S O U T H   F L O R I D A   W A T E R   M A N A G E M E N T   D I S T R I C T

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

Evaluation of the Influence of Canal Conveyance Features on Stormwater Treatment Area and Flow Equalization Basin Inflow and Outflow Total Phosphorus Concentrations

Stormwater Treatment Area 1 West Discharge Canal Evaluation Report

WR-2017-005

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EXECUTIVE SUMMARY

The Everglades Stormwater Treatment Areas (STAs) were constructed and are operated to reduce total phosphorus (TP) concentrations in runoff water. To further optimize the performance of the STAs and meet stringent regulatory limits, the South Florida Water Management District has been conducting scientific evaluations that could provide information related to new management and operational strategies.

The objective of the Evaluation of the Influence of Canal Conveyance Features on Stormwater Treatment Area and Flow Equalization Basin Inflow and Outflow Total Phosphorus Concentrations Study is to determine if TP concentrations change when water is conveyed along STA canals and to estimate how much TP load has been exported from or accumulated in canals throughout the analysis period. A mass balance approach based on the different temporal scales was used in the analysis. The temporal scales studied include monthly, seasonal, and annual analyses. This report documents the Phase I evaluation (analysis of existing data) for the STA-1 West (STA-1W) Discharge Canal.

The various analyses suggest that from the inflow structures to outflow structures there was a significant reduction in particulate phosphorus and a corresponding reduction in TP in the canal over the period analyzed (May 1, 2002, to April 30, 2013). The results suggest that the canal acted as a TP sink during the period, depositing approximately 51 to 55 metric tons of TP, approximately 45 metric tons of which was in the form of particulate phosphorus.

During the evaluation of this canal, the design for STA-1W Expansion Project was finalized and construction began. Once the Expansion #1 construction is complete, the STA-1W Discharge Canal will no longer serve as the discharge canal for the STA. Therefore, no further analysis is recommended for the STA-1W Discharge Canal.

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INTRODUCTION

BACKGROUND

To address water quality concerns associated with existing flows to the Everglades Protection Area (EPA), the South Florida Water Management District (SFWMD or District), Florida Department of Environmental Protection (FDEP), and United States Environmental Protection Agency (USEPA) engaged in technical discussions starting in 2010. The primary objectives were to establish a water quality based effluent limit (WQBEL) that would achieve compliance with the State of Florida's numeric total phosphorus (TP) criterion in the EPA and to identify a suite of additional water quality projects to work in conjunction with the existing Everglades Stormwater Treatment Areas (STAs) to meet the WQBEL. The *Science Plan for the Everglades Stormwater Treatment Areas* (Science Plan; SFWMD, 2013) is being implemented to evaluate critical factors that influence phosphorus (P) treatment performance. It was developed in coordination with key state and federal agencies and experts and was designed to increase the understanding of factors that affect treatment performance at low TP concentrations (< 20 micrograms per liter [µg/L], or parts per billion [ppb]). The findings from these studies are intended to be used to inform the design and operation of other Restoration Strategies for Clean Water for the Everglades (Restoration Strategies) projects, which will ultimately help improve the SFWMD's capabilities to manage TP in the STAs for achievement of the WQBEL. The Evaluation of the Influence of Canal Conveyance Features on STA and Flow Equalization Basin (FEB) Inflow and Outflow TP Concentrations Study (Canal Study) is one study included in the Science Plan.

Surface water TP concentrations have been observed to change along canal reaches between STA inflow pump stations and inflow structures at the upstream end of the STA flow-ways. Several mechanisms could drive these changes. Particulates, which could include total suspended, settleable, and dissolved solids, are a component of stormwater and are present in STA inflow and outflow canals. Settleable particulates, including those containing P, can settle in these canals. Total suspended solids (TSS) can also settle when resistance to flow is present, such as vegetation, soil formation, or debris. It is hypothesized that high flow velocities can induce sediment resuspension, which can result in elevated TP in inflow water or elevated TP in the outflow collection canals. Also, during severe droughts, water levels in some canals are lowered to the extent that the sediments are exposed. When reflooded, mineralized sediment P may be released to the overlying water column, which could also influence the water TP concentrations observed at the inflow and outflow structure sampling locations. Excessive algal growth, floating aquatic vegetation growth, and turnover can also potentially influence the concentration of P in canal surface water. Anaerobic conditions at the sediment-flood water interface could trigger release of soluble P. Seepage of water into STA canals or from adjacent water bodies might also be a contributing factor in changes in surface water TP concentration. All these factors may contribute to TP concentration changes along canals.

The Canal Study was organized in two phases consisting of desktop data analyses (Phase I) and, if needed, field studies (Phase II). The objective of the study was to determine if TP concentrations change when conveyed through STA inflow or outflow canals and, if so, determine what factors influence the change in concentrations. For the STA-1 West (STA-1W) Discharge Canal, the objective of the Phase I evaluation was to evaluate TP changes along the canal from the G-306A structure (near the north end of the STA-1W Discharge Canal) to G-310 (the STA-1W outflow pump station at the south end of the STA-1W Discharge Canal) (**Figure 1**).

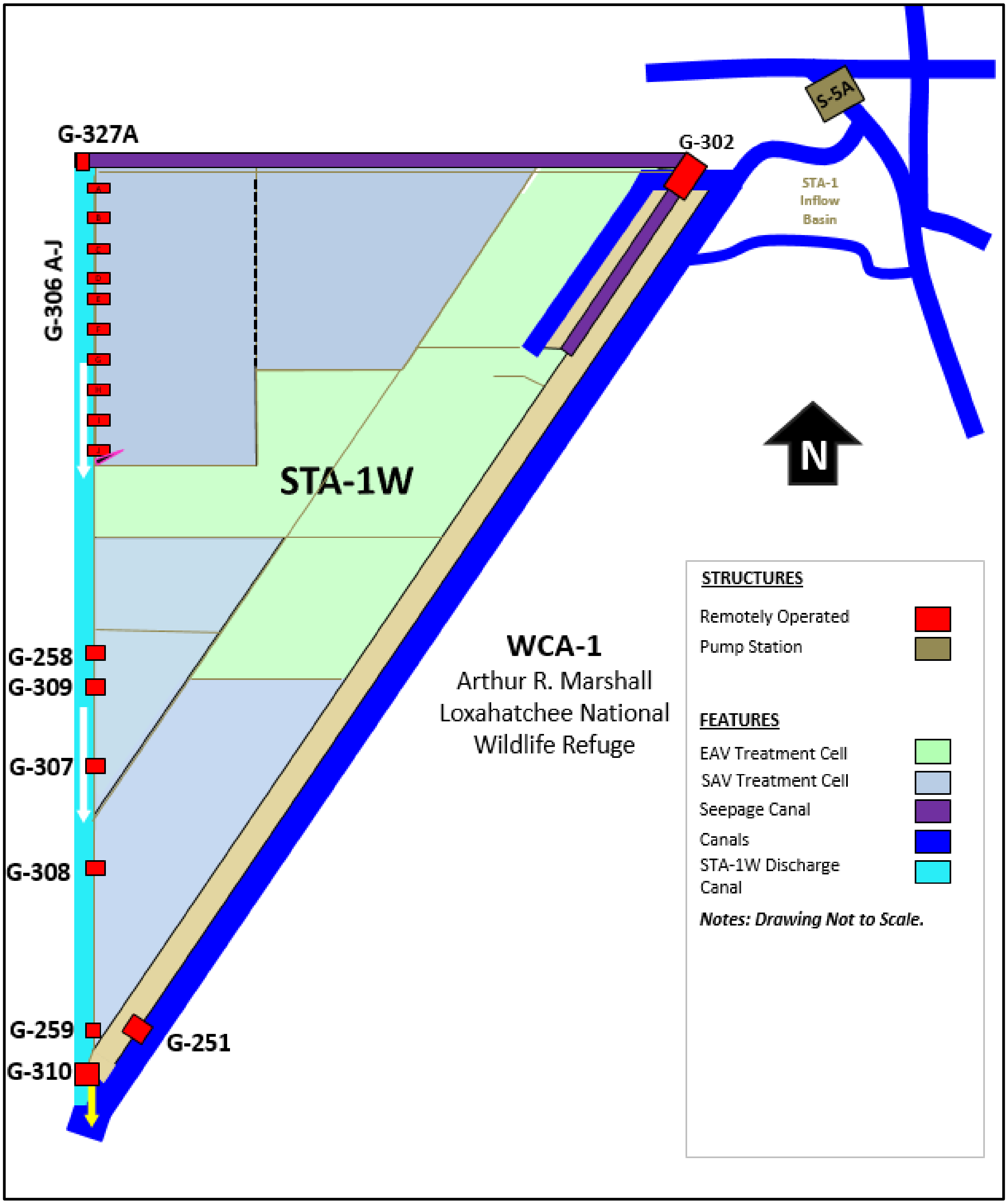

Figure 1. Map of STA-1W showing location of the STA-1W Discharge Canal. (Note: EAV – emergent aquatic vegetation; SAV – submerged aquatic vegetation; and WCA-1 – Water Conservation Area 1.)

STA-1W DISCHARGE CANAL AND STRUCTURES

The STA-1W Discharge Canal extends along the western boundary of STA-1W, from gated culvert G-327A in the northwest corner of the STA to the outflow pump station G-310 (**Figure 1**). The canal conveys discharges from the Northern Flow-way via culverts G-306A-J; the Western Flow-way via G-258, G-307, and G-309; and the Eastern Flow-way via G-259 and G-308 to the G-310 outflow pump station. The total length of the canal is approximately 30,000 feet (ft; 5.7 miles). At its origin near the G-327A structure, the canal was designed with a trapezoidal cross-section, with a bottom width of 50 ft at elevation –5.0 ft National Geodetic Vertical Datum of 1929 (NGVD29) and side slopes of 2.5:1 (horizontal:vertical). South of G-306J, the canal has a bottom width of 30 ft at elevation -5.0 ft NGVD29. The canal continues south with this cross-section until it reaches just north of outflow structure G-309, at which point the canal bottom widens to approximately 50 ft. This was done to accommodate the Western Flow-way discharges. Just north of G-308, the cross-section widens to 80 ft to accommodate the additional flows from the Eastern Flow-way. The canal cross-section bottom width expands just south of G-259 to 100 ft wide, and continues with this width to the G-310 outflow pump station (Zhao et al. 2015).

METHODS

A mass balance approach based on different temporal scales was used to evaluate the STA-1W Discharge Canal. The temporal scales studied include monthly, seasonal, and annual analyses. The mass balance analyses were conducted using the District's web-based Nutrient Load Program (NLP). Different concentration calculation modes within the NLP were used as described in the *Load Calculation Modes* section.

WATER QUALITY DATA ANALYSES

Flow and the following water quality parameters were analyzed: TP, total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), particulate phosphorus (PP), TSS, and total dissolved chloride (CL).

Conducting flow and TP mass balance was an essential step for this study. Mass balance provides an estimate of the TP discharged from or accumulated in a canal. CL acts like a conservative tracer. CL mass balance helps verify the accuracy of the water budget. TSS mass balance will give an estimate of sediments that have accumulated in a canal. Mass balance for various P fractions may help in understanding the P transformation and physical movement features. For example, increased PP concentration from the upstream to downstream location under high velocity conditions may indicate canal scouring or increased resuspension. Reduction in SRP load may indicate uptake by plants and conversion into tissue P or absorption by wetland soil and sediments. A mass balance of TDP in the system may provide an indication of any sorption of soluble P by suspended organic material in the canal water column or interaction of this P fraction with soil and vegetation in a canal. Mass balance of DOP in STA canals may provide important information if this organic P fraction undergoes any microbial or enzymatic transformation in these canals.

The nutrient load and sediment accretion (or export) estimates based on the different calculation modes were evaluated for appropriateness and reasonableness and the selected data were used to try to address the following five questions:

1. Is the canal a TP source or sink (qualitative assessment)?
2. What is the sediment accrual status (source or sink) in a canal based on the TSS load analysis (qualitative assessment)?
3. How much sediment (in metric tons [t]) has been accrued in a canal during the analysis period?

