 23 µg/L from Cell 3A and the 32 µg/L from Cell 1A.
- Of the three SAV cells, Cell 3B had the lowest annual average outflow TP FWM concentration of 13 µg/L compared to 16 µg/L from Cell 1B and 19 µg/L from Cell 2B.
- Even though Cell 2B had the lowest annual inflow TP FWM concentrations compared to Cells 1B and 3B, the annual average outflow TP FWM concentrations from Cell 2B were the highest.
- The TP retention rates in the three EAV cells (1A, 2A and 3A) were 0.90, 0.89, and 0.81 $g/m^2/yr$, respectively. In comparison, the TP retention rates in the SAV cells (1B, 2B and 3B) were much lower with values of 0.35, 0.13, and 0.33 $g/m^2/yr$, respectively.

Numerous factors affect STA treatment performance such as HRT, HLR, PLR, and inflow TP concentration, as well as other factors not discussed herein including but not limited to operational decisions, management strategies, vegetation condition, antecedent land use, soil characteristics, treatment cell hydraulics, and extreme weather events. The improved water and phosphorus budgets from this study can be used in combination with other pertinent information to develop a better understanding of the key factors that affect the treatment performance of the STA-3/4 treatment cells (2019 SFER Volume I Chapter 5C and Appendices). More detailed analysis of STA-3/4's treatment performance is also expected to occur as part of the ongoing Data Integration effort which will be presented in future annual reports.

Table 2. Annual water budget for each cell.

Cell 1A											
Water Year	Inflow	Seepage In	Rain	Total Inflow	Outflow	Seepage Out	ET	Total Outflow	Change in Storage	Residual	Residual
	(million cubic meters [m^3 X 10^6])										%
2006	472	<1	18	490	535	10	16	561	-9	63	12
2007	218	<1	15	233	221	7	16	244	-1	9	4
2008	168	<1	17	186	168	7	16	191	5	10	6
2009	243	1	13	257	228	7	17	252	-5	-9	-4
2010	269	1	19	288	271	7	17	295	3	10	4
2011	125	4	11	140	133	3	17	153	-6	8	5
2012	105	1	19	126	107	3	17	127	6	8	6
2013	241	<1	19	260	270	7	17	294	0	34	13
2014	217	<1	18	236	254	6	17	277	-2	39	15
2015	247	<1	13	261	225	4	16	245	4	-12	-5
2016	199	<1	19	218	183	6	11	200	-2	-20	-10
2017	112	1	17	129	111	3	16	131	<1	2	2
Average	**218**	**1**	**17**	**235**	**226**	**6**	**16**	**248**	**-1**	**12**	**5**
Minimum	**105**	<1	**11**	**126**	**107**	**3**	**11**	**127**	**-9**	**-20**	**-10**
Maximum	**472**	**4**	**19**	**490**	**535**	**10**	**17**	**561**	**6**	**63**	**15**

Table 2. Continued.

Cell 1B											
Water Year	Inflow	Seepage In	Rain	Total Inflow	Outflow	Seepage Out (m^3 X 10^6)	ET	Total Outflow	Change in Storage	Residual	Residual %
2006	535	2	20	557	552	2	19	573	-6	10	2
2007	221	1	17	239	213	2	19	234	<1	-6	-2
2008	168	<1	20	189	151	3	19	173	4	-12	-7
2009	228	1	15	244	224	2	19	245	-3	-1	<1
2010	271	<1	22	293	269	3	19	291	<1	-2	-1
2011	133	1	13	147	115	2	20	137	-1	-11	-8
2012	107	<1	22	129	98	2	19	119	3	-7	-6
2013	270	<1	22	292	233	3	19	255	-2	-39	-14
2014	254	<1	21	276	230	2	19	251	0	-25	-10
2015	225	<1	15	240	207	2	19	227	2	-11	-5
2016	183	<1	21	204	187	4	12	203	-1	-2	-1
2017	111	<1	19	131	105	3	19	127	<1	-4	-3
Average	**226**	**1**	**19**	**245**	**215**	**3**	**18**	**236**	<1	**-9**	**-4**
Minimum	**107**	<1	**13**	**129**	**98**	**2**	**12**	**119**	**-6**	**-39**	**-14**
Maximum	**535**	**2**	**22**	**557**	**552**	**4**	**20**	**573**	**4**	**10**	**2**

Table 2. Continued.