4. How much TP mass has been accreted in the canal during the analysis period?
5. How did the composition of TP change in the water column along the canal?

WATER QUALITY SAMPLING AND SURROGATES FOR MISSING DATA

The water quality parameters analyzed for the STA-1W Discharge Canal are listed in **Table 1**. **Table 2** and **Table 3** list the sampling methods and the beginning sampling dates for the water quality parameters.

Table 1. Water quality parameters analyzed.

Parameter	Unit	Test Number
Phosphate, Total as P (TP)	µg/L	25
Phosphate, ORTHO as P (SRP)	µg/L	23
Phosphate, Dissolved as P (TDP)	µg/L	26
Particulate P (PP) (calculated)	µg/L	Not applicable
Dissolved Organic P (DOP) (calculated)	µg/L	Not applicable
Total Suspended Solids (TSS)	mg/L	16
Dissolved Chloride (CL)	µg/L	32

Table 2. Sampling methods used for the water quality parameters.

Parameter	G-310	G-306A-J	G-258	G-309	G-308	G-259	G-307
TP	Auto/Grab	Auto/Grab	Auto/Grab	Auto/Grab	Auto/Grab	Auto/Grab	Auto/Grab
SRP	Grab	Grab	Grab	Grab	Grab	Grab	Grab
TDP	Grab	Grab	Grab	Grab	Grab	Grab	Grab
TSS	Grab	Grab	Grab	Grab	Grab	Grab	Grab
CL	Grab	Grab	Grab	Grab	Grab	Grab	Grab

Table 3. Beginning sampling dates for the water quality parameters.

Structures	TP	TDP	SRP	TSS	CL
G-310	6/1/2000	7/18/2000	7/18/2000	7/18/2000	7/18/2000
G-306A-E	3/5/2003	3/5/2003	3/5/2003	3/5/2003	3/5/2003
G-306F-J	5/4/1999	1/25/2000	1/26/2000	1/26/2000	1/26/2000
G-258	10/18/2000	10/18/2000	10/18/2000	12/27/2001	9/13/2005
G-309	10/18/2000	10/18/2000	10/18/2000	12/27/2001	9/13/2005
G-308	10/18/2000	11/20/2001	11/20/2001	1/19/2001	4/12/2005
G-259	10/17/2001	5/10/2005	5/10/2005	5/10/2005	5/10/2005
G-307	5/30/2006	10/5/2006	10/5/2006	10/12/2006	10/11/2006

The data set used for this analysis covers flow and water quality data from May 1, 2000, to April 30, 2013. The final data set for selected structures was adjusted based on data availability. Water quality data were from samples collected at structures G-306C and G-306G. Due to lack of water quality data at structure G-306C for the period May 1, 2000, to April 30, 2003, data for grab samples collected from G-306G, which is a similar gated culvert used to convey discharges from Cell 5B, were used. Similarly, due to lack of water quality data from structure G-259 for the period October 18, 2000, to April 30, 2005, data from grab samples taken at G-258, which is the primary structure used to convey water from the Eastern Flow-way, were used as a surrogate for G-259. Also, due to lack of water quality data from structure G-307 for the period October 18, 2000, to April 30, 2006, data for grab samples from G-309, which is a structure similar to G-307 that also conveys treated water from the Western Flow-way, were used as a surrogate for G-307. It is recognized that the use of surrogates for missing data may add some uncertainties to the overall results.

LOAD CALCULATION MODES

Load calculation modes M2 and M3 as defined in the NLP and shown below were used in the STA-1W Discharge Canal analyses. During the analysis of another canal in the Canal Study (i.e., the STA-1 Inflow Basin Canal) (Zhao et al 2016), it was found that if no autosampler data were available, the loads calculated by mode M3 and M5 were equivalent. Therefore, mode M5 was not used for the analysis of the STA-1W Discharge Canal. Using data from the grab sampling method only, the loads calculated by M3 are more reasonable than the loads calculated by other modes since M3 eliminates the possibility of calculating a load using a concentration data value that was sampled many days or months before a flow event. As TP is the only parameter collected by both autosamplers and grab samples, it is the only parameter that loads were calculated by modes M2 and M3 and the results were compared. Due to the similarity of the results obtained using these two modes, only the TP results from M2 are presented in this report. For all other water quality parameters, the loads were calculated using M3.

- Mode 2 (M2): Use autosampler results first; if missing, then use grab sample results only on days with flow; extrapolate between missing values.
- Mode 3 (M3): Use autosampler results first; if missing, then use grab samples; extrapolate between missing values.
- Mode 5 (M5): Use grab sample results; use sample results if flow or no flow exists to extrapolate between missing values.

WET AND DRY SEASON DEFINITION

In South Florida, the wet season generally starts in late May and ends in October. For consistency, a fixed period of six months was used for the wet season and the dry season, i.e., May 1 to October 31 for the wet season and November 1 to April 30 for the dry season.

MASS BALANCE EQUATION

The basic mass balance equation is as follows:

$$\text{Inflow} - \text{Outflow} = \text{Residual} \tag{1}$$

where:

Inflow Structures = G-306A-J, G-258, G-259, G-309, G-308, and G-307
Outflow Structure = G-310

RESULTS AND DISCUSSION

This section summarizes monthly, seasonal, and annual mass balance analyses for flow and water quality parameters: TP, TDP, SRP, DOP, PP, TSS, and CL. **Table 4** summarizes mass balance results for various water quality parameters associated with the STA-1W Discharge Canal. The detailed annual, monthly, and wet/dry season analyses for these parameters are presented in subsequent sections.

Table 4. STA-1W Discharge Canal Data Summary.

Parameter	Data Period	Calculation Mode	Inflow to the Canal	Outflow to the Canal	Difference (in - out)	Difference/ Inflow
Flow (ac-ft) [a]	WY2002 to WY2013	Not applicable	2,483,157	2,466,237	19,919	0.7%
TP load (t)	WY2002 to WY2013	M2	220.0	168.9	51.1	23%
	WY2002 to WY2013	M3	224.1	168.9	55.2	25%
TDP load (t)	WY2003 to WY2013	M3	124.1	119.3	4.9	3.9%
PP load (t)	WY2003 to WY2013	M3	82.9	37.6	45.3	55%
SRP load (t)	WY2003 to WY2013	M3	99.0	94.2	4.8	4.9%
DOP load (t)	WY2003 to WY2013	M3	27.1	25.1	2.0	8%
CL load (t)	WY2007 to WY2012	M3	137,969	129,054	8,915	6%
TSS load (t)	WY2003 to WY2013	M3	13,636	11,722	1,913	14%

a. ac-ft – acre-feet.

FLOW (WY2002–WY2013)

Monthly and Seasonal Flows

Figure 2 shows the monthly mean inflow and outflow volumes for the analysis period. The mean monthly inflow ranged from 2,354 acre-feet (ac-ft) in April to 41,494 ac-ft in August and the mean monthly outflow ranged from 2,174 ac-ft in April to 41,859 ac-ft in August. Both inflow and outflow volumes demonstrated an increased trend from May to October. The highest inflow and outflow volumes were in the months of August and September, which accounted for approximately 40% of annual inflow and outflow volumes. The driest month was April when both inflow and outflow volumes were approximately 2,300 ac-ft, or only 1% of the annual flow.

As shown in **Figure 3**, the mean inflow and outflow volumes also indicates a very good mass balance in the wet season with a mean percentage difference of 1% during the dry season, the mean percentage difference was relatively high at 5.9%. In 10 out of 12 years, the inflows exceeded the outflows. For the dry season, the lowest inflow and outflow volumes occurred in WY2009 (November 1, 2008–April 30, 2009) with total volume of less than 1,000 ac-ft. WY2009 was the year that South Florida experienced a severe drought with a temporary wet condition in the summer (Abtew et al. 2010). The two highest total inflow and outflow volumes during the wet season occurred in WY2003 and WY2005.

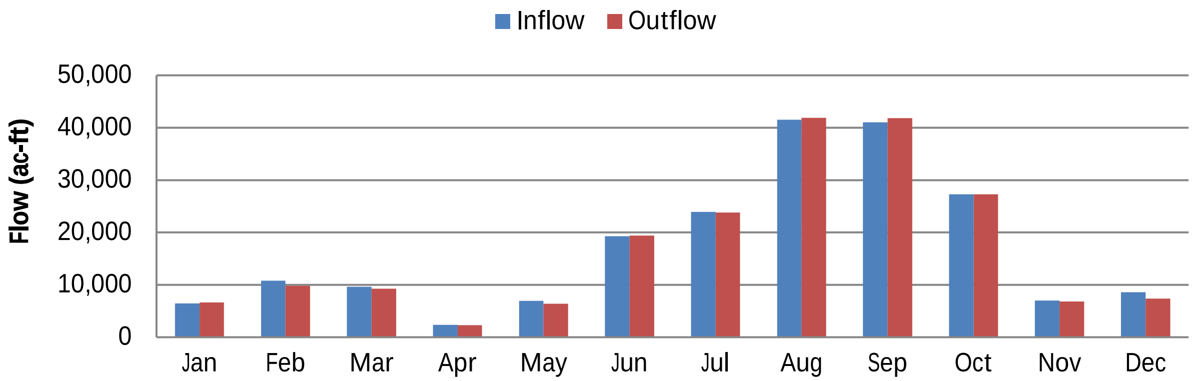

Figure 2. Monthly mean flow comparison for STA-1W discharge canal, inflow versus outflow.

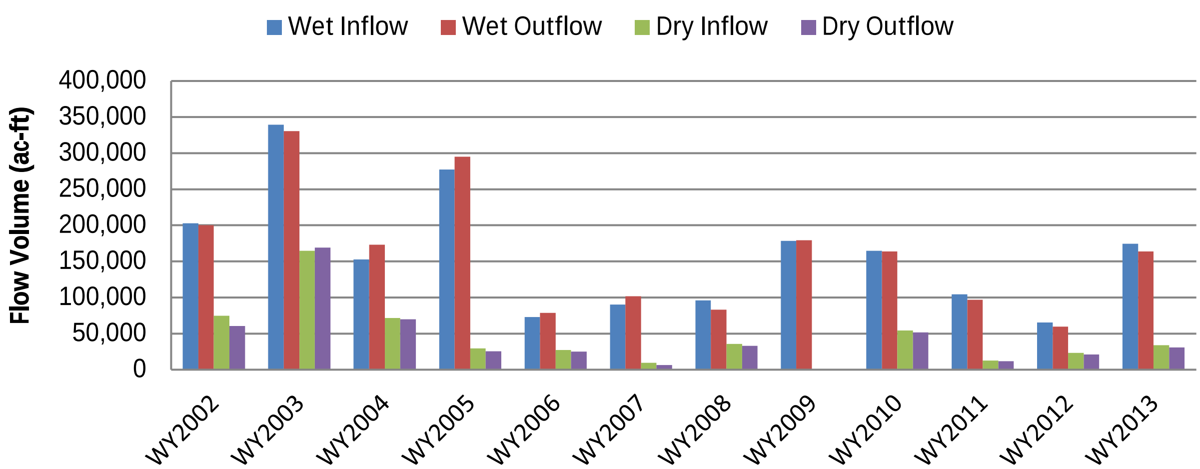

Figure 3. Seasonal flow comparison for STA-1W discharge canal, inflow versus outflow.