Cell 2A											
Water Year	Inflow	Seepage In	Rain	Total Inflow	Outflow	Seepage Out (m^3 X 10^6)	ET	Total Outflow	Change in Storage	Residual	Residual %
2006	412	<1	15	427	324	5	14	343	-5	-90	-23
2007	164	<1	12	176	128	2	14	144	<1	-33	-21
2008	113	1	14	129	111	2	14	126	3	1	1
2009	171	1	11	183	154	3	14	171	-4	-16	-9
2010	262	<1	16	278	254	2	14	270	5	-3	-1
2011	118	<1	9	128	128	4	14	146	-4	14	10
2012	114	<1	16	130	123	2	14	139	2	11	8
2013	173	3	16	191	178	2	14	194	-4	-1	-1
2014	107	7	15	129	105	<1	14	119	4	-7	-5
2015	125	3	11	139	118	1	13	132	1	-5	-4
2016	168	1	16	184	146	1	9	155	-1	-30	-17
2017	196	1	14	211	171	2	13	187	<1	-24	-12
Average	**177**	**1**	**14**	**192**	**162**	**2**	**13**	**177**	<1	**-15**	**-8**
Minimum	**107**	<1	**9**	**128**	**105**	<1	**9**	**119**	**-5**	**-90**	**-23**
Maximum	**412**	**7**	**16**	**427**	**324**	**5**	**14**	**343**	**5**	**14**	**10**

Table 2. Continued.

Cell 2B											
Water Year	Inflow	Seepage In	Rain	Total Inflow	Outflow	Seepage Out (m^3 X 10^6)	ET	Total Outflow	Change in Storage	Residual	Residual %
2006	324	<1	17	341	354	2	15	372	-2	29	8
2007	132	1	14	147	155	2	15	173	-2	24	15
2008	111	1	16	128	101	3	16	120	4	-4	-3
2009	154	<1	12	167	168	3	16	187	-3	17	10
2010	254	<1	18	272	267	2	16	284	1	13	5
2011	128	1	11	140	120	3	16	138	-1	-2	-2
2012	123	<1	18	141	117	2	16	135	2	-4	-3
2013	168	<1	18	186	177	2	16	195	-1	8	4
2014	108	<1	17	125	107	2	16	125	<1	-1	<1
2015	118	<1	13	131	107	2	15	124	1	-6	-5
2016	146	<1	18	164	158	2	10	170	<1	6	4
2017	171	<1	16	187	168	3	15	186	<1	-1	<1
Average	**161**	**<1**	**16**	**177**	**167**	**2**	**15**	**184**	<1	**7**	**4**
Minimum	**108**	**<1**	**11**	**125**	**101**	**2**	**10**	**120**	**-3**	**-6**	**-5**
Maximum	**324**	**1**	**18**	**341**	**354**	**3**	**16**	**372**	**4**	**29**	**15**

Table 2. Continued.

Water Year	Cell 3A										
	Inflow	Seepage In	Rain	Total Inflow	Outflow	Seepage Out (m^3 X 10^6)	ET	Total Outflow	Change in Storage	Residual	Residual %
2009	217	3	11	230	201	1	14	215	-4	-19	-8
2010	286	2	15	303	262	2	13	277	5	-22	-7
2011	151	2	9	162	151	2	14	166	-5	0	<1
2012	161	1	15	178	145	2	13	160	5	-13	-8
2013	252	<1	15	268	241	3	13	257	-2	-12	-5
2014	276	<1	15	291	273	6	13	292	1	2	1
2015	267	<1	11	278	260	6	13	279	1	1	1
2016	171	1	15	187	162	3	9	173	-1	-15	-8
2017	254	<1	13	267	235	5	13	253	1	-13	-5
Average	**226**	**1**	**13**	**241**	**214**	**3**	**13**	**230**	**<1**	**-10**	**-4**
Minimum	**151**	**<1**	**9**	**162**	**145**	**1**	**9**	**160**	**-5**	**-22**	**-8**
Maximum	**286**	**3**	**15**	**303**	**273**	**6**	**14**	**292**	**5**	**2**	**1**

Table 2. Continued.