Annual Flow Volume

Over the analysis period, the annual inflow ranged from 88,852 ac-ft in WY2012 to 504,024 ac-ft in WY2003 with an overall inflow volume of 2,456,860 ac-ft for the entire analysis period (**Table 5** and **Figure 4**). The inflow volume for WY2003 (504,024 ac-ft) accounted for 21% of the total inflow during the analysis period, and more than 50% of the total inflow volume occurred from WY2002 to WY2005 (1,312,498 ac-ft). Outflow volumes for the same period ranged from 242,926 ac-ft in WY2004 to 499,476 in WY2003 (Table 2-5 and Figure 2-1), with an overall outflow volume of 2,432,149 ac-ft for the entire analysis period (Table 2-4). Similar to the inflow volumes, WY2003 (499,476 ac-ft) accounted for 21% of the total outflow during the analysis period, and more than 50% of the total discharge volume occurred from WY2002 to WY2005 (**Table 5** and **Figure 4**). High water levels in Lake Okeechobee during the summer of 2002 required the release of water from the lake to the Everglades with approximately 300,000 ac-ft delivered through STA-1W for treatment prior to discharge to the Water Conservation Area 1 (Goforth et al., 2004). Also, during WY2005, South Florida suffered the impact of multiple hurricanes, causing unusually high hydraulic loading and high TP inflow concentrations to the STAs. In contrast, the low inflow and outflow volumes reported for WY2001 were influenced considerably by the regional drought during this period. It was reported that except for one storm event and minimal seepage control, both discharge pumps from this STA remained idle during the dry season (Jorge et al. 2002). The overall difference of total inflow and outflow volumes was 1% (**Table 5**). The differences between inflows and outflows as summarized by water year ranged from -8.3% (WY2004) to 11.5% (WY2008). During the period from WY2002 to WY2007, the annual inflow to the canal had a mean of 252,000 ac-ft, which is 1.6 times greater than the 157,000 ac-ft annual mean inflow to the canal that occurred during the period from WY2008 toWY2013.

Table 5. Annual total flow comparison between the inflow and outflow for the STA-1W Discharge Canal Study.

Water Year	Inflow (ac-ft)	Outflow (ac-ft)	Difference (ac-ft)	Difference/Inflow (%)
WY2002	277,481	260,791	16,690	6.0
WY2003	504,024	499,476	4,548	0.9
WY2004	224,314	242,926	-18,612	-8.3
WY2005	306,679	320,518	-13,839	-4.5
WY2006	100,338	103,703	-3,365	-3.4
WY2007	100,033	108,341	-8,308	-8.3
WY2008	131,753	116,584	15,169	11.5
WY2009	178,949	179,926	-977	-0.5
WY2010	219,167	215,698	3,468	1.6
WY2011	116,924	108,751	8,174	7.0
WY2012	88,852	80,617	8,235	9.3
WY2013	208,347	194,817	13,530	6.5
Total	2,456,860	2,432,149	24,712	1.0
Mean	204,738	202,679	2,059	1.0

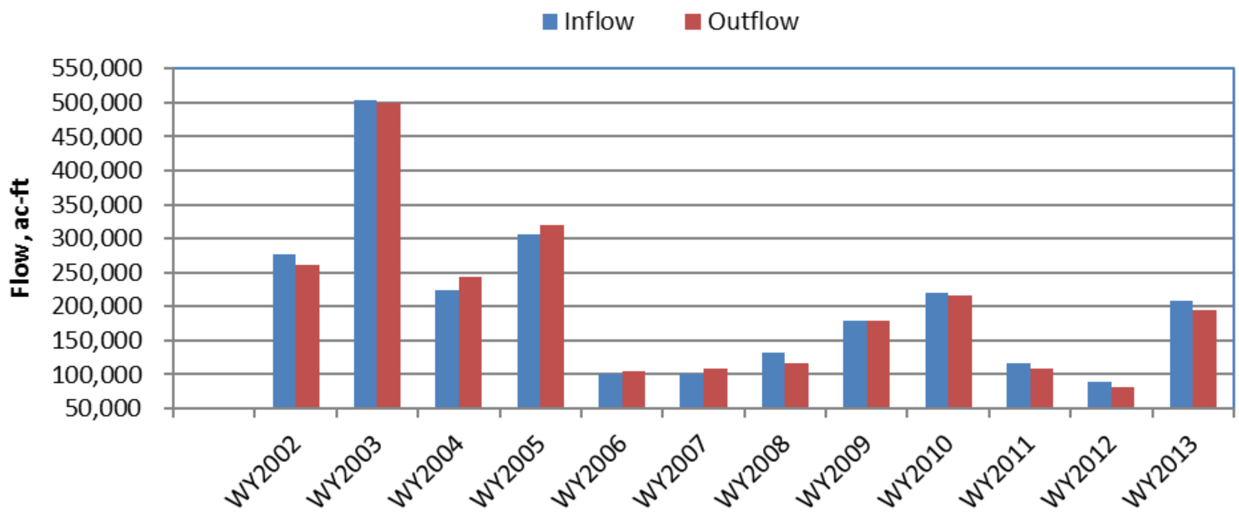

Figure 4. Annual flow comparison for the STA-1W Discharge Canal, inflow versus outflow.

TOTAL PHOSPHORUS LOADS (WY2002–WY2013)

TP Monthly and Seasonal

The monthly data indicates that, on average, the highest TP loads occurred over the three months of the wet season (August, September, and October) (**Figure 5**). Approximately 60% of the inflow and outflow TP load occurred in these three months. From May to October, there was an increasing trend in both inflow TP and outflow TP load. Reductions in TP load was observed in all 12 months. The bar chart (**Figure 5**) shows the mean TP load for each month of the 13 years analyzed. The monthly load distributions were dominated by the results from WY2003 and WY2005 due to the significant high TP inflow loads that occurred in these two years.

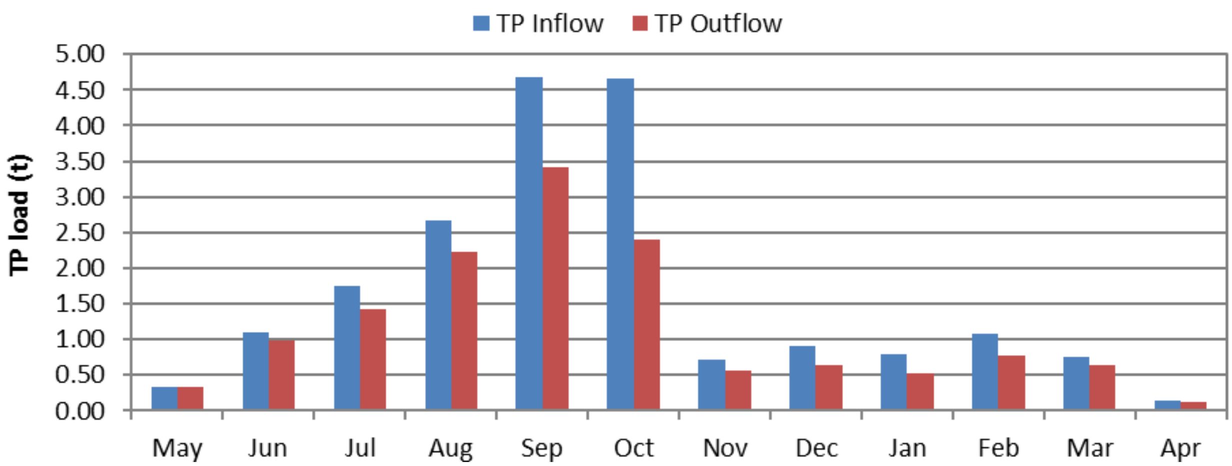

Figure 5. Monthly TP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Approximately 75% of the inflow and outflow TP load occurred in the wet season and 25% occurred in the dry season (**Figure 6**). The difference between inflow and outflow TP load for both wet and dry seasons was approximately 25%. A slight reversal (outflow load greater than inflow load) was observed in

WY2008 and WY2009. In WY2012 and WY2013, the estimated inflow and outflow TP loads were equivalent.

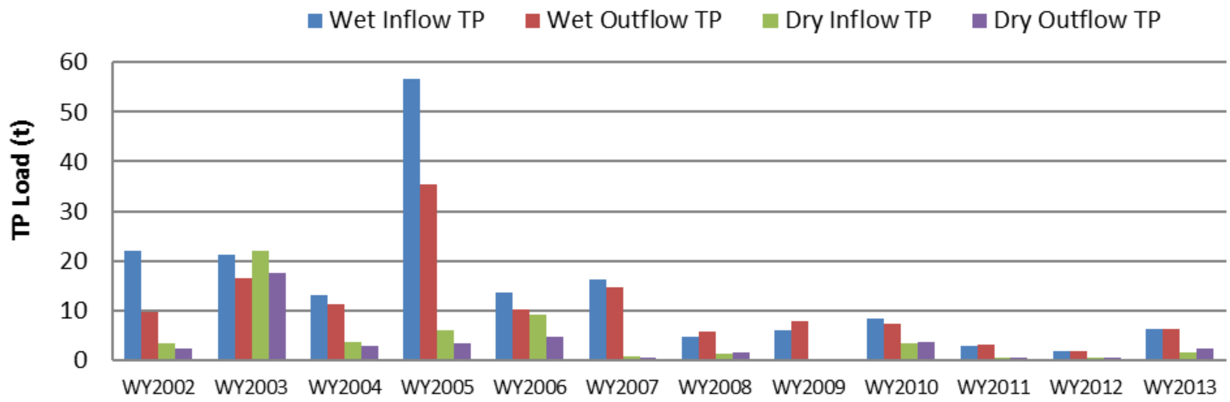

Figure 6. Seasonal total TP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

TP Annual Load Analyses

Total P loads, regardless of the calculation mode, showed high variability during WY2002-WY2013 with markedly higher loads observed during WY2002 to WY2005 (**Table 6** and **Figure 7**). Inflow TP load mean was an estimated 18.3 t per water year, with loads ranging from 2.2 t in WY2012 to 62.6 t in WY2005 (**Table 6**). During WY2002–WY2013, the STA-1W Discharge Canal received 220 t of TP (**Table 6**), with WY2005 accounting for 28.4%, and the period from WY2002 to WY2005 accounting for 66.1% of the overall inflow TP load. Outflow TP loads were generally lower, averaging an estimated 14.1 t per water year, with estimated loads ranging from 2.3 t in WY2012 to 38.7 t in WY2005. During this study period, an estimated total of 168.9 t of TP were discharged from this canal, with WY2003 and WY2005 accounting for 43.0% of the overall discharged TP (**Figure 7**). As stated in the *Flow (WY2002 TO WY2013)* section, between July 2002 and February 2003, approximately 300,000 ac-ft of Lake Okeechobee water was delivered to STA-1W for treatment prior to discharge to Water Conservation Area 1 (Goforth et al. 2004). Also during WY2005, STA-1W was impacted by strong winds and heavy rainfall from Hurricanes Frances and Jeanne, resulting in inflow TP loads 3.8 times greater than the original long-term design amount for this STA (Pietro et al. 2006). Load analysis using the M2 calculation mode suggested that 51.0 t (23.2% of inflow TP load) were retained in the STA-1W Discharge Canal, with approximately half attributed to WY2005 when there was a reduction of 38.1% of the inflow TP load. Between WY2002 and WY2007, the annual TP load to the canal mean of 31.9 t is six times more than the load from the period from WY2008 to WY2013. Prior to WY2008, the canal was a TP sink with substantial TP load reduction observed in all six years ranging from 8.3 to 49.7%. Since WY2008, the STA-1W Discharge Canal became a TP source, with estimated TP load increases from the canal inflow structures to the canal outflow structure occurred in 5 out of 6 years and ranging from 0.1 t in WY2012 to 1.7 t in WY2009.

In summary, the results from the monthly and seasonal TP analyses were consistent with the results of the annual TP analyses suggesting this canal behaved as a TP sink during the analysis period. The annual and the wet and dry season results demonstrated a slight reversal (outflow load greater than inflow load) during the period of WY2008–WY2009.