Cell 3B											
Water Year	Inflow	Seepage In	Rain	Total Inflow	Outflow	Seepage Out (m^3 X 10^6)	ET	Total Outflow	Change in Storage	Residual	Residual %
2009	201	1	9	211	222	2	12	236	-2	23	10
2010	262	<1	13	275	273	2	11	287	1	13	5
2011	151	1	8	159	145	3	12	159	-2	-2	-1
2012	145	<1	13	158	150	2	12	164	3	9	5
2013	241	1	13	254	233	2	12	247	-1	-9	-4
2014	273	<1	13	286	249	6	11	266	<1	-20	-7
2015	260	<1	9	270	247	3	11	261	<1	-9	-3
2016	162	1	13	176	161	2	7	170	<1	-6	-3
2017	235	1	12	248	225	2	11	238	1	-9	-4
Average	**214**	**1**	**11**	**226**	**212**	**3**	**11**	**225**	**<1**	**-1**	**< 1**
Minimum	**145**	**<1**	**8**	**158**	**145**	**2**	**7**	**159**	**-2**	**-20**	**-7**
Maximum	**273**	**1**	**13**	**286**	**273**	**6**	**12**	**287**	**3**	**23**	**10**

Table 3. Annual TP budget for each cell. [a]

Cell 1A															
Water Year	**TP Load Inflow Structures (t)**	**TP Conc. Inflow Structures (µg/L)**	**TP Load Outflow Structures (t)**	**TP Conc. Outflow Structures (µg/L)**	**TP Load Rain (t)**	**TP Load Dry Deposition (t)**	**TP Conc. Seepage In (µg/L)**	**TP Load Seepage In (t)**	**TP Conc. Seepage Out (µg/L)**	**TP Load Seepage Out (t)**	**Total TP Load In (t)**	**Total TP Load Out (t)**	**Total TP Load Retained (t)**	**Percent Total TP Load Retained (%)**	**Percent TP Conc. Reduction (%)**
2006	57.22	121	30.56	59	0.18	0.39	13	0.00	51	0.50	57.79	31.05	26.74	46	51
2007	30.24	139	14.48	59	0.15	0.39	11	0.00	56	0.38	30.78	14.86	15.92	52	57
2008	14.79	88	7.45	38	0.17	0.39	9	0.00	36	0.23	15.36	7.69	7.68	50	57
2009	18.05	74	4.55	17	0.13	0.39	10	0.01	26	0.19	18.58	4.74	13.84	74	77
2010	27.37	102	10.83	36	0.19	0.39	13	0.01	39	0.28	27.96	11.11	16.85	60	65
2011	10.53	84	3.92	27	0.11	0.39	12	0.04	32	0.10	11.07	4.02	7.06	64	68
2012	6.17	59	6.29	48	0.19	0.39	13	0.01	30	0.10	6.76	6.39	0.37	5	19
2013	18.98	79	5.33	19	0.19	0.39	11	0.00	28	0.18	19.56	5.52	14.05	72	75
2014	11.43	53	6.49	26	0.18	0.39	11	0.01	22	0.13	12.01	6.61	5.40	45	50
2015	15.03	61	5.26	19	0.13	0.39	11	0.01	23	0.10	15.56	5.36	10.20	66	69
2016	12.60	63	4.31	19	0.19	0.39	11	0.00	23	0.15	13.18	4.46	8.72	66	70
2017	6.24	56	2.24	16	0.17	0.39	9	0.00	21	0.07	6.80	2.31	4.50	66	71
Average	**19.05**	**82**	**8.48**	**32**	**0.17**	**0.39**	**11**	**0.01**	32	0.20	**19.62**	8.68	10.94	56	61
Minimum	**6.17**	**53**	**2.24**	**16**	**0.11**	**0.39**	**9**	**0.00**	21	0.07	**6.76**	2.31	0.37	5	19
Maximum	**57.22**	**139**	**30.56**	**59**	**0.19**	**0.39**	**13**	**0.04**	56	0.50	**57.79**	31.05	26.74	74	77

a. All concentrations (Conc.) are flow-weighted means. Calculations labeled “Total” include all inflow and/or outflow sources. Percent TP Conc. Reduction was calculated based on the structure flow TP concentrations.

Table 3. Continued.