Table 6. Annual TP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	TP (Mode M2)				TP (Mode M3)			
	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)
WY2002	23.9	12.0	11.9	49.8	25.4	12.0	13.3	52.6
WY2003	42.5	33.9	8.5	20.1	43.1	33.9	9.2	21.3
WY2004	16.6	14.1	2.6	15.4	16.7	14.1	2.6	15.5
WY2005	62.6	38.7	23.9	38.1	62.5	38.7	23.8	38.1
WY2006	21.2	14.7	6.4	30.4	22.7	14.7	7.9	35.0
WY2007	16.6	15.2	1.4	8.3	16.9	15.2	1.6	9.7
WY2008	6.0	7.4	-1.3	-22.2	6.0	7.4	-1.3	-21.9
WY2009	6.1	7.8	-1.7	-28.6	6.1	7.8	-1.7	-28.6
WY2010	11.5	10.8	0.7	6.1	11.6	10.8	0.8	7.2
WY2011	3.2	3.5	-0.3	-8.6	3.2	3.5	-0.3	-8.6
WY2012	2.2	2.3	-0.1	-4.0	2.3	2.3	0.0	0.1
WY2013	7.7	8.6	-0.9	-11.7	7.8	8.5	-0.7	-9.2
Total	220.0	168.9	51.1	23.2	224.1	168.9	55.2	24.6
Mean	18.3	14.1	4.3	23.2	18.7	14.1	4.6	24.6

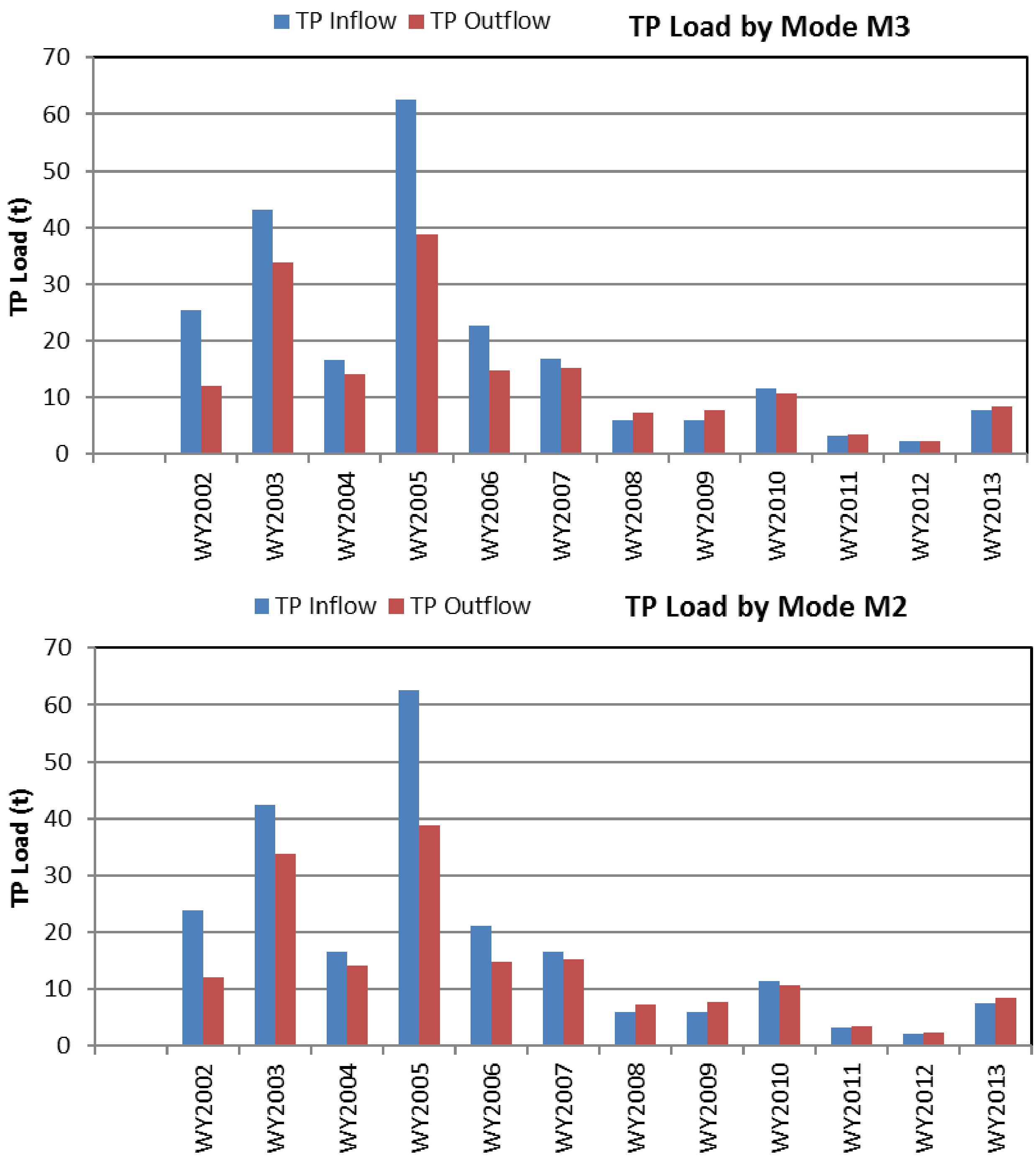

Figure 7. Annual TP load comparison by different calculation modes for the STA-1W Discharge Canal, inflow versus outflow.

TOTAL DISSOLVED PHOSPHORUS (WY2003–WY2013)

TDP Monthly and Seasonal Analyses

The monthly data suggest that, on average, for both inflow and outflow, the highest TDP loads occurred over three months of the wet season (August, September, and October) (**Figure 8**). Approximately 61% of the TDP load in and out of the canal occurred in these three months. From May to September, an increasing trend in TDP load can be observed for both inflow and outflow, consistent with flow distribution. During the dry season months, TDP loads are generally very low.

Based on the wet and dry season data (**Figure 9**), on average, for both inflow and outflow, approximately 80% of the TDP load occurred during the wet season. The seasonal chart shows total TDP loads to the canal were high during WY2003 to WY2007. The estimated annual mean TDP load to the canal during this period was 21.1 t, which is six times the annual mean TDP load to the canal occurred during WY2008 to WY2013. Despite the difference in TDP load between these two periods, the canal was a sink for TDP.

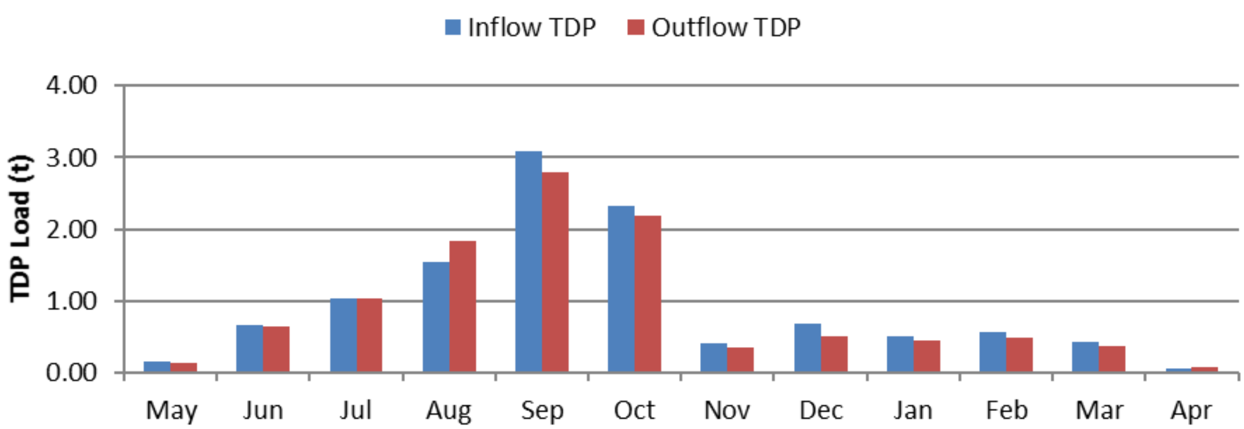

Figure 8. Monthly TDP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

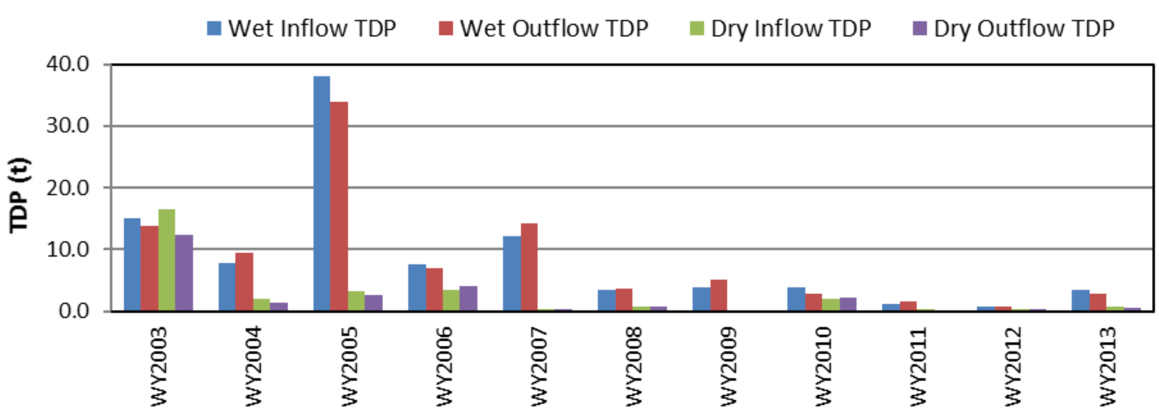

Figure 9. Seasonal TDP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

TDP Annual Analyses

The total inflow TDP load for the period from WY2003 to WY2013 was 124.1 t, which represents 62.4% of the inflow TP for the same period (**Table 7**). Annual mean inflow TDP load was 11.3 t, which ranged from 1.0 t in WY2012 to 38.9 t in WY2005. Similar to the observed TP load trend, TDP loads were considerably higher during WY2003–WY2005, with that period accounting for 65.2% of the total inflow TDP load to the STA-1W Discharge Canal (**Table 7**). Outflow TDP loads were generally lower, averaging 10.8 t per water year and ranging from 0.9 t in WY2012 to 36.5 t in WY2005. During this period, 119.3 t of TDP was discharged from the STA-1W Discharge Canal, with 53% of the total TDP load discharged in WY2003 and WY2005 (**Figure 10**). As indicated earlier in this report, approximately 300,000 ac-ft of Lake Okeechobee water was delivered to STA-1W in WY2003 (Goforth eta al. 2004). In addition, South Florida was severely impacted by Hurricanes Frances and Jeanne during WY2005 (Pietro et al. 2006). Load analysis suggests that an estimated total of 4.9 t of TDP (3.9% of inflow TDP) were retained in the STA-1W Discharge Canal. The small load difference between the inflow and outflow structures demonstrates a good conservation of mass despite the uncertainties associated with the measured flow data, water quality concentration measurement, and assumptions from the load calculation mode. More than 80% of the TDP component is SRP, which is the form of P taken up readily by plants and microorganisms and converted to tissue phosphorus (Kadlec and Wallace 2009). The small difference in percentage of TDP may be explained by the lack of vegetation in the canal. This segment of canal is very well maintained with little floating vegetation. The typical conditions in this canal most likely do not allow the sequestration of TDP due to the lack of submerged aquatic vegetation (SAV) communities and the fact that the pH level is lower than 8.5 in general.