Cell 1B															
Water Year	**TP Load Inflow Structures (t)**	**TP Conc. Inflow Structures (µg/L)**	**TP Load Outflow Structures (t)**	**TP Conc. Outflow Structures (µg/L)**	**TP Load Rain (t)**	**TP Load Dry Deposition (t)**	**TP Conc. Seepage In (µg/L)**	**TP Load Seepage In (t)**	**TP Conc. Seepage Out (µg/L)**	**TP Load Seepage Out (t)**	**Total TP Load In (t)**	**Total TP Load Out (t)**	**Total TP Load Retained (t)**	**Percent Total TP Load Retained (%)**	**Percent TP Conc. Reduction (%)**
2006	31.67	59	12.55	23	0.20	0.45	13	0.02	23	0.06	32.34	12.60	19.74	61	62
2007	13.02	59	4.64	22	0.17	0.45	11	0.01	23	0.05	13.64	4.69	8.95	66	63
2008	6.40	38	2.90	19	0.20	0.45	9	0.00	16	0.06	7.06	2.96	4.10	58	49
2009	3.83	17	2.89	13	0.15	0.45	10	0.01	8	0.02	4.44	2.91	1.53	34	23
2010	9.66	36	3.68	14	0.22	0.45	13	0.00	14	0.04	10.33	3.72	6.61	64	62
2011	3.54	27	1.86	16	0.13	0.45	12	0.01	12	0.03	4.12	1.88	2.24	54	39
2012	5.09	48	1.95	20	0.22	0.45	13	0.00	19	0.03	5.76	1.98	3.78	66	58
2013	5.27	19	3.46	15	0.22	0.45	11	0.00	10	0.03	5.93	3.48	2.45	41	24
2014	6.62	26	2.94	13	0.21	0.45	11	0.01	11	0.02	7.28	2.97	4.31	59	51
2015	4.30	19	3.16	15	0.15	0.45	11	0.00	10	0.02	4.90	3.17	1.73	35	20
2016	3.44	19	1.97	11	0.21	0.45	11	0.00	8	0.03	4.10	2.00	2.09	51	44
2017	1.84	16	1.09	10	0.19	0.45	9	0.00	8	0.02	2.48	1.12	1.36	55	37
Average	**7.89**	**32**	**3.59**	**16**	**0.19**	**0.45**	**11**	**0.01**	13	0.03	8.53	3.63	4.91	58	50
Minimum	**1.84**	**16**	**1.09**	**10**	**0.13**	**0.45**	**9**	**0.00**	8	0.02	2.48	1.12	1.36	34	20
Maximum	**31.67**	**59**	**12.55**	**23**	**0.22**	**0.45**	**13**	**0.02**	23	0.06	32.34	12.60	19.74	66	63

a. All concentrations (Conc.) are flow-weighted means. Calculations labeled “Total” include all inflow and/or outflow sources. Percent TP Conc. Reduction was calculated based on the structure flow TP concentrations.

Table 3. Continued.

Cell 2A															
Water Year	TP Load Inflow Structures (t)	TP Conc. Inflow Structures (µg/L)	TP Load Outflow Structures (t)	TP Conc. Outflow Structures (µg/L)	TP Load Rain (t)	TP Load Dry Deposition (t)	TP Conc. Seepage In (µg/L)	TP Load Seepage In (t)	TP Conc. Seepage Out (µg/L)	TP Load Seepage Out (t)	Total TP Load In (t)	Total TP Load Out (t)	Total TP Load Retained (t)	Percent Total TP Load Retained (%)	Percent TP Conc. Reduction (%)
2006	48.27	117	20.29	63	0.15	0.32	13	0.00	51	0.24	48.75	20.53	28.22	58	47
2007	16.58	101	4.35	34	0.12	0.32	11	0.00	38	0.08	17.03	4.42	12.61	74	66
2008	5.32	47	2.74	25	0.14	0.32	9	0.01	20	0.04	5.79	2.78	3.01	52	47
2009	12.50	73	2.40	16	0.11	0.32	10	0.01	25	0.08	12.94	2.48	10.46	81	79
2010	20.08	77	6.62	26	0.16	0.32	13	0.01	29	0.06	20.57	6.68	13.89	68	66
2011	6.29	53	2.34	18	0.09	0.32	12	0.00	20	0.07	6.71	2.41	4.30	64	66
2012	5.92	52	1.90	15	0.16	0.32	13	0.01	19	0.04	6.40	1.94	4.47	70	70
2013	10.26	59	2.20	12	0.16	0.32	11	0.03	21	0.04	10.77	2.24	8.53	79	79
2014	5.89	55	1.75	17	0.15	0.32	11	0.07	20	0.00	6.44	1.75	4.69	73	70
2015	6.74	54	1.65	14	0.11	0.32	11	0.03	19	0.01	7.21	1.66	5.55	77	74
2016	9.35	56	1.72	12	0.15	0.32	11	0.01	19	0.01	9.84	1.74	8.11	82	79
2017	6.07	31	1.95	11	0.14	0.32	9	0.01	12	0.02	6.55	1.97	4.57	70	63
Average	**12.77**	**65**	**4.16**	**22**	**0.14**	**0.32**	**11**	**0.02**	25	0.1	13.25	4.22	9.03	68	66
Minimum	**5.32**	**31**	**1.65**	**11**	**0.09**	**0.32**	**9**	**0.00**	12	0.0	5.79	1.66	3.01	52	47
Maximum	**48.27**	**117**	**20.29**	**63**	**0.16**	**0.32**	**13**	**0.07**	51	0.2	48.75	20.53	28.22	82	79

a. All concentrations (Conc.) are flow-weighted means. Calculations labeled “Total” include all inflow and/or outflow sources. Percent TP Conc. Reduction was calculated based on the structure flow TP concentrations.

Table 3. Continued.

Cell 2B															
Water Year	TP Load Inflow Structures (t)	TP Conc. Inflow Structures (µg/L)	TP Load Outflow Structures (t)	TP Conc. Outflow Structures (µg/L)	TP Load Rain (t)	TP Load Dry Deposition (t)	TP Conc. Seepage In (µg/L)	TP Load Seepage In (t)	TP Conc. Seepage Out (µg/L)	TP Load Seepage Out (t)	Total TP Load In (t)	Total TP Load Out (t)	Total TP Load Retained (t)	Percent Total TP Load Retained (%)	Percent TP Conc. Reduction (%)
2006	20.28	63	9.14	26	0.17	0.37	13	0.00	25	0.05	20.82	9.19	11.63	56	59
2007	4.49	34	3.46	22	0.14	0.37	11	0.01	16	0.03	5.00	3.49	1.51	30	34
2008	2.74	25	2.34	23	0.16	0.37	9	0.00	13	0.04	3.28	2.38	0.90	27	7
2009	2.40	16	2.28	14	0.12	0.37	10	0.00	8	0.02	2.90	2.31	0.59	20	13
2010	6.62	26	4.37	16	0.18	0.37	13	0.00	12	0.02	7.16	4.39	2.77	39	37
2011	2.34	18	2.45	20	0.11	0.37	12	0.01	11	0.03	2.82	2.48	0.34	12	-12
2012	1.89	15	2.46	21	0.18	0.37	13	0.00	10	0.02	2.44	2.48	-0.04	-2	-37
2013	2.07	12	2.85	16	0.18	0.37	11	0.00	8	0.02	2.62	2.86	-0.25	-9	-30
2014	1.79	17	2.38	22	0.17	0.37	11	0.00	11	0.03	2.34	2.41	-0.07	-3	-33
2015	1.65	14	1.97	18	0.13	0.37	11	0.00	9	0.02	2.15	1.99	0.16	8	-32
2016	1.72	12	1.97	12	0.18	0.37	11	0.00	7	0.02	2.27	1.99	0.29	13	-5
2017	1.95	11	2.04	12	0.16	0.37	9	0.00	7	0.02	2.48	2.06	0.42	17	-6
Average	**4.16**	**22**	**3.14**	**19**	**0.16**	**0.37**	**11**	**0.00**	11	0.0	4.69	3.17	1.52	32	15
Minimum	**1.65**	**11**	**1.97**	**12**	**0.11**	**0.37**	**9**	**0.00**	7	0.0	2.15	1.99	-0.25	-9	-37
Maximum	**20.28**	**63**	**9.14**	**26**	**0.18**	**0.37**	**13**	**0.01**	25	0.1	20.82	9.19	11.63	56	59

a. All concentrations (Conc.) are flow-weighted means. Calculations labeled “Total” include all inflow and/or outflow sources. Percent TP Conc. Reduction was calculated based on the structure flow TP concentrations.

Table 3. Continued.