Table 7. Annual TDP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)
WY2003	31.4	26.1	5.3	16.8
WY2004	10.7	10.8	-0.1	-1.0
WY2005	38.8	36.5	2.3	5.9
WY2006	10.3	10.9	-0.5	-4.9
WY2007	12.3	14.5	-2.2	-17.5
WY2008	4.2	4.4	-0.2	-4.5
WY2009	3.9	5.1	-1.2	-31.1
WY2010	5.7	4.9	0.8	14.4
WY2011	1.4	1.7	-0.3	-23.5
WY2012	1.0	0.9	0.2	17.5
WY2013	4.3	3.4	0.8	19.1
Total	124.1	119.3	4.9	3.9
Mean	11.3	10.8	0.4	3.9

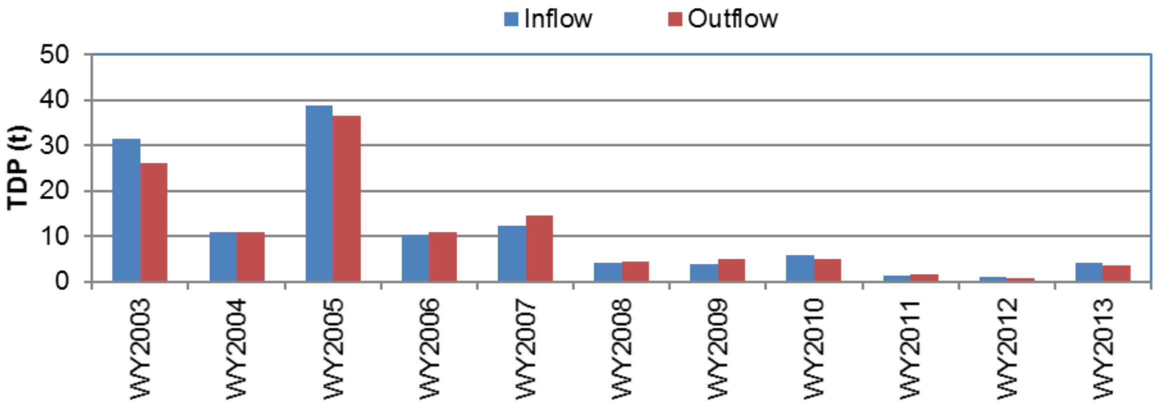

Figure 10. Annual TDP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

During WY2003 to WY2007, the inflow TDP/TP percentages (**Table 8**) were lower than the outflow TDP/TP percentages and the inflow PP/TP percentages were higher than the outflow PP/TP percentages. In other words, even though the TDP mass conservation was very well preserved in the canal, PP settling occurred during the early operation period from WY2003 to WY2007. This trend of PP settling was not observed for the operation period WY2008–WY2013 showing both positive and negative TDP/TP percentage differences.

Table 8. Inflow and outflow TDP/TP and PP/TP percentage comparison.

Water Year	TDP/TP Percentage			PP/TP Percentage		
	Inflow	Outflow	Difference	Inflow	Outflow	Difference
WY2003	73	77	-4	27	23	4
WY2004	64	77	-13	36	23	13
WY2005	62	94	-32	38	6	32
WY2006	45	74	-29	55	26	29
WY2007	73	95	-22	27	5	22
WY2008	70	60	10	30	40	-10
WY2009	64	65	-1	36	35	1
WY2010	49	45	4	51	55	-4
WY2011	44	49	-5	56	51	5
WY2012	44	39	4	56	61	-4
WY2013	55	40	15	45	60	-15

SOLUBLE REACTIVE PHOSPHORUS (WY2003–WY2013)

SRP Monthly and Seasonal Analyses

The monthly data indicates that, on average, the highest SRP loads occurred over three months of the wet season (August, September, and October) (**Figure 11)**. Approximately 65% SRP load in and out of the canal occurred in these three months. There was a notable increase in SRP load from May to September for both inflow and outflow. The comparison indicates an SRP load increase in August and a decrease for other months (**Figure 11**). Monthly data suggest some SRP settling might have occurred. The monthly distributions followed the trend that occurred in WY2003 and WY2005 due to the significantly high inflow volumes that occurred in these two years.

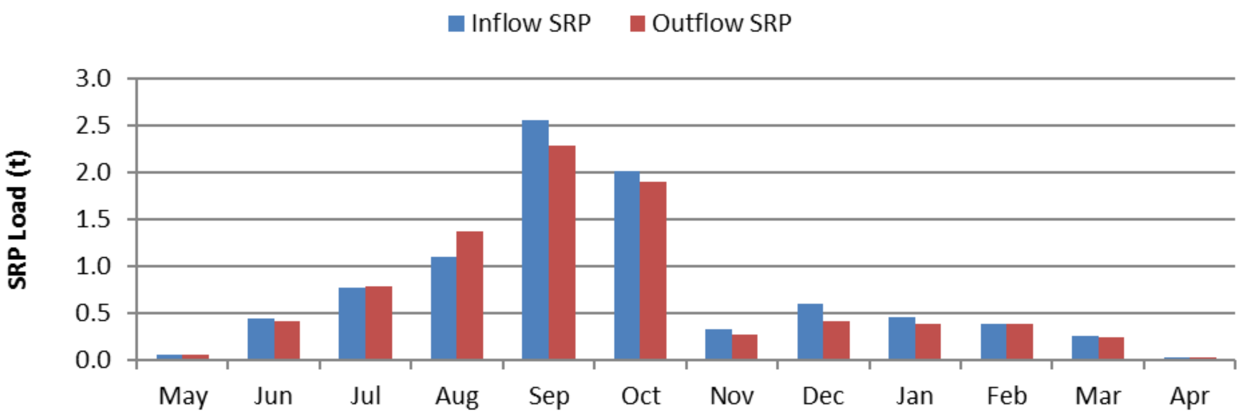

Figure 11. Monthly SRP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

The wet and dry season data indicate on average approximately 80% of the SRP load into and out of the canal occurred during the wet season (**Figure 12**). The SRP percentage changes were approximately 2%. The percentage change for the dry season was not calculated because the SRP loads were less than 1 t most of the years. The accuracy of these small numbers is questionable because of the uncertainties associated with the measured flow data, SRP measurement, and assumptions used for the load calculation, etc.

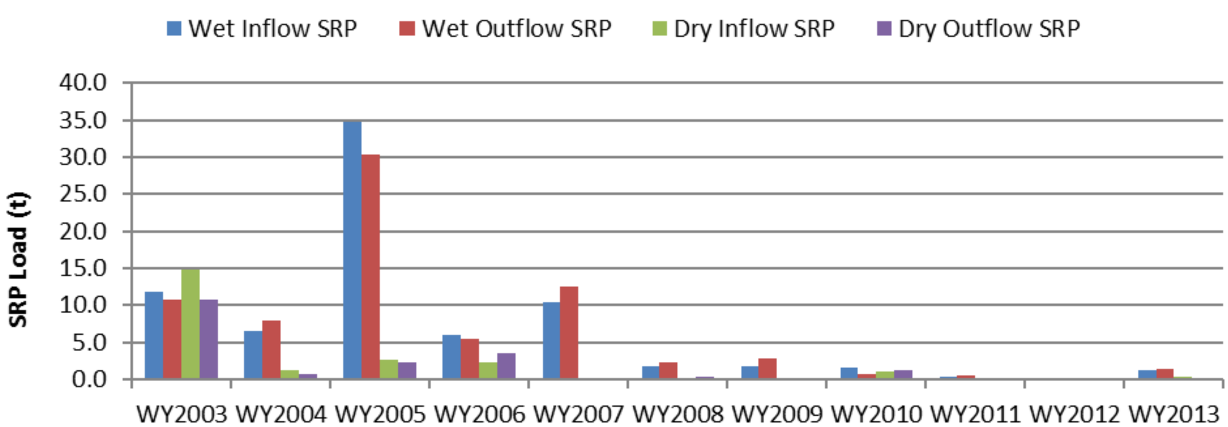

Figure 12. Seasonal SRP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

The seasonal chart shows total SRP loads to the canal were high during WY2003–WY2007. During this period, the annual mean wet season SRP load into the canal was 13.9 t, which is 12 times the annual mean wet season SRP load into the canal during WY2008–WY2013. In comparison, outflow load from WY2003 to WY2007 is approximately 10 times the annual outflow SRP discharged from the canal in WY2008–WY2013. This significantly high SRP load is consistent with the annual data.

SRP Annual Analyses

Total inflow SRP to the STA-1W Discharge Canal during the analysis period was estimated as 99.0 t, which represents about 80% of the inflow TDP and 51% of the overall inflow TP for the same period (**Table 9**). Annual inflow SRP loads mean was 9.0 t and ranged from 0.2 t in WY2012 to 37.6 t in WY2005. Similar to the trends observed for TP and TDP, SRP loads were considerably higher during WY2003–WY2007. During this period, the estimated annual mean SRP load to the canal was 18.1 t, which is 13 times the annual mean SRP load to the canal during WY2008–WY2013.

Table 9. Annual SRP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)
WY2003	26.6	21.5	5.1	19
WY2004	7.7	8.6	-0.9	-12
WY2005	37.6	32.7	4.8	13
WY2006	8.3	9.0	-0.7	-8
WY2007	10.4	12.6	-2.2	-22
WY2008	1.9	2.7	-0.7	-37
WY2009	1.8	2.7	-1.0	-56
WY2010	2.6	2.1	0.5	21
WY2011	0.3	0.6	-0.2	-68
WY2012	0.2	0.2	0.0	12
WY2013	1.6	1.6	0.0	3
Total	99.0	94.2	4.8	4.9
Mean	9.9	9.42	0.48	4.9

During the same analysis period, 94.4 t of SRP load was discharged from the STA-1W Discharge Canal. The annual mean SRP load from the canal was 16.9 t for WY2003–WY2007, which is 10 times the annual mean SRP load from the canal which occurred in WY2008–WY2013. Total SRP load discharged in WY2003 and WY2005 accounted for 53% of the total SRP discharged (**Figure 13**). As indicated earlier in this report, a high volume of Lake Okeechobee water was routed to STA-1W in WY2003, and the area was impacted by hurricanes in WY2005 (Pietro et al. 2006).

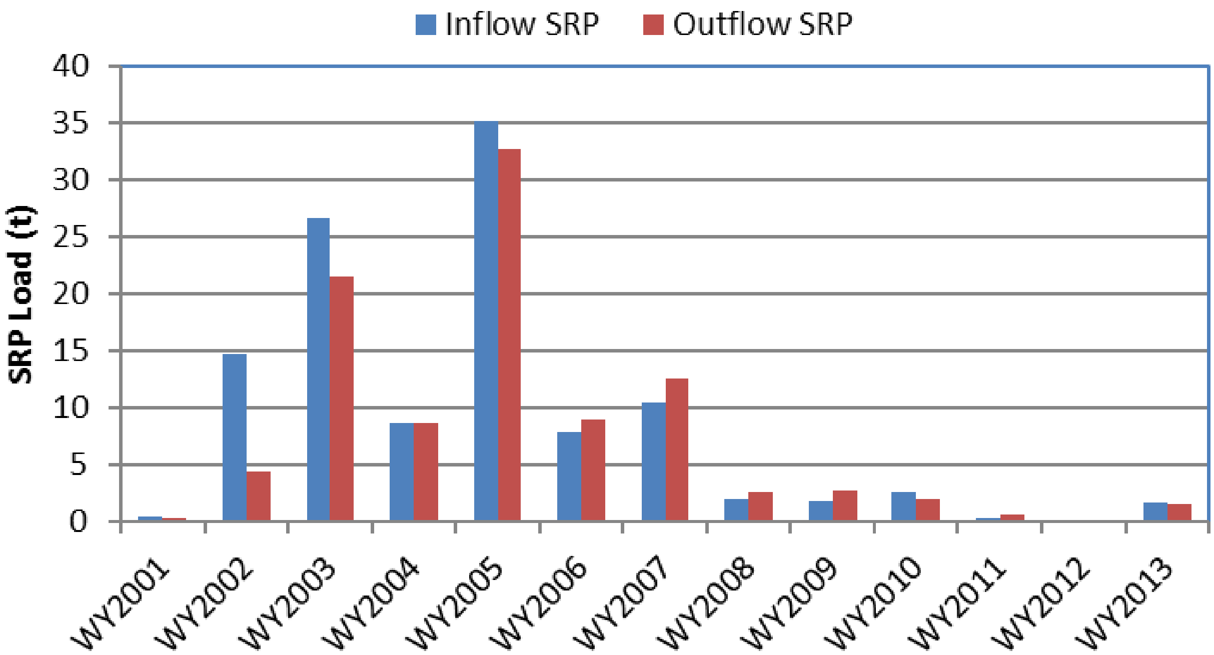

Figure 13. Annual SRP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Load analysis indicates a difference of 4.8 t of SRP (4.9% of inflow SRP) between inflow and outflow SRP loads for the 11 years of operations. This small load difference between the inflow and outflow structures suggests a good conservation of mass despite the uncertainties and errors associated with the flow data and water quality concentration, and assumptions in the load program calculation. Results suggest that there was no major SRP net export or net retention within the STA-1W Discharge Canal during the analysis period.

PARTICULATE PHOSPHORUS (WY2003–WY2013)

PP was calculated as the difference between TP and TDP, using grab samples.

PP Monthly and Seasonal Analyses

The highest inflow and outflow PP loads occurred during the wet season months from June to October (**Figure 14**). High monthly PP load reduction from the inflow to outflow structures occurred during the months of July, August, September, and October. For all other months, inflow PP load was higher than the outflow PP load. An increased PP inflow load trend was observed from April to October. In terms of the difference between inflow and outflow PP load, the only month showing a PP load increase is May with a very insignificant PP load increase of 0.025 t.

The results from the seasonal analysis were consistent with the results from the monthly analysis (**Figure 15**). There was a decrease in PP load from the inflow to the outflow structures in 7 out of 11 wet seasons. For the 4 wet seasons showing PP load increase, the total PP load increase was minimal. For the dry seasons, the PP load differences between the inflow and outflow structures were also minimal. Although 5 out of 11 dry seasons suggested PP load increases, the total amount of PP load increase was estimated as only 1.3 t in dry seasons during these five years.

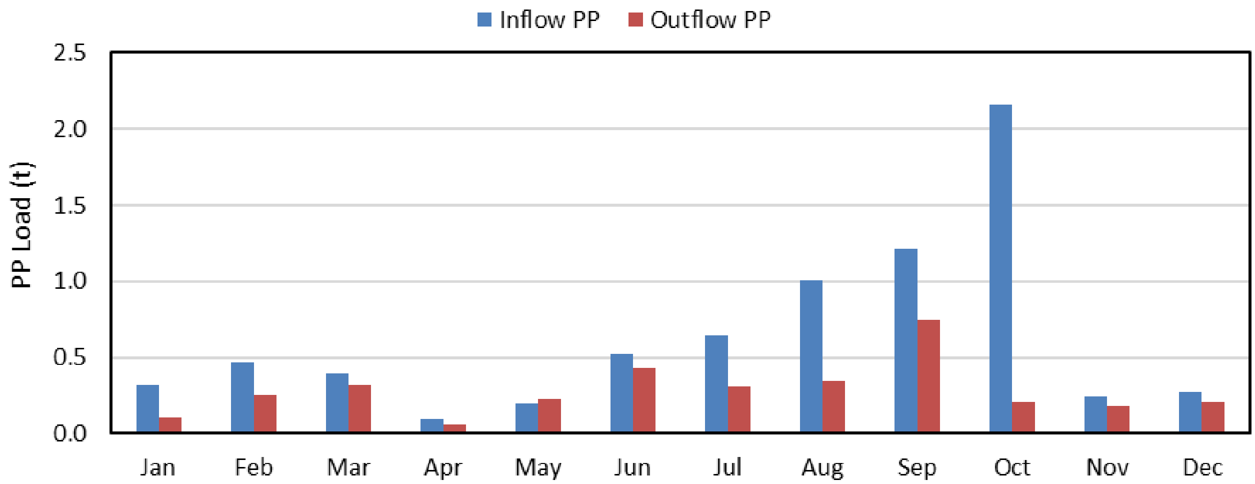

Figure 14. Monthly PP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

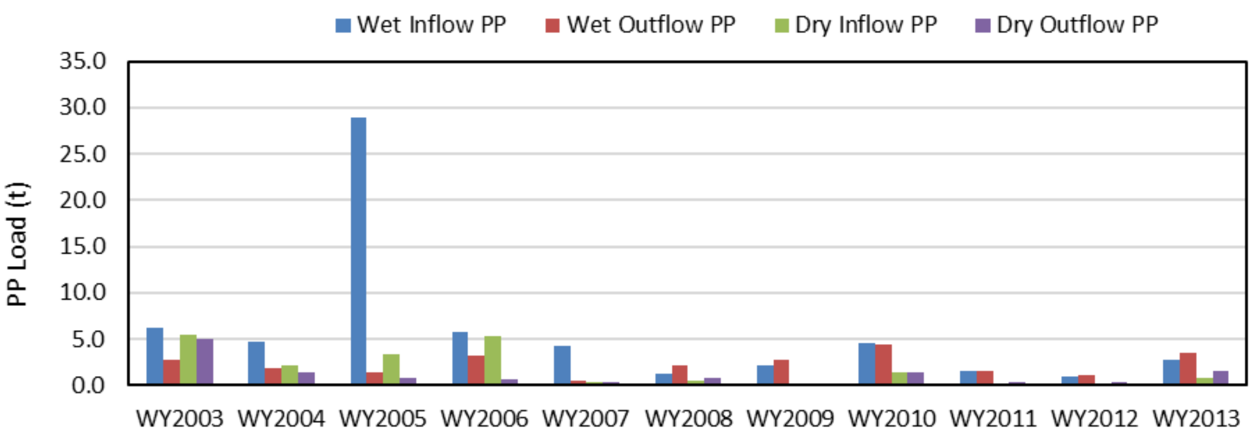

Figure 15. Seasonal PP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

PP Annual Analyses

The total inflow PP load was 82.9 t, which represents 32% of the inflow TP load for the same period (**Table 10** and **Figure 16**). This percentage was similar to the proportion of PP found at the STA-1W inflow structure, G-302, reported by Chimney (2007). Annual mean inflow PP load was 7.5 t and ranged from a low value of 1.2 t in WY2012 to high loading of 32.3 t in WY2005. The outflow PP load from this canal was 37.6 t (**Table 10** and **Figure 16**). As indicated previously, the hurricanes that hit the area in WY2005 resulted in canal inflow PP loads that were approximately two times higher than the long-term annual mean value. During WY2005, approximately 30 t of the PP load, or 66% of the total PP load accumulation, was transported to the canal. In 7 out of 11 years, outflow PP loads were lower than the inflow PP loads, with a load reduction of 48.7 t. For the remaining four years showing PP load increases, the estimated inflow PP loads in were small at 1.2 to 3.5 t. For the entire analysis period, the results suggest that this canal system was a PP sink, with PP load reduction of 45.3 t. In addition to the net PP load reductions, the change in PP/TP percentage from inflow structures to outflow structure also indicates PP settling. During this period, the percentage of PP/TP for the inflow was 42% and the percentage of PP/TP for the outflow was 24%. Furthermore, since TDP load mass conservation was well preserved, the PP load reduction was likely the main contributing factor to the TP load reduction.

Table 10. Annual PP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)
WY2003	11.7	7.8	3.9	33
WY2004	6.8	3.2	3.6	52
WY2005	32.3	2.2	30.1	93
WY2006	11.1	3.9	7.2	65
WY2007	4.6	0.8	3.9	84
WY2008	1.8	3.0	-1.1	-62
WY2009	2.2	2.7	-0.5	-24
WY2010	5.9	5.9	0.0	0
WY2011	1.8	1.8	0.1	3
WY2012	1.2	1.4	-0.2	-15
WY2013	3.5	5.1	-1.5	-43
Total	82.9	37.6	45.3	55
Mean	7.5	3.4	4.1	55

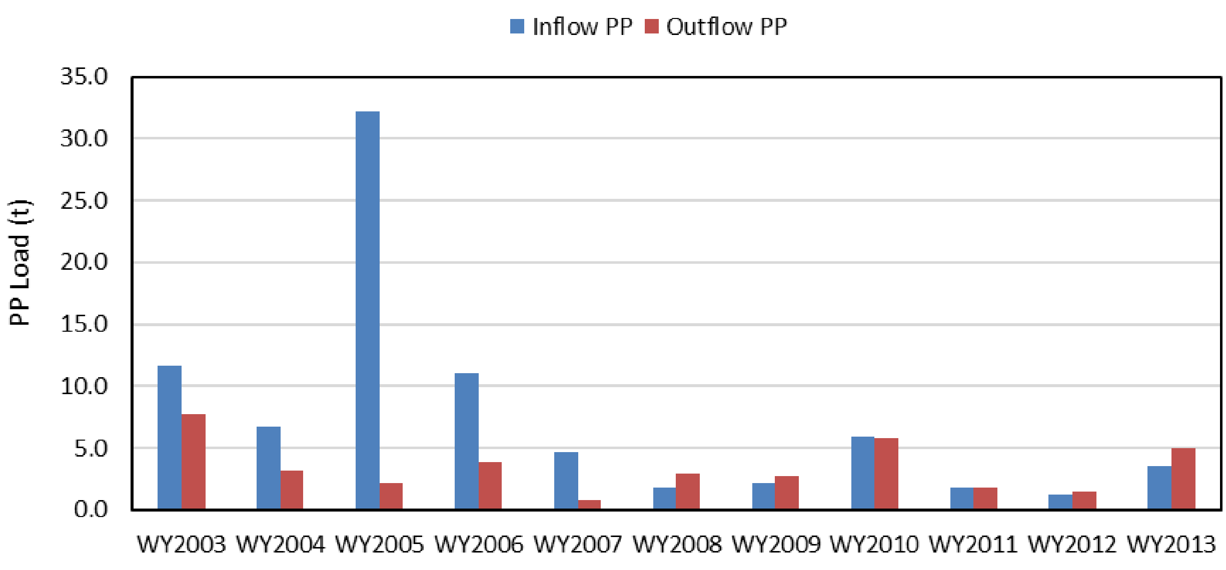

Figure 16. Annual PP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

DISSOLVED ORGANIC PHOSPHORUS (WY2003–WY2013)

DOP, which is the difference between TDP and SRP, was calculated using data for grab samples.

DOP Monthly and Seasonal Analyses

The monthly data indicates that, on average, the highest DOP loads occurred over three months of the wet season (August, September, and October) (**Figure 17**). Approximately 50% of the DOP load in and out of the canal occurred in these three months. An increasing trend in DOP load for both inflow and outflow was observed. The monthly comparison indicates some DOP load increase in April and August and decrease in other months (**Figure 17**). Monthly data suggest some small DOP reduction.

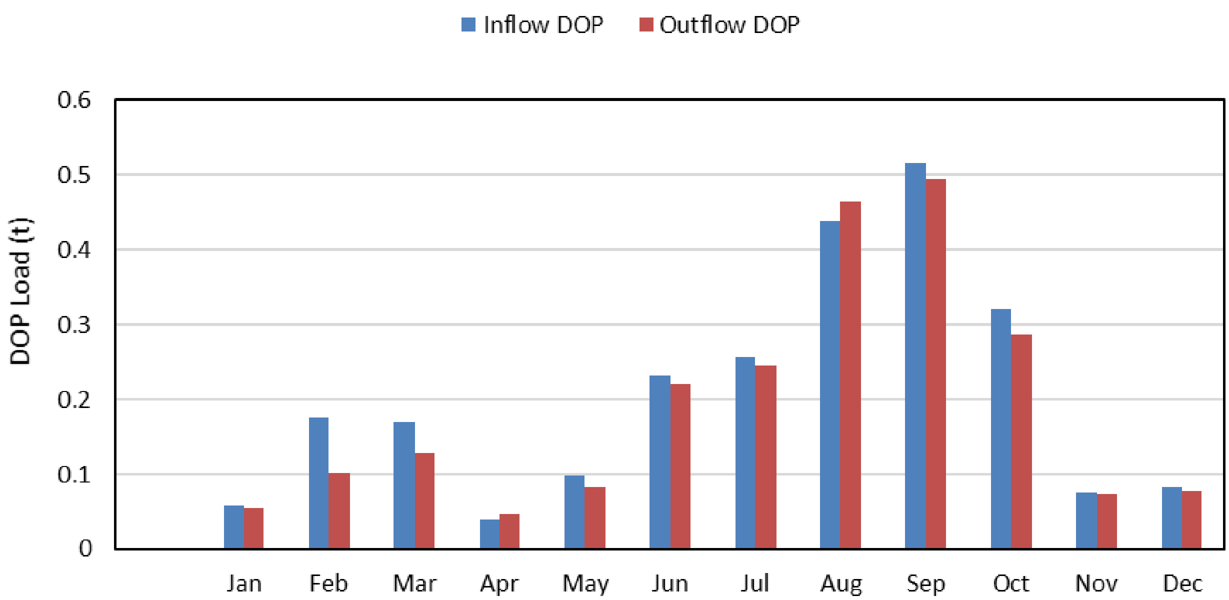

Figure 17. Monthly DOP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

The wet anddry season data indicate, on average, approximately 76% of DOP load into and 79% of DOP load out of the canal occurred during the wet season (**Figure 18**). For the dry seasons, the percentages are 24% and 21%, respectively. The seasonal chart suggests lowest DOP annual loads in WY2011 and WY2012. Data indicates that the canal was neither a sink nor a source for DOP.