Cell 3A															
Water Year	TP Load Inflow Structures (t)	TP Conc. Inflow Structures (µg/L)	TP Load Outflow Structures (t)	TP Conc. Outflow Structures (µg/L)	TP Load Rain (t)	TP Load Dry Deposition (t)	TP Conc. Seepage In (µg/L)	TP Load Seepage In (t)	TP Conc. Seepage Out (µg/L)	TP Load Seepage Out (t)	Total TP Load In (t)	Total TP Load Out (t)	Total TP Load Retained (t)	Percent Total TP Load Retained (%)	Percent TP Conc. Reduction (%)
2009	18.42	85	4.04	20	0.11	0.31	10	0.03	30	0.02	18.86	4.06	14.80	78	76
2010	19.92	70	9.62	37	0.15	0.31	13	0.03	30	0.04	20.41	9.66	10.75	53	47
2011	7.78	52	3.09	20	0.09	0.31	12	0.02	20	0.03	8.20	3.12	5.08	62	60
2012	5.75	36	3.14	22	0.15	0.31	13	0.02	16	0.02	6.23	3.17	3.07	49	39
2013	12.74	51	4.12	17	0.15	0.31	11	0.00	19	0.06	13.21	4.17	9.03	68	66
2014	12.53	45	9.28	34	0.15	0.31	11	0.00	22	0.12	12.99	9.40	3.60	28	25
2015	17.06	64	5.46	21	0.11	0.31	11	0.00	24	0.13	17.48	5.59	11.89	68	67
2016	9.96	58	3.77	23	0.15	0.31	11	0.01	23	0.05	10.43	3.83	6.60	63	60
2017	9.88	39	3.95	17	0.13	0.31	9	0.00	16	0.07	10.33	4.02	6.30	61	57
Average	**12.67**	**55**	**5.16**	**23**	**0.13**	**0.31**	**11**	**0.01**	22	0.06	13.13	5.23	7.90	60	58
Minimum	**5.75**	**36**	**3.09**	**17**	**0.09**	**0.31**	**9**	**0.00**	16	0.02	6.23	3.12	3.07	28	25
Maximum	**19.92**	**85**	**9.62**	**37**	**0.15**	**0.31**	**13**	**0.03**	30	0.13	20.41	9.66	14.80	78	76

a. All concentrations (Conc.) are flow-weighted means. Calculations labeled “Total” include all inflow and/or outflow sources. Percent TP Conc. Reduction was calculated based on the structure flow TP concentrations.

Table 3. Continued.

Cell 3B															
Water Year	TP Load Inflow Structures (t)	TP Conc. Inflow Structures (µg/L)	TP Load Outflow Structures (t)	TP Conc. Outflow Structures (µg/L)	TP Load Rain (t)	TP Load Dry Deposition (t)	TP Conc. Seepage In (µg/L)	TP Load Seepage In (t)	TP Conc. Seepage Out (µg/L)	TP Load Seepage Out (t)	Total TP Load In (t)	Total TP Load Out (t)	Total TP Load Retained (t)	Percent Total TP Load Retained (%)	Percent TP Conc. Reduction (%)
2009	4.04	20	2.63	12	0.09	0.27	10	0.01	9	0.01	4.41	2.64	1.77	40	41
2010	9.62	37	4.07	15	0.13	0.27	13	0.00	15	0.02	10.03	4.10	5.93	59	59
2011	3.09	20	1.92	13	0.08	0.27	12	0.01	9	0.02	3.45	1.94	1.51	44	35
2012	3.14	22	2.24	15	0.13	0.27	13	0.00	10	0.02	3.55	2.26	1.29	36	31
2013	4.12	17	2.93	13	0.13	0.27	11	0.01	8	0.01	4.52	2.95	1.58	35	26
2014	9.28	34	3.14	13	0.13	0.27	11	0.00	13	0.05	9.68	3.19	6.48	67	63
2015	5.46	21	3.17	13	0.09	0.27	11	0.00	10	0.02	5.83	3.19	2.64	45	39
2016	3.77	23	1.91	12	0.13	0.27	11	0.01	10	0.02	4.18	1.93	2.25	54	49
2017	3.95	17	2.46	11	0.12	0.27	9	0.01	8	0.01	4.35	2.47	1.87	43	35
Average	**5.16**	**23**	**2.72**	**13**	**0.11**	**0.27**	**11**	**0.01**	10	0.02	5.55	2.74	2.81	51	45
Minimum	**3.09**	**17**	**1.91**	**11**	**0.08**	**0.27**	**9**	**0.00**	8	0.01	3.45	1.93	1.29	35	26
Maximum	**9.62**	**37**	**4.07**	**15**	**0.13**	**0.27**	**13**	**0.01**	15	0.05	10.03	4.10	6.48	67	63

a. All concentrations (Conc.) are flow-weighted means. Calculations labeled “Total” include all inflow and/or outflow sources. Percent TP Conc. Reduction was calculated based on the structure flow TP concentrations.

Table 4. Effective treatment area, operational period, depth, HLR, PLR, and HRT for each cell.

Cell 1A						
Water Year	**Effective Treatment Area (hectare)**	**Days of Operation (day)**	**Average Depth (meter)**	**HLR (cm/d)**	**PLR ($g/m^2/yr$)**	**HRT (day)**
2006	1,222	365	0.72	10.6	4.73	6
2007	1,222	365	0.52	4.9	2.52	11
2008	1,222	365	0.53	3.8	1.26	14
2009	1,222	366	0.65	5.4	1.52	13
2010	1,222	365	0.64	6.0	2.29	11
2011	1,222	365	0.44	2.8	0.91	15
2012	1,222	365	0.46	2.4	0.55	19
2013	1,222	366	0.63	5.4	1.60	10
2014	1,222	365	0.62	4.9	0.98	11
2015	1,222	365	0.65	5.5	1.27	13
2016	1,222	365	0.71	4.5	1.08	17
2017	1,222	366	0.67	2.5	0.56	27
Average	**1,222**	**365**	**0.60**	4.9	**1.61**	14
Minimum	**1,222**	**365**	**0.44**	2.4	**0.55**	6
Maximum	**1,222**	**366**	**0.72**	10.6	**4.73**	27
Cell 1B						
Water Year	**Effective Treatment Area (hectare)**	**Days of Operation (day)**	**Average Depth (meter)**	**HLR (cm/d)**	**PLR ($g/m^2/yr$)**	**HRT (day)**
2006	1,399	365	0.54	10.5	2.31	5
2007	1,399	365	0.46	4.3	0.98	11
2008	1,399	365	0.49	3.3	0.50	17
2009	1,399	366	0.52	4.4	0.32	12
2010	1,399	365	0.50	5.3	0.74	9
2011	1,399	365	0.43	2.6	0.29	19
2012	1,399	365	0.40	2.1	0.41	21
2013	1,399	366	0.48	5.3	0.42	11
2014	1,399	365	0.44	5.0	0.52	10
2015	1,399	365	0.46	4.4	0.35	11
2016	1,399	365	0.54	3.6	0.29	15
2017	1,399	366	0.53	2.2	0.18	26
Average	**1,399**	**365**	**0.48**	4.41	**0.61**	14
Minimum	**1,399**	**365**	**0.40**	2.10	**0.18**	5
Maximum	**1,399**	**366**	**0.54**	10.48	**2.31**	26

Table 4. Continued.

Cell 2A						
Water Year	**Effective Treatment Area (hectare)**	**Days of Operation (day)**	**Average Depth (meter)**	**HLR (cm/d)**	**PLR ($g/m^2/yr$)**	**HRT (day)**
2006	1,014	365	0.69	11.1	4.81	8
2007	1,014	365	0.52	4.4	1.68	15
2008	1,014	365	0.59	3.1	0.57	20
2009	1,014	366	0.69	4.6	1.28	17
2010	1,014	365	0.67	7.1	2.03	10
2011	1,014	365	0.60	3.2	0.66	17
2012	1,014	365	0.51	3.1	0.63	15
2013	1,014	366	0.59	4.6	1.06	12
2014	1,014	365	0.45	2.9	0.64	16
2015	1,014	365	0.57	3.4	0.71	18
2016	1,014	365	0.65	4.5	0.97	17
2017	1,014	366	0.72	5.3	0.65	16
Average	**1,014**	**365**	**0.61**	4.77	**1.31**	15
Minimum	**1,014**	**365**	**0.45**	2.90	**0.57**	8
Maximum	**1,014**	**366**	**0.72**	11.14	**4.81**	20
Cell 2B						
Water Year	**Effective Treatment Area (hectare)**	**Days of Operation (day)**	**Average Depth (meter)**	**HLR (cm/d)**	**PLR ($g/m^2/yr$)**	**HRT (day)**
2006	1,151	365	0.54	7.7	1.81	6
2007	1,151	365	0.46	3.2	0.43	12
2008	1,151	365	0.50	2.6	0.29	21
2009	1,151	366	0.55	3.6	0.25	14
2010	1,151	365	0.50	6.0	0.62	8
2011	1,151	365	0.45	3.1	0.25	16
2012	1,151	365	0.40	2.9	0.21	14
2013	1,151	366	0.48	4.0	0.23	11
2014	1,151	365	0.40	2.6	0.20	16
2015	1,151	365	0.42	2.8	0.19	17
2016	1,151	365	0.49	3.5	0.20	13
2017	1,151	366	0.51	4.1	0.22	13
Average	**1,151**	**365**	**0.48**	3.84	**0.41**	13
Minimum	**1,151**	**365**	**0.40**	2.57	**0.19**	6
Maximum	**1,151**	**366**	**0.55**	7.72	**1.81**	21

Table 4-3A. Continued.