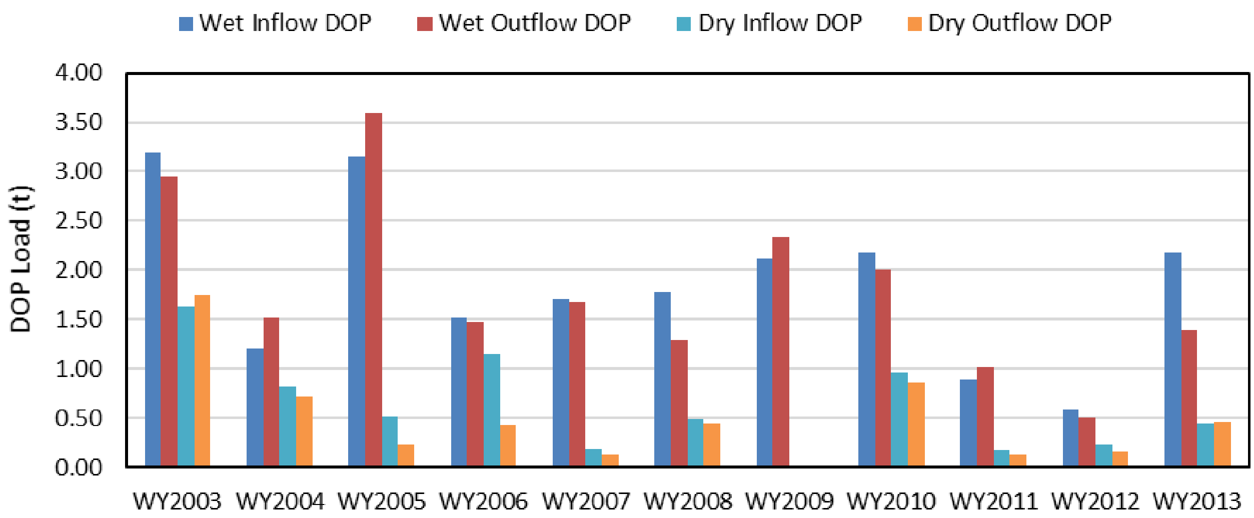

Figure 18. Seasonal DOP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

DOP Annual Analyses

Table 11 and **Figure 19** summarize the inflow and outflow DOP loads by water year. During the analysis period, the estimated inflow DOP loads mean was about 2.5 t per water year and the estimated total DOP load to the canal was approximately 27.1 t. Estimated outflow DOP loads mean was about 2.3 t per year and the estimated total DOP load from the canal was approximately 25.1 t. The estimated total DOP load difference was approximately 2.0 t (8% of inflow DOP). The difference is minimal and might be an artifact of the uncertainties from different sources, the small proportion of DOP (i.e., the overall calculated percentage of DOP/TP was approximately 6% and the TDP/TP percentage was approximately 14%), the measurement errors associated with both TDP and SRP measurement, the uncertainties in the flow estimates, and the load calculation assumptions. For these reasons, there is insufficient evidence to indicate whether the canal is a DOP source or sink.

Table 11. Annual DOP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)
WY2003	4.8	4.7	0.1	3
WY2004	2.0	2.2	-0.2	-10
WY2005	3.7	3.8	-0.2	-4
WY2006	2.7	1.9	0.8	28
WY2007	1.9	1.8	0.1	5
WY2008	2.3	1.7	0.5	24
WY2009	2.1	2.3	-0.2	-11
WY2010	3.1	2.9	0.3	9
WY2011	1.1	1.2	-0.1	-9
WY2012	0.8	0.7	0.2	19
WY2013	2.6	1.8	0.8	29
Total	27.1	25.1	2.0	8
Mean	2.5	2.3	0.2	8

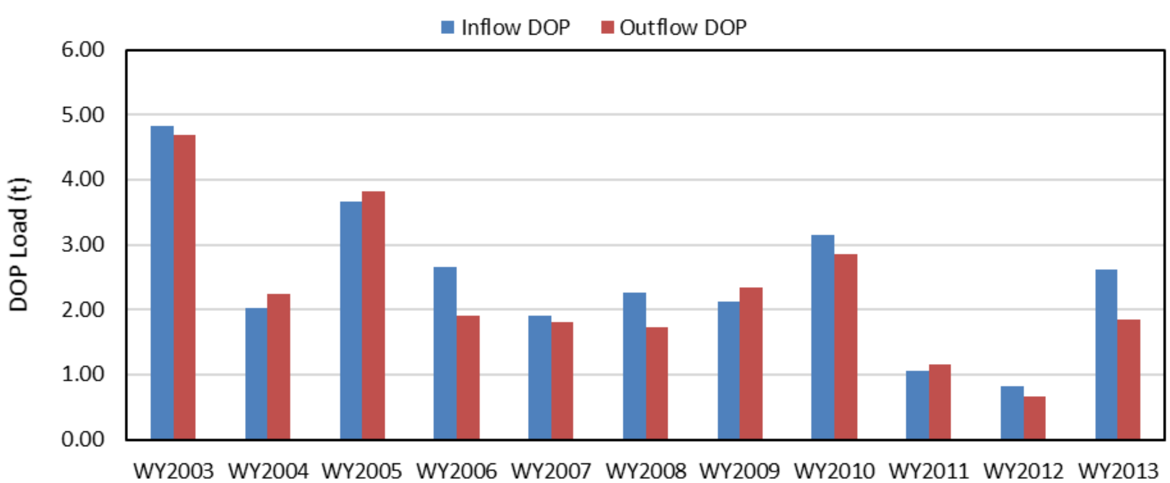

Figure 19. Annual DOP load comparison for the STA-1W Discharge Canal, inflow versus outflow.

TOTAL SUSPENDED SOLIDS (WY2003–WY2013)

TSS Monthly and Seasonal Analyses

Based on the monthly data, TSS decreased from the canal inflow to outflow structures in 9 out of 12 months (**Figure 20**). The TSS inflow and outflow loads were essentially equivalent in June with only 0.8% difference, which could be due to measurement errors and load calculation uncertainties. For the dry season months, the differences between inflow and outflow loads were minimal. The seasonal analyses also suggest that from WY2003 to WY2013, the canal was generally a TSS sink (**Figure 21**). For the wet seasons, in 8 out of 11 years, the analyses suggest that the canal was a TSS sink. The differences were minor for both the wet and dry seasons in WY2009 and the dry season in WY2004. In WY2003, the canal was a TSS source during both the wet and dry seasons.

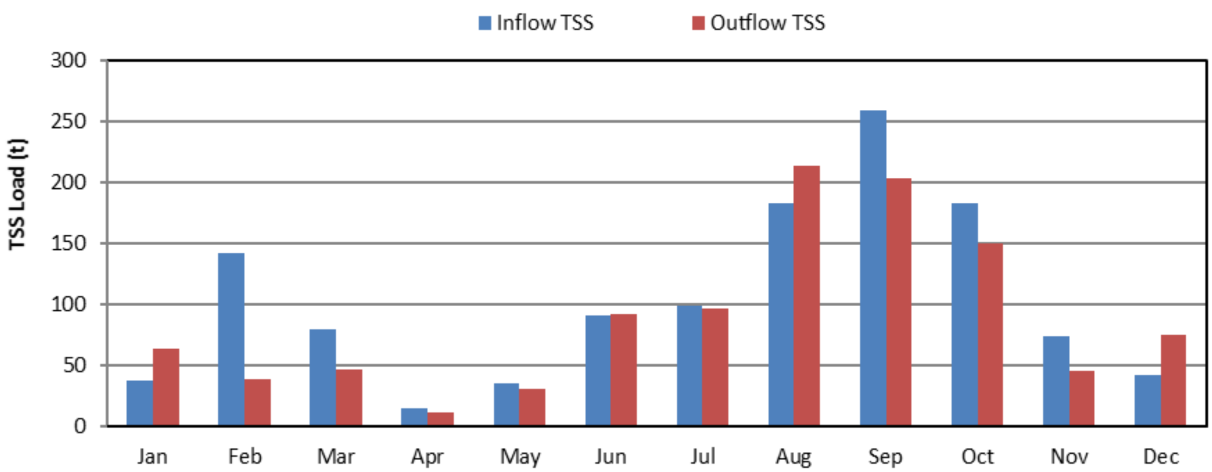

Figure 20. Monthly TSS load comparison for the STA-1W Discharge Canal, inflow versus outflow.

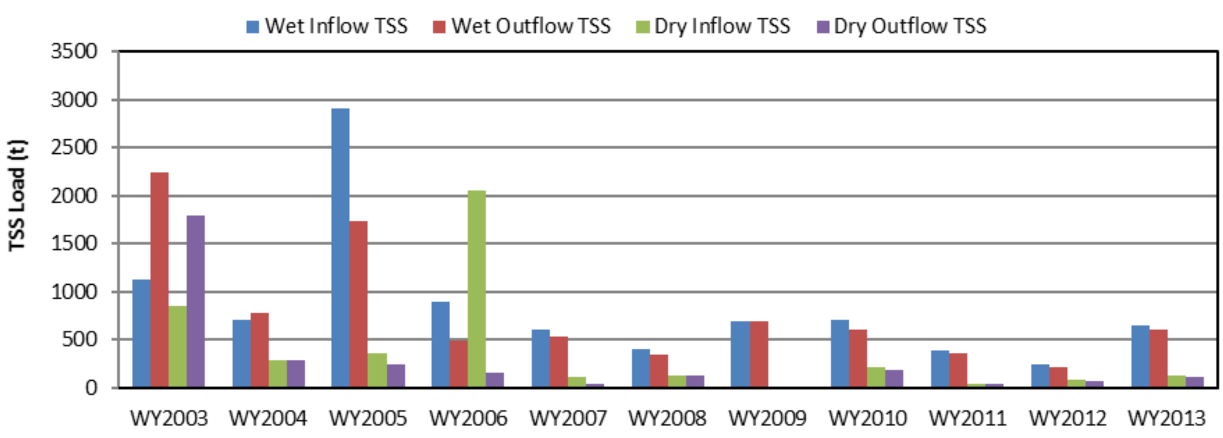

Figure 21. Seasonal TSS load comparison for the STA-1W Discharge Canal, inflow versus outflow.

TSS Annual Analyses

The annual mean inflow TSS load to the canal was 1,240 t and ranged from a low of 329 t in WY2012 to a high of 3,278 in WY2005 (**Table 12** and **Figure 22**). During the analysis period, the STA-1W Discharge Canal received 13,636 t of TSS. TSS loads were higher at the inflow than outflow in 8 out of 11 years and higher at the outflow than inflow in 3 out of 11 years, averaging 1,066 t per water year, with estimated loads ranging from 298 t in WY2012 to 4,035 in WY2003. During the analysis period, an estimated total of 11,722 t of TSS were discharged from this canal. WY2002 was excluded from the analyses since the data were highly variable creating large uncertainties in the load calculations.

Overall, the analyses suggest that the STA-1W Discharge Canal was a TSS sink, however, significant TSS export was observed in WY2003 likely due to the delivery of approximately 300,000 ac-ft regulatory releases from Lake Okeechobee (Goforth et al. 2004). A small TSS export was observed in WY2004 (**Figure 22**). After WY2004, the analyses suggest that the canal was a TSS sink. In WY2009, the difference between inflow and outflow TSS was only 1%, indicating that the canal was neither a net sink nor a source of TSS. In the most recent three years, the differences (net TSS reduction) were less than 10%.