Cell 3A						
Water Year	**Effective Treatment Area (hectare)**	**Days of Operation (day)**	**Average Depth (meter)**	**HLR (cm/d)**	**PLR ($g/m^2/yr$)**	**HRT (day)**
2009	977	366	0.50	6.0	1.93	9
2010	977	365	0.54	8.0	2.09	7
2011	977	365	0.47	4.2	0.84	11
2012	977	365	0.44	4.5	0.64	11
2013	977	366	0.57	7.0	1.35	8
2014	977	365	0.57	7.7	1.33	7
2015	977	365	0.60	7.5	1.79	8
2016	977	365	0.58	4.8	1.07	13
2017	977	366	0.67	7.1	1.06	10
Average	**977**	**365**	**0.55**	6.33	**1.34**	9
Minimum	**977**	**365**	**0.44**	4.23	**0.64**	7
Maximum	**977**	**366**	**0.67**	8.02	**2.09**	13
Cell 3B						
Water Year	**Effective Treatment Area (hectare)**	**Days of Operation (day)**	**Average Depth (meter)**	**HLR (cm/d)**	**PLR ($g/m^2/yr$)**	**HRT (day)**
2009	845	366	0.48	6.5	0.52	7
2010	845	365	0.49	8.5	1.19	6
2011	845	365	0.43	4.9	0.41	9
2012	845	365	0.40	4.7	0.42	8
2013	845	366	0.47	7.8	0.54	6
2014	845	365	0.46	8.9	1.15	6
2015	845	365	0.44	8.4	0.69	5
2016	845	365	0.46	5.2	0.50	9
2017	845	366	0.48	7.6	0.51	7
Average	**845**	**365**	**0.46**	6.94	**0.66**	7
Minimum	**845**	**365**	**0.40**	4.70	**0.41**	5
Maximum	**845**	**366**	**0.49**	8.86	**1.19**	9

Table 5. Period of record[a] treatment performance summary for all treatment cells in STA-3/4. [b]

	Total TP Load Retained (%)	TP Concentration Reduction (%)	HRT (days)	HLR (cm/d)	PLR ($g/m^2/yr$)	TP Load Retained (t)	Average TP Load Retained (t/year)	TP Load Retained for POR (g/m^2)	Unit TP Load Retention Rate ($g/m^2/yr$)
Cell 1A	56	61	14	4.9	1.61	131.3	10.94	10.74	0.90
Cell 1B	58	50	14	4.4	0.61	58.9	4.91	4.21	0.35
Cell 2A	68	66	15	4.8	1.31	108.4	9.03	10.69	0. 89
Cell 2B	32	15	13	3.8	0.41	18.3	1.52	1.59	0.13
Cell 3A	60	58	9	6.3	1.34	71.1	7.90	7.28	0.81
Cell 3B	51	45	7	6.9	0.66	25.3	2.81	3.00	0.33

a. The period of record for Cells 1A, 1B, 2A, and 2B is from WY2006 to WY2017 and for Cells 3A and 3B is from WY2009 to WY2017.

b. Calculations labeled “Total” include all inflow and/or outflow sources.

LITERATURE CITED

Pietro, K. and D. Ivanoff. 2015. Comparison of long-term phosphorous removal performance of two large-scale constructed wetlands in South Florida, U.S.A. *Ecological Engineering* 79:143-157.

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

SFWMD. 2007. Chapter 5B: Performance and Operation of the Everglades Stormwater Treatment Areas. In: *2007 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2013. Appendix 5-2: Water Budgets, Total Phosphorus Budgets and Treatment Performance in STA treatment Cells and Flow-ways. In: *2013 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Zhao, H and T. Piccone. In prep. *Water and Total Phosphorus Budget and Performance Analysis for STA-3/4 Treatment Cells*. South Florida Water Management District, West Palm Beach, FL.

James, R.T., D. Ivanoff, T. Piccone, and J. King. Chapter 5C, Restoration Strategies Science Plan Implementation. In 2019 South Florida Environmental Report -Volume I (Draft), West Palm Beach, FL. November 2018.