Table 12. Annual TSS load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	Inflow (t)	Outflow (t)	Difference (t)	Difference/Inflow (%)
WY2003	1,975	4,035	-2,060	-104
WY2004	990	1,072	-83	-8
WY2005	3,278	1,985	1,293	39
WY2006	2,960	647	2,312	78
WY2007	734	579	155	21
WY2008	543	479	65	12
WY2009	690	700	-9	-1
WY2010	930	799	131	14
WY2011	433	402	30	7
WY2012	329	298	30	9
WY2013	775	727	48	6
Total	13,636	11,722	1,913	14
Mean	1,240	1,066	174	14

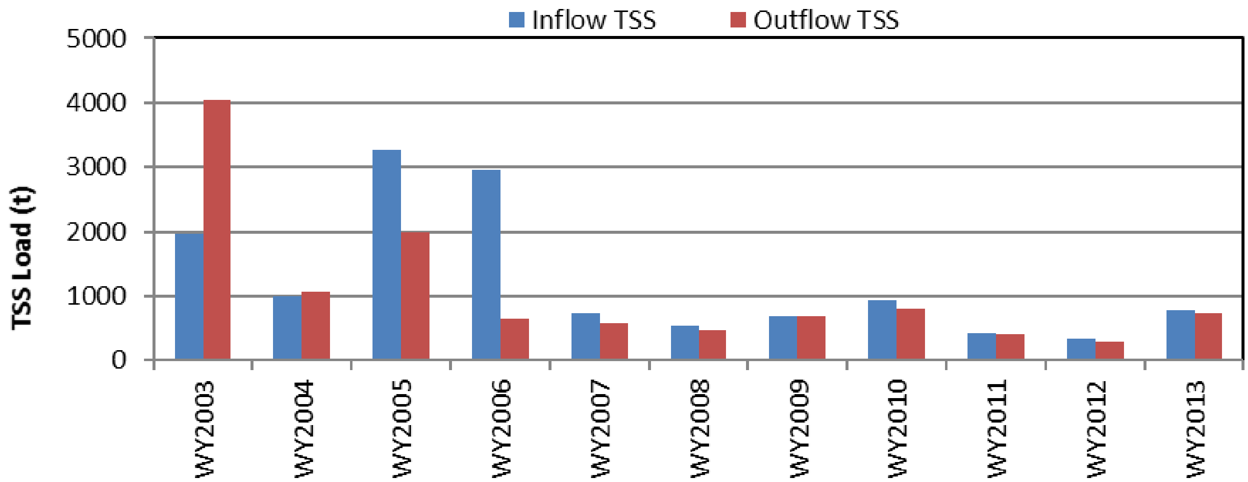

Figure 22. Annual TSS load comparison for the STA-1W Discharge Canal, inflow versus outflow.

DISSOLVED CHLORIDE (WY2007–WY2012)

CL Monthly and Seasonal Load

A monthly CL decrease from the canal inflow to outflow structures occurred in 10 out of 12 months. In July, the difference was only 2%, which could be due to measurement errors and load calculation uncertainties. A CL load increase can be observed in August. For the dry season months, the differences between inflow loads and outflow loads were relatively small (**Figure 23**). The monthly results are consistent with the annual results showing slight occurrences of CL settling.

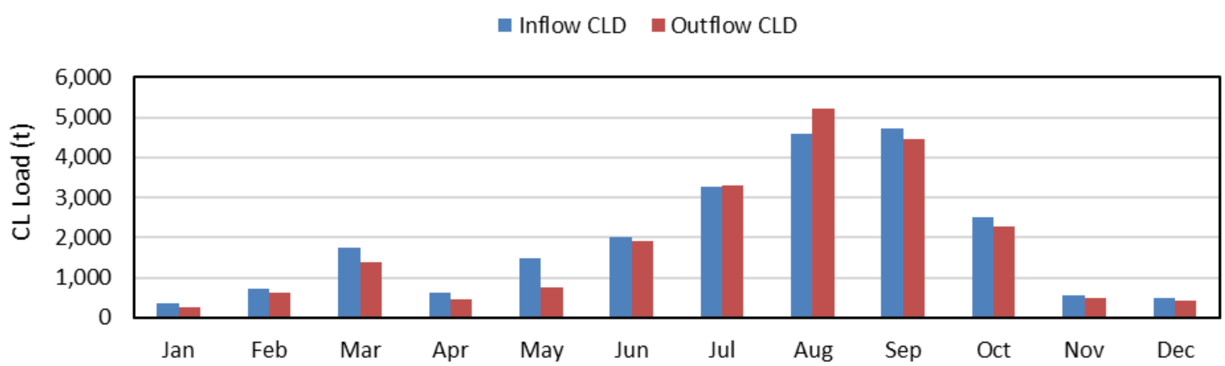

Figure 23. Monthly CL load comparison for the STA-1W Discharge Canal, inflow versus outflow.

The seasonal analyses also suggest slight occurrences of CL decreases from WY2007 to WY2013. For the wet and dry seasons, for five out of six years, the inflow CL loads were higher than the outflow CL loads. In the WY2009 wet season, the outflow CL loads were higher than the inflow loads (**Figure 24**).

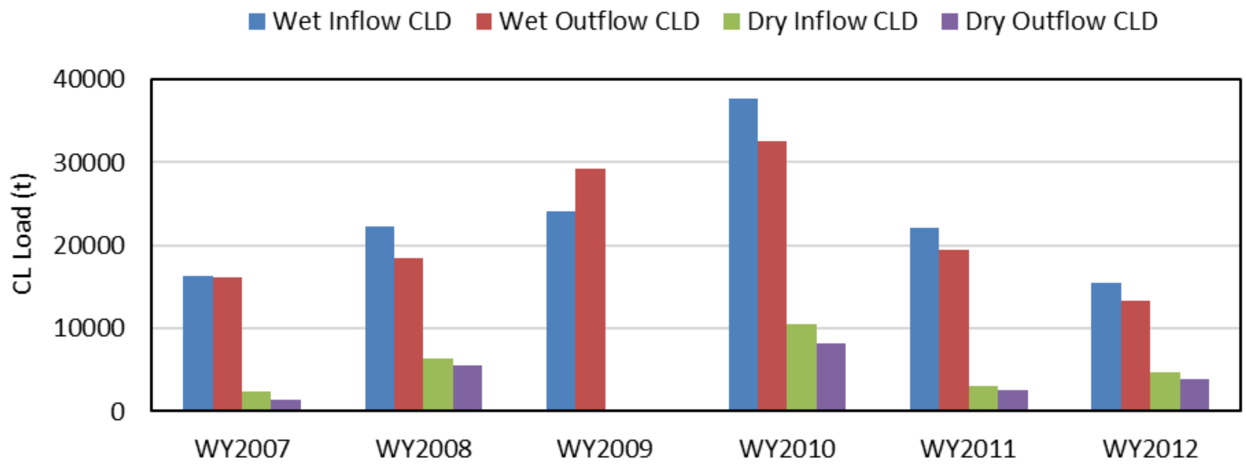

Figure 24. Seasonal CL load comparison for the STA-1W Discharge Canal, inflow versus outflow.

CL Annual Load

Based on data availability, the analysis period for CL was from WY2007 to WY2012. During the 6-year period, estimated inflow CL mean was 22,995 t per water year (**Table 13** and **Figure 25**). Estimated outflow CL loads during the analysis period was mean 21,509 t. The difference between the inflow and outflow CL loads was approximately 1,486 t, or approximately 6% of the total inflow CL for the same period. CL load reduction was observed in five out of six years. Due to the relatively short analysis period, the small percentage of difference could also be attributed to the uncertainties associated with the measured flow data, CL concentration measurement, the load calculation assumptions, etc.

Table 13. Annual CL load comparison for the STA-1W Discharge Canal, inflow versus outflow.

Water Year	Inflow CL (t)	Outflow CL (t)	Difference (t)	Difference/Inflow (%)
WY2007	16,354	16,120	234	1
WY2008	22,208	18,415	3,793	17
WY2009	24,158	29,188	-5,030	-21
WY2010	37,667	32,598	5,069	13
WY2011	22,152	19,431	2,720	12
WY2012	15,431	13,302	2,128	14
Total	137,969	129,054	8,915	6
Mean	22,995	21,509	1,486	6

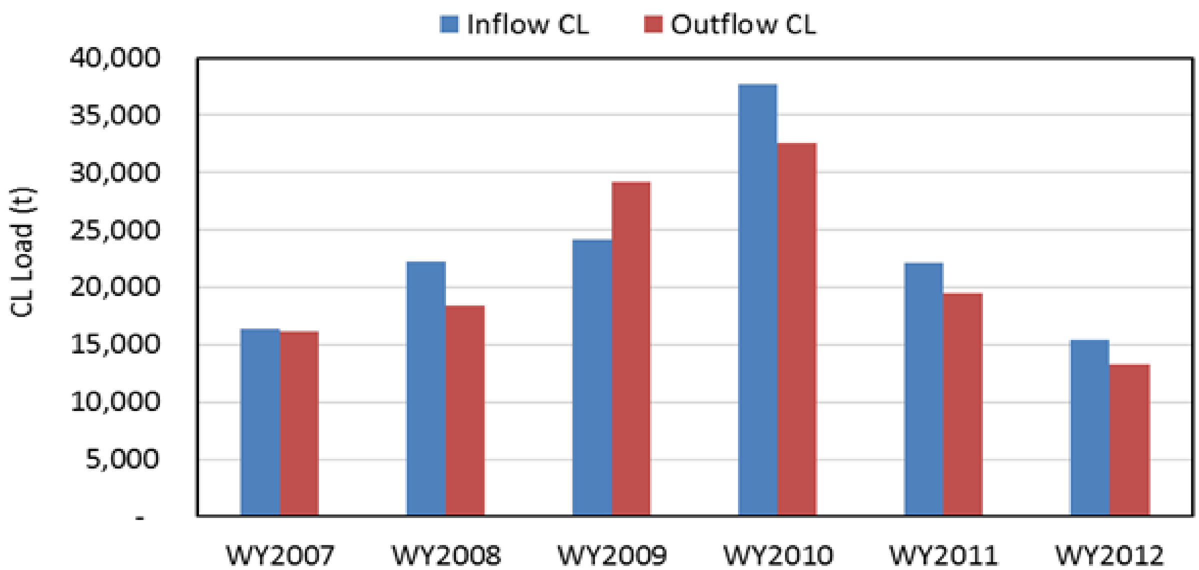

Figure 25. Annual CL load comparison for the STA-1W Discharge Canal, inflow versus outflow.

SUMMARY

The results of the data analyses conducted for the STA-1W Discharge Canal are summarized below:

- Flow estimates (inflows versus outflows) for the canal were very well balanced suggesting all sources of water were accounted for in the evaluation. This also indicated that seepage may not be an important component of the water budget for this canal.
- Overall, the load-based analyses suggest that this canal acted as a TP sink over the analysis period from WY2003 to WY2013. The annual and the wet and dry season results also demonstrated a noticeable shift in TP uptake and release during the period WY2007–WY2008. From WY2003 to WY2007, the canal acted as a TP sink with substantial TP load reduction in the surface water in all five years ranging from 8.3 to 49.7%. Between WY2008 and WY2013, the STA-1W Discharge Canal acted as a TP source, with estimated TP load increases in the surface water in five out of six years, ranging from 0.1 t in WY2012 to 1.7 t in WY2009.
- The PP mass balance results also suggest that the TP accreted in this canal was primarily PP. The PP settling was greatest in WY2005 when the area was impacted by multiple hurricanes and accounts for 66% of the total PP load accreted between WY2003 and WY2013.
- The TSS mass balance results suggest that this canal acted as a TSS sink over the analysis period.
- An acceptable conservation of mass for TDP, SRP, and DOP suggest minor changes in these parameters in this canal system over time. The mass balance for these P fractions also confirms that the TP load reduction can be mainly attributed to the PP reduction.

Overall, the analyses suggest that the STA-1W Discharge Canal behaved as a TP sink over the analysis period and that the TP reduction is due to settling of particulates. During the evaluation of this canal, the design for STA-1W Expansion Project was finalized and construction began. Once the Expansion #1 construction is complete, the STA-1W Discharge Canal will no longer serve as the discharge canal for the STA. Therefore, no further analysis is recommended for the STA-1W Discharge Canal.

